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CHAPTER 5.0REACTOR COOLANT SYSTEM AND CONNECTED SYSTEMS

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CHAPTER 5.0REACTOR COOLANT SYSTEM AND CONNECTED SYSTEMS5.1 SUMMARY DESCRIPTION

5.1.1 DESIGN BASES

The performance and safety design bases of the reactor coolant system (RCS) and its major components are interrelated. These design bases are listed below:

- a. The RCS has the capability to transfer to the steam and power conversion system the heat produced during power operation and when the reactor is subcritical, including the initial phase of plant cooldown.
- b. The RCS has the capability to transfer to the residual heat removal system the heat produced during the subsequent phase of plant cooldown and cold shutdown.
- c. The RCS heat removal capability under power operation and normal operational transients, including the transition from forced to natural circulation, assures no fuel damage within the operating bounds permitted by the reactor control and protection systems.
- d. The RCS provides the water used as the core neutron moderator and reflector and as a solvent for chemical shim control.
- e. The RCS maintains the homogeneity of the soluble neutron poison concentration and the rate of change of the coolant temperature, so that uncontrolled reactivity changes do not occur.
- f. The RCS pressure boundary is capable of accommodating the temperatures and pressures associated with operational transients.
- g. The reactor vessel supports the reactor core and control rod drive mechanisms.
- h. The pressurizer maintains the system pressure during operation and limits pressure transients. During the reduction or increase of plant load, the pressurizer accommodates volume changes in the reactor coolant.
- i. The reactor coolant pumps supply the coolant flow necessary to remove heat from the reactor core and transfer it to the steam generators.

- j. The steam generators provide high quality steam to the turbine. The tube and tubesheet boundary are designed to prevent the transfer of radioactivity generated within the core to the secondary system.
- k. The RCS piping contains the coolant under operating temperature and pressure conditions and limits leakage (and activity release) to the containment atmosphere. The RCS piping contains demineralized borated water which is circulated at the flow rate and temperature consistent with achieving the reactor core thermal and hydraulic performance.
- I. The RCS is monitored for loose parts, as described in [Section 4.4.6](#).

5.1.2 DESIGN DESCRIPTION

The RCS, shown in [Figure 5.1-1](#), consists of four similar heat transfer loops connected in parallel to the reactor pressure vessel. Each loop contains a reactor coolant pump, steam generator, and associated piping and valves. In addition, the system includes a pressurizer, pressurizer relief and safety valves, interconnecting piping, and instrumentation necessary for operational control. All the above components are located in the containment building.

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

The RCS pressure boundary is a barrier against the release of radioactivity generated within the reactor, and is designed to ensure a high degree of integrity throughout the life of the plant.

RCS pressure is controlled by the use of the pressurizer where water and steam are maintained in equilibrium by electrical heaters and water sprays. Steam can be formed (by the heaters) or condensed (by the pressurizer spray) to minimize pressure variations due to contraction and expansion of the reactor coolant. Spring-loaded safety valves and power-operated relief valves from the pressurizer provide for steam discharge from the RCS. Discharged steam is piped to the pressurizer relief tank, where the steam is condensed and cooled by mixing with water.

The extent of the RCS is defined as:

- a. The reactor vessel, including control rod drive mechanism housings
- b. The portion of the steam generators containing reactor coolant

- c. Reactor coolant pumps
- d. The pressurizer
- e. Safety and relief valves
- f. The interconnecting piping, valves, and fittings between the principal components listed above
- g. The piping, fittings, and valves leading to connecting auxiliary or support systems up to and including the second isolation valve (from the high pressure side) on each line

The RCS is shown schematically in [Figure 5.1-2](#). Included on this figure is a tabulation of principal pressures and temperatures and the flow rate of the system under normal steady state full power operating conditions. These parameters are based on the best estimate flow at the pump discharge. RCS volume under the above conditions is presented in [Table 5.1-1](#).

A piping and instrumentation diagram of the RCS is shown in [Figure 5.1-1](#) (Sheets 1 through 4). The diagrams show the extent of the systems located within the containment and the points of separation between the RCS and the secondary (heat utilization) system. [Figures 1.2-9](#) through [1.2-18](#) provide plan and elevation views of the reactor building. These figures show principal dimensions of reactor coolant system components in relationship with supporting and surrounding steel and concrete structures and demonstrate the protection provided to the reactor coolant system by its physical layout.

5.1.3 SYSTEM COMPONENTS

The major components of the RCS are as follows:

- a. Reactor vessel

The reactor vessel is cylindrical and has a welded, hemispherical bottom head and a removable, flanged, hemispherical upper head. The vessel contains the core, core-supporting structures, control rods, and other parts directly associated with the core.

The vessel has inlet and outlet nozzles located in a horizontal plane just below the reactor vessel flange but above the top of the core. Coolant enters the vessel through the inlet nozzles and flows down the core barrel-vessel wall annulus, turns at the bottom, and flows up through the core to the outlet nozzles.

- b. Steam generators

The steam generators are vertical shell and U-tube evaporators with integral moisture separating equipment. The reactor coolant flows through the inverted U-tubes, entering and leaving through the 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 the outlet nozzle at the top of the vessel. The steam generator design is designated by Areva as Model 73/19T.

c. Reactor coolant pumps

The reactor coolant pumps are single speed centrifugal units driven by air-cooled, three-phase induction motors. Heat from the air-cooling system is rejected to the component cooling water. The shaft is vertical with the motor mounted above the pump. A flywheel on the shaft above the motor provides additional inertia to extend pump coastdown. The flow inlet is at the bottom of the pump, and the discharge is on the side.

d. Piping

The reactor coolant piping is seamless stainless steel piping. The hot leg is defined as the piping between the reactor vessel outlet nozzle and the steam generator. The cold leg is defined as the piping between the reactor coolant pump outlet and the reactor vessel. The crossover leg is defined as the piping between the steam generator and the reactor coolant pump inlet.

e. Pressurizer

The pressurizer is a vertical, cylindrical vessel with hemispherical top and bottom heads. Electrical heaters are installed through the bottom head of the vessel while the spray nozzle and relief and safety valve connections are located in the top head of the vessel.

f. Safety and relief valves

The pressurizer safety valves are of the totally enclosed pop-type. The valves are spring loaded and self activated with backpressure compensation. The power-operated relief valves have electric solenoid actuators. They are operated automatically based on RCS pressure or by remote manual control. Remotely operated valves are provided to isolate the inlet to the power-operated relief valves if excessive leakage occurs.

Steam from the pressurizer safety and relief valves is discharged into the pressurizer relief tank through a sparger pipe under the water level. This condenses and cools the steam by mixing it with water that is near ambient temperature.

5.1.4 SYSTEM PERFORMANCE CHARACTERISTICS

Design and performance characteristics of the RCS are provided in [Table 5.1-1](#).

a. Reactor coolant flow

The reactor coolant flow, a major parameter in the design of the system and its components, is established with a detailed design procedure supported by operating plant performance data, by pump model tests and analysis, and by pressure drop tests and analyses of the reactor vessel and fuel assemblies. Data from all operating plants have indicated that the actual flow has been well above the flow specified for the thermal design of the plant. By applying the design procedure described below, it is possible to specify the expected operating flow with reasonable accuracy.

Three reactor coolant flow rates are identified for the various plant design considerations. The definitions of these flows are presented in the following paragraphs.

b. 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.

System pressure drops, based on best estimate flow with the replacement steam generator, are presented in [Table 5.1-1](#).

Although the best estimate flow is the most likely value to be expected in operation, more conservative flow rates are applied in the thermal and mechanical designs.

c. Thermal design flow

Thermal design flow is the flow rate used as a basis for the reactor core thermal performance, the steam generator thermal performance, and the nominal plant parameters used throughout the design. The thermal design flow accounts for the uncertainties in flow resistances (reactor vessel, steam generator, and piping), reactor coolant pump head, and the methods used to measure flow rate. The thermal design flow is approximately 9.6 percent less than the best estimate flow with 5% steam generator tube plugging (SGTP). The thermal design flow is confirmed when the plant is placed in operation. Tabulations of important design and performance

characteristics of the RCS, as provided in [Table 5.1-1](#), are based on the thermal design flow.

d. Mechanical design flow

Mechanical design flow is a conservatively high flow used in the mechanical design of the reactor vessel internals and fuel assemblies. The mechanical design flow is based on a reduced system resistance and on increased pump head capability. The mechanical design flow was increased to 109,200 gpm per loop with the RSGs and is approximately 3.8 percent greater than the best estimate flow at 0% SGTP.

Pump overspeed due to a turbine generator overspeed of 20 percent results in a peak reactor coolant flow of 120 percent of the mechanical design flow. The overspeed condition is applicable only to operating conditions when the reactor and turbine generator are at power.

TABLE 5.1-1 SYSTEM DESIGN AND OPERATING PARAMETERS

| | |
|--|--|
| Plant design life, years | 40 |
| Nominal operating pressure, psig | 2,235 |
| Nominal total system volume, including pressurizer and surge line, ft ³ * | 13,903 (± 100 ft ³ at a nominal T _{avg} of 557°F) |
| Nominal system liquid volume, including pressurizer water at maximum guaranteed power, ft ³ | 13,061 |
| Pressurizer spray rate, maximum, gpm | 900 |
| Pressurizer heater capacity, kW | 1,800 |

* This nominal volume will change dependent on SG tube plugging (assumes 3% thermal expansion)

System Thermal and Hydraulic Data

| | <u>4 Pumps Running</u> |
|---|----------------------------|
| NSSS power, MWt | 3,579 |
| Reactor power, MWt | 3,565 |
| Thermal design flows, gpm | |
| Per loop | 93,600 |
| Reactor | 374,400 |
| Total reactor flow, 10 ⁶ lb/hr | 139.4* |
| **Temperatures, °F | |
| Reactor vessel outlet | 620.0*** |
| Reactor vessel inlet | 556.8*** |
| Steam generator outlet | 556.6 |
| Steam generator steam | 547.2**** |
| Feedwater | 390.0 to 446.0 |

* Based on T_{in} = 556.8°F and pressurizer pressure = 2250 psia. See [Tables 1.3-1, 4.1-1, and 4.4-1](#).

** Temperatures based on a 0% tube plugging level in the steam generators, thermal design flow (non-RTDP).

*** Operation with RCS T_{avg} reduced as low as 570.7°F has been evaluated to meet all criteria for acceptable plant operation with the RSGs installed.

TABLE 5.1-1 (Sheet 2)

**** 528.3°F based on T_{avg} of 570.7°F and 0% equivalent SG tube plugging.

System Thermal and Hydraulic Data

| | 4 Pumps Running $T_{AVG}=588.4^{\circ}\text{F}$ | 4 Pumps Running $T_{AVG}=570.7^{\circ}\text{F}^{****}$ |
|---------------------------------------|---|--|
| Steam pressure, psia* | 1022** | 872** |
| Total steam flow, 10^6 lb/hr* | 15.96*** | 15.85*** |
| Best estimate flows, gpm* | | |
| Per loop | 104,300 | 105,200 |
| Reactor | 417,200 | 420,800 |
| Mechanical design flows, gpm | | |
| Per loop | 109,200 | 109,200 |
| Reactor | 436,800 | 436,800 |
| System Pressure Drops* | | |
| Reactor vessel ΔP , psi | 52.6 | 52.1 |
| Steam generator ΔP , psi | 31.9 | 33.1 |
| Hot leg piping ΔP , psi | 1.3 | 1.4 |
| Crossover leg piping ΔP , psi | 3.4 | 3.6 |
| Cold leg piping ΔP , psi | 3.6 | 3.8 |
| Pump head, ft | 289 | 285 |

* Based on 0% equivalent steam generator tube plugging.

** 1016 psia with 5% SGTP at $T_{avg} = 588.4^{\circ}\text{F}$; 867 psia with 5% SGTP at $T_{avg} = 570.7^{\circ}\text{F}$

*** 15.95×10^6 lb/hr with 5% SGTP at $T_{avg} = 588.4^{\circ}\text{F}$; 15.84×10^6 lb/hr with 5% SGTP at $T_{avg} = 570.7^{\circ}\text{F}$

**** Flows and pressure drops at 570.7°F assumes thimble plugs are removed from core to yield maximum results

5.2 INTEGRITY OF REACTOR COOLANT PRESSURE BOUNDARY

This section discusses the measures employed to provide and maintain the integrity of the reactor coolant pressure boundary (RCPB) for the plant design lifetime. Section 50.2 of 10 CFR 50 defines the RCPB as extending to the outermost containment isolation valve in system piping which penetrates the containment and is connected to the RCS. This section is limited to a description of the components of the RCS as defined in **Section 5.1**, unless otherwise noted. Components which are part of the RCPB (as defined in 10 CFR 50) but are not described in this section are described in the following sections:

- a. **Section 6.3** - RCPB components which are part of the emergency core cooling system.
- b. **Section 9.3.4** - RCPB components which are part of the chemical and volume control system.
- c. **Section 3.9(N).1** - Design loadings, stress limits, and analyses applied to the RCS and ASME Code Class 1 components.
- d. **Section 3.9(N).3** - Design loadings, stress limits, and analyses applied to ASME Code Class 2 and 3 components.

The phrase RCS, as used in this section, is as defined in **Section 5.1**. When the term RCPB is used in this section, its definition is that of Section 50.2 of 10 CFR 50.

5.2.1 COMPLIANCE WITH CODES AND CODE CASES

5.2.1.1 Compliance with 10 CFR 50.55a

RCS components are designed and fabricated in accordance with 10 CFR 50, Section 50.55a, "Codes and Standards." The addenda of the ASME Code applied in the design of each component are listed in **Table 5.2-1**.

5.2.1.2 Applicable Code Cases

Regulatory Guides 1.84, 1.85 and 1.147 are discussed in **Appendix 3A**.

Code Case 1528 (SA-508, Class 2a) material has been used in the manufacture of the SNUPPS pressurizers. Regulatory Guide 1.85 presently reflects a conditional NRC approval of Code Case 1528. Westinghouse has conducted a test program which demonstrates the adequacy of Code Case 1528 material. The results of the test program are documented in Reference 1. Reference 1 and a request for approval (Ref. 2) of the use of Code Case 1528 have been submitted to the NRC.

The specific code cases used were:

| | |
|------------------|---------------------------------|
| Steam Generator: | 2142, 2143, N-20-3, and N-474-1 |
| Pressurizer: | 1528 |
| Piping: | 1423-2 |
| Valves: | 1649, 1769, and N-3-10 |

5.2.2 OVERPRESSURE PROTECTION

RCS overpressure protection is accomplished by the utilization of pressurizer safety valves along with the reactor protection system and associated equipment. Combinations of these systems provide compliance with the overpressure requirements of the ASME Boiler and Pressure Vessel Code, Section III, Paragraphs NB-7300 and NC-7300, for pressurized water reactor systems.

Auxiliary or emergency systems connected to the RCS are not utilized for the prevention of RCS overpressurization protection.

5.2.2.1 Design Bases

Overpressure protection is provided for the RCS by the pressurizer safety valves which discharge to the pressurizer relief tank by means of a common header. The transient which establishes the design requirements for the primary system overpressure protection is a complete loss of steam flow to the turbine with operation of the steam generator safety valves and maintenance of main feedwater flow. However, for the sizing of the pressurizer safety valves, no credit is taken for reactor trip nor the operation of the following:

- a. Pressurizer power-operated relief valves
- b. Steam line relief valve
- c. Steam dump system
- d. Reactor control system
- e. Pressurizer level control system
- f. Pressurizer spray valve

For this transient, the peak RCS and peak steam system pressure must be limited to 110 percent of their respective design values.

Assumptions for the overpressure analysis include: 1) the plant is operating at the power level corresponding to the engineered safeguards design rating and 2) the RCS average temperature and pressure are at their maximum values. These are the most limiting assumptions with respect to system overpressure.

Overpressure protection for the steam system is provided by steam generator safety valves. The steam system safety valve capacity is based on providing enough relief to remove 105 percent of the engineered safeguards design steam flow. This must be done by limiting the maximum steam system pressure to less than 110 percent of the steam generator shell side design pressure.

Blowdown and heat dissipation systems of the NSSS connected to the discharge of these pressure relieving devices are discussed in [Section 5.4.11](#).

Steam generator blowdown systems for the balance-of-plant are discussed in [Section 10.4.8](#).

Postulated events and transients on which the design requirements of the overpressure protection system are based and discussed in Reference 3 and Reference 3a.

5.2.2.2 Design Evaluation

The relief capacities of the pressurizer and steam generator safety valves are determined from the postulated overpressure transient conditions in conjunction with the action of the reactor protection system. An evaluation of the functional design of the system and an analysis of the capability of the system to perform its function are presented in Reference 3 and Reference 3a. The report describes in detail the types and number of pressure relief devices employed, relief device description, locations in the systems, reliability history, and the details of the methods used for relief device sizing based on typical worst-case transient conditions and analysis data for each transient condition. The description of the analytical model used in the analysis of the overpressure protection system and the basis for its validity are discussed in Reference 4.

A description of the pressurizer safety valves performance characteristics along with the design description of the incidents, assumptions made, method of analysis, and conclusions are discussed in [Chapter 15.0](#).

5.2.2.3 Piping and Instrumentation Diagrams

Overpressure protection for the RCS is provided by pressurizer safety valves shown in [Figure 5.1-1](#), Sheet 2.

These discharge to the pressurizer relief tank by means of a common header.

The steam system safety valves are discussed in **Section 10.3** and are shown on **Figure 1.2-15**

5.2.2.4 Equipment and Component Description

The operation, significant design parameters, number and types of operating cycles, and environmental conditions of the pressurizer safety valves are discussed in **Sections 5.4.13, 3.9(N).1, and 3.11(N)**.

Section 10.3 contains a discussion of the equipment and components of the steam system overpressure system.

5.2.2.5 Mounting of Pressure-Relief Devices

5.2.2.5.1 Location of Pressure Relief Devices

The design bases for the assumed loads for the primary and secondary side pressure relief devices of the steam generator are described in Paragraph 3.9(B).3.3. **Figure 5.2-1** provides design and installation details for the pressure relief devices mounted on the secondary side of the steam generator. Pressure relief devices for the reactor coolant system are three pressurizer safety relief valves and two power-operated relief valves. These valves discharge to the pressurizer relief tank via a common header.

5.2.2.5.2 Pressurizer Safety Relief Valves

The pressurizer safety valve discharge piping system is a closed system in which no sustained reaction force from a free discharging jet of fluid can exist. However, transient hydraulic forces are imposed at various points in the piping system from the time a safety valve begins to open until a steady flow is completely developed. Since a water loop seal is applied, transient hydraulic forces caused by the liquid being forced through the safety valve and then accelerated down the piping system does occur.

The pressurizer relief devices are mounted and installed as follows:

- a. Each straight leg of the discharge pipe is supported as necessary to take the valve discharge transient force along that leg.
- b. The supports at the valve discharge piping are connected to the adjacent structure.
- c. Snubbers are used to restrain the valve discharge transient forces as necessary when thermal movements are of a high magnitude.

Thermal hydraulic analysis was performed using the method of characteristics approach to generate fluid parameters as a function of time, including provisions for analysis of valve opening and closing situations.

Unbalanced forces were calculated for each straight segment of pipe from the pressurizer to the relief tank. The time histories of these forces were used for the subsequent structural analysis of the pressurizer safety and relief lines.

Hydraulic forcing functions were generated assuming the simultaneous opening of either the safety valves or the relief valves and included water discharge transients when the relief valves were utilized for cold overpressure mitigation.

A dynamic analysis using computer program PS + CAEPIPE was performed to verify the design of the support configuration. The results of these analyses are described below:

a. For loading combinations see [Table 3.9\(B\)-2](#).

b. Material Type

| | |
|----------------|------------------------------|
| Class I Piping | 3" Sch. 160, SA-312, TP-304 |
| | 6" Sch. 160, SA-312, TP-304 |
| B31.1 Piping | 3" Sch. 80S, SA-312, TP-304 |
| | 6" Sch. 80S, SA-312, TP-304 |
| | 12" Sch. 80S, SA-312, TP-304 |

c. Maximum stress points within piping system

| | | |
|----------------|---|----------|
| Class I Piping | Node point - 4690 | |
| | Type - reducer | |
| | Max. primary stress | 20.9 ksi |
| | Allowable primary stress | 24.2 ksi |
| B31.1 Piping | Node point - 5090 | |
| | Max. primary stress | 21.8 ksi |
| | Allowable primary stress | 22.6 ksi |
| | Node point - 4610 | |
| | Max. primary + secondary stress | 43.3 ksi |
| | Allowable primary + secondary stress | 43.4 ksi |

5.2.2.5.3 Main Steam Safety Relief Valves

[Figure 5.2-1](#) provides design and installation details.

The steady-state flow condition reached after the valve has opened and is exhausting into the stack was considered in the stress analysis of the safety valve installation. With these conditions, the valve moments are balanced due to the split valve discharge design, and the vertical discharge thrust force is reacted by the header supports via the header. The discharge force from the vent stack is reacted by an in-line anchor and the supports near the top of the stack. The effects of thermal expansion, pipe weight, seismic anchor movements, seismic occurrence, and relief valve discharge thrust forces were considered in the stress analysis of the vent stack piping. These effects were also considered in the stress analysis of the main steam header piping in addition to the water hammer effects caused by fast valve closure of the main steam isolation valves.

A 10 percent unbalanced discharge from the two split discharge ports of each safety valve was assumed for the stress analysis of the header piping. Therefore, one discharge port had an assumed vertical thrust load of 13,574 pounds and the other an assumed thrust load of 12,227 pounds. These values are based on a relief valve discharge from a line pressure of 1,185 psi and a dynamic load factor of 1.2. It was conservatively assumed that each valve opened simultaneously, resulting in the following header stresses and support loads:

- a. For loading combinations see [Table 3.9\(B\)-2](#) and [Table 3.9\(B\)-14](#).
- b. Material type

28-inch OD wall thickness of 1.5 inch, SA 106, Gr C.

- c. Maximum stress points within system

Node point - 45

| | |
|--------------------------|------------|
| Maximum primary stress | 12,421 psi |
| Allowable primary stress | 21,000 psi |

Node point - 5

| | |
|----------------------------|------------|
| Maximum secondary stress | 16,131 psi |
| Allowable secondary stress | 26,250 psi |

- d. Support loads

| <u>Node Point</u> | <u>Header Support Loads (vertical supports and loads only)</u> |
|-------------------|--|
| 5 | 21,942 lbs |
| 33 | 187,800 lbs |

| <u>Node Point</u> | <u>Header Support Loads (vertical supports and loads only)</u> |
|-------------------|--|
| 83 | 112,700 lbs |
| 85 | 166,300 lbs |
| 300 | 33,347 lbs |
| 294 | 187,800 lbs |
| 282 | 112,700 lbs |
| 281 | 166,300 lbs |
| 347 | 33,362 lbs |
| 341 | 187,800 lbs |
| 329 | 112,700 lbs |
| 328 | 166,300 lbs |
| 397 | 10,100 lbs |
| 391 | 184,400 lbs |
| 380 | 112,800 lbs |
| 379 | 166,300 lbs |

5.2.2.6 Applicable Codes and Classification

The requirements of ASME Boiler and Pressure Vessel Code, Section III, Paragraphs NB-7300 (Overpressure Protection Report) and NC-7300 (Overpressure Protection Analysis), are followed and complied with for pressurized water reactor systems.

Piping, valves, and associated equipment used for overpressure protection are classified in accordance with ANS-N18.2, "Nuclear Safety Criteria for the Design of Stationary Pressurized Water Reactor Plants." These safety class designations are delineated on [Table 3.2-1](#) and shown on [Figure 5.1-1](#).

For further information, refer to [Section 3.9\(N\)](#).

5.2.2.7 Material Specifications

Refer to [Section 5.2.3](#) for a description of material specifications.

5.2.2.8 Process Instrumentation

Each pressurizer safety valve discharge line incorporates a control board temperature indicator and alarm to notify the operator of steam discharge due to either leakage or actual valve operation. Safety-related control room positive position indication is provided for the PORVs and safety valves. For a further discussion on process instrumentation associated with the system, refer to [Chapter 7.0](#).

5.2.2.9 System Reliability

The reliability of the pressure relieving devices is discussed in Section 4 of Reference 3.

5.2.2.10 RCS Pressure Control During Low Temperature Operation

Administrative procedures are developed to aid the operator in controlling RCS pressure during low temperature operation. However, to provide a back-up to the operator and to minimize the frequency of RCS overpressurization, an automatic system is provided to maintain pressures within allowable limits.

Analyses have shown that one pressurizer power-operated relief valve (PORV) or one RHR suction relief valve is sufficient to prevent violation of these limits due to anticipated mass and heat input transients. However, redundant protection against an overpressurization event is provided through the use of two pressurizer PORVs, two RHR suction relief valves, or one PORV and one RHR suction relief valve to mitigate any potential pressure transients. The mitigation system is required during the Applicability of Technical Specification (TS) LCO 3.4.12, with RCP startup restrictions as governed by TS LCO 3.4.6 and TS LCO 3.4.7, when the PORVs are manually armed and automatically actuated and the RHR suction relief valves are made available by cross-connecting the RCS and RHR systems.

5.2.2.10.1 System Operation

Two pressurizer power-operated relief valves are supplied with actuation logic in the cold overpressure mitigation system (COMS) to ensure that a redundant and independent RCS pressure control back-up feature is provided for the operator during low temperature operations. This system provides the capability for RCS inventory letdown, thereby maintaining RCS pressure within allowable limits. Refer to [Sections 5.4.7, 5.4.10, 5.4.13, 7.6.6, and 9.3.4](#) for additional information on RCS pressure and inventory control during other modes of operation.

The basic function of the system logic is to continuously monitor RCS temperature and pressure conditions whenever plant operation is at low temperatures. An auctioneered low wide range RCS temperature will be continuously converted to an allowable pressure and then compared to the actual wide range RCS pressure. The system logic will first annunciate a main control board alarm whenever the measured pressure approaches within a pre-determined amount of the allowable pressure thereby indicating

that a pressure transient is occurring. On a further increase in measured pressure, an actuation signal is transmitted to open the pressurizer power-operated relief valves (if the COMS actuation logic has been manually armed) when required to mitigate the pressure transient.

When the RCS and RHR systems are cross-connected, the RHR suction relief valves are available to maintain RCS pressure within allowable limits.

5.2.2.10.2 Evaluation of Low Temperature Overpressure Transients

The ASME Code (Section III, Appendix G) establishes guidelines and upper limits for RCS pressure primarily for low temperature conditions (<350°F). The cold overpressure mitigation system discussed in [Section 5.2.2.10.1](#) addresses these conditions as discussed in the following paragraphs.

Transient analyses have been performed to determine the maximum pressure for the postulated mass input and heat input events.

The mass input pressure transient which would occur most frequently during the course of normal plant operation would involve letdown isolation with charging pumps delivering an input less than or equal to 120 gpm. However, the mass input analysis has been performed assuming one safety-related ECCS charging pump and the non-safety related normal charging pump operating in a configuration producing maximum delivery rates. This configuration is like the case of an inadvertent Safety Injection with flow from both pumps through the boron injection header and the RCP seals, with a simultaneous loss of letdown.

The heat input transient has been performed over the entire RCS shutdown temperature range. This analysis assumes an inadvertent reactor coolant pump startup with a 50°F mismatch between the RCS and the temperature of the hotter secondary side of the steam generators.

Both the heat input and mass input analyses take into account the single failure criterion and therefore, only one pressurizer power-operated relief valve or one RHR suction relief valve was assumed to be available for pressure relief. The above events have been evaluated considering the allowable pressure/temperature limits established by the Appendix G guidelines. The evaluation of the transient results conclude that reactor vessel integrity is not impaired.

5.2.2.10.3 Operating Basis Earthquake Evaluation

A fluid systems evaluation has been performed considering the potential for overpressure transients following an operating basis earthquake.

The Callaway pressurizer power-operated relief valves and RHR suction relief valves have been designed in accordance with the ASME Code and seismically qualified under the Westinghouse valve operability program which is discussed in [Section 3.9\(N\).3.2](#).

Therefore, the cold overpressure mitigation system will be available to provide pressure relief following an operating basis earthquake.

5.2.2.10.4 Administrative Procedures

Although the system described in [Section 5.2.2.10.1](#) is installed to maintain RCS pressure within allowable limits, administrative procedures minimize the potential for occurrence and the consequences of any transient that could actuate the cold over pressure mitigation system. The following discussion highlights these procedural controls, listed in hierarchy of their function in mitigating RCS cold overpressurization transients.

Of primary importance is the basic method of operation of the plant. Normal plant operating procedures will maximize the use of a pressurizer cushion (steam bubble) during periods of low pressure, low temperature operation. This cushion will dampen the plants' response to potential transient generating inputs, providing easier pressure control with the slower response rates.

An adequate cushion substantially reduces the severity of potential pressure transients, such as reactor coolant pump induced heat input, and slows the rate of pressure rise for others. In conjunction with the alarms discussed in [Section 7.6.6](#), this provides reasonable assurance that most potential transients can be terminated by operator action before the overpressure relief system actuates.

5.2.2.10.4.1 Overpressurization Transient

However, for those modes of operation when water solid operation may still be possible, procedures will further highlight precautions that minimize the severity of, or the potential for, developing an overpressurization transient. The following precautions or measures are considered in developing the operating procedures:

- a. The residual heat removal inlet lines from the reactor coolant loop are normally open when the RCS pressure is less than 400 psi (subject to procedural requirements related to preventing void formation associated with exceeding saturation conditions in the RHR suction lines from the RWST). This precaution assures that there is a relief path from the reactor coolant loop to the residual heat removal suction line relief valves when the RCS is at low pressure and is water solid.
- b. Whenever the plant is water solid and the reactor coolant pressure is being maintained by the low pressure letdown control valve, letdown flow

normally bypasses the normal letdown orifices. In addition, all three letdown orifices normally remain open.

- c. If all reactor coolant pumps have stopped for more than 5 minutes during plant heatup and the reactor coolant temperature is greater than the charging and seal injection water temperature, a steam bubble is procedurally required to be formed in the pressurizer prior to restarting a reactor coolant pump. This precaution minimizes the pressure transient when the pump is started and the cold water previously injected by the charging pumps is circulated through the warmer reactor coolant components. The steam bubble will accommodate the resultant expansion as the cold water is rapidly warmed.
- d. If all reactor coolant pumps are stopped and the RCS is being cooled down by the residual heat exchangers, a nonuniform temperature distribution may occur in the reactor coolant loops. Prior to restarting a reactor coolant pump, the RCP startup restrictions in TS LCOs 3.4.6 and 3.4.7 shall be met. If RCS temperature has been reduced by more than 20°F by RHR, a steam bubble is procedurally required to be formed in the pressurizer prior to restarting a RCP.
- e. During plant cooldown, all steam generators will normally be connected to the steam header to assure a uniform cooldown of the reactor coolant loops.
- f. At least one reactor coolant pump will normally remain in service until the reactor coolant temperature is reduced to 160°F.

These special precautions back-up the normal operational mode of maximizing periods of steam bubble operation so that cold overpressure transient prevention is continued during periods of transitional operations. These precautions do not apply to reactor coolant system hydrostatic testing.

5.2.2.10.4.2 Cold Overpressurization Transients

The specific plant configurations of emergency core cooling system testing and alignment will also highlight procedural recommendations to prevent developing cold overpressurization transients. During these limited periods of plant operation, the following precautions/measures are considered in developing the operating procedures:

- a. To preclude inadvertent emergency core cooling system actuation during heatup and cooldown, procedures require blocking the pressurizer pressure and low steam line pressure safety injection signal actuation logic at approximately 1,900 psig (below the P-11 interlock setpoint).

- b. During further cooldown, the accumulator isolation valves are closed and power is disconnected at the MCC after the RCS has been depressurized below 1,000 psig, providing additional back-up to Item a above. One ECCS centrifugal charging pump and both safety injection pumps are rendered incapable of injecting into the RCS prior to entering TS 3.4.12 Applicability.

However, two ECCS centrifugal charging pumps may be capable of injecting for \leq 1 hour for pump swap operations throughout TS 3.4.12 Applicability. With the reactor coolant water level below the top of the reactor vessel flange and with the vessel head on in MODES 5 and 6, the Safety Injection pumps may be operated to mitigate the effects of a loss of decay heat removal during partially drained conditions.

- c. The recommended procedure for periodic emergency core cooling system pump performance testing will be to test the pumps during normal power operation or at hot shutdown conditions. This precludes any potential for developing a cold overpressurization transient.

Should cold shutdown (CSD) testing of the pumps be desired, the test will be done when the vessel is open to atmosphere, again precluding overpressurization potential.

If CSD testing with the vessel closed is necessary, the procedures require emergency core cooling system pumps discharge valve closure and RHRS alignment to isolate potential emergency core cooling system pump input and to provide back-up benefit of the RHRS relief valves.

- d. SIS circuitry testing, if done during CSD, requires RHRS alignment and steps to preclude RCS injection from one ECCS centrifugal charging pump and both safety injection pumps to preclude developing cold overpressurization transients.

The above procedural precautions covering normal operations with a steam bubble, transitional operations where potentially water solid, and specific testing operations provide in-depth cold overpressure preventions or reductions, augmenting the installed overpressure relief system. Refer to Technical Specification 3.4.12.

5.2.2.11 Testing and Inspection

Testing and inspection of the overpressure protection components are discussed in **Section 5.4.13.4.**

5.2.3 MATERIALS SELECTION, FABRICATION, AND PROCESSING

5.2.3.1 Material Specifications

Material specifications used for the principal pressure retaining applications in components of the RCPB are listed in **Table 5.2-2** for ASME Class 1 primary components and **Table 5.2-3** for ASME Class 1 and 2 auxiliary components. **Tables 5.2-2** and **5.2-3** also include the material specifications of unstabilized austenitic stainless steel used for components in systems required for reactor shutdown and for emergency core cooling.

The material specifications of unstabilized austenitic stainless steel used for reactor vessel internals which are essential for emergency core cooling and for core structural support are listed in **Table 5.2-4**.

Table 5.2-3 is not totally inclusive of the material specifications used in the listed applications. However, the listed specifications are representative.

The materials utilized conform to the applicable ASME Code rules.

The welding materials used for joining the ferritic base materials of the RCPB conform to or are equivalent to ASME Material Specifications SFA 5.1, 5.2, 5.5, 5.17, 5.18, and 5.20. They are qualified to the requirements of the ASME Code, Section III.

The welding materials used for joining the austenitic stainless steel base materials of the RCPB conform to ASME Material Specifications SFA 5.4, 5.9, and 5.22. They are qualified to the requirements of the ASME Code, Section III.

The welding materials used for joining nickel-chromium-iron alloy in similar base material combination and in dissimilar ferritic or austenitic base material combination conform to ASME Material Specifications SFA 5.11 and 5.14. They are qualified to the requirements of the ASME Code, Section III.

5.2.3.2 Compatibility With Reactor Coolant

5.2.3.2.1 Chemistry of Reactor Coolant

The RCS chemistry specifications are listed in Chemistry Department Procedures, and are based on industry guidelines (such as the EPRI PWR Primary Water Chemistry Guidelines and the Westinghouse Guidelines for Primary Water Chemistry), Technical Specifications, **Table 5.2-5** and FSAR Ch. 16.

The RCS water chemistry is selected to minimize corrosion. Routinely scheduled analyses of the coolant chemical composition are performed to verify that the reactor coolant chemistry meets the specifications.

The chemical and volume control and RHR systems provide a means for adding chemicals to the RCS which perform the following functions: 1) control the pH of the coolant during pre-startup testing and subsequent operation, 2) scavenge oxygen from the coolant during heatup, and 3) control radiolysis reactions involving hydrogen, oxygen, and nitrogen during all power operations subsequent to startup. The normal limits for chemical additives and reactor coolant impurities for power operation are shown in **Table 5.2-5**.

The pH control chemical utilized is lithium hydroxide monohydrate, enriched in the lithium-7 isotope to 99.9 percent. This chemical is chosen for its compatibility with the materials and water chemistry of borated water/stainless steel/zirconium/inconel systems. In addition, lithium-7 is produced in solution from the neutron irradiation of the dissolved boron in the coolant. The lithium-7 hydroxide may be introduced into the RCS via the charging flow, or via alternate suitable flowpaths. The solution is prepared in the laboratory and is added via various installed plant systems or components. Reactor makeup water, or other suitable liquid, may then be used to flush the solution into the RCS. The concentration of lithium-7 hydroxide in the RCS is maintained in the range specified for pH control. If the concentration exceeds this range, the cation bed demineralizer is employed in the letdown line in series operation with the mixed bed demineralizer.

During reactor startup from the cold condition, and at other times as necessary, hydrazine is employed as an oxygen scavenging agent. The hydrazine solution may be introduced into the RCS in the same manner as described above for the pH control agent.

The reactor coolant is treated with dissolved hydrogen to control the net decomposition of water by radiolysis in the core region. The hydrogen also reacts with oxygen and nitrogen introduced into the RCS as impurities under the impetus of core radiation. Sufficient partial pressure of hydrogen is maintained in the volume control tank so that the specified equilibrium concentration of hydrogen is maintained in the reactor coolant. A self-contained pressure control valve maintains a minimum pressure in the vapor space of the volume control tank. This can be adjusted to provide the correct equilibrium hydrogen concentration.

Boron, in the chemical form of boric acid, is added to the RCS for long-term reactivity control of the core.

Suspended solids (corrosion product particulates) are minimized in the reactor coolant by controlling makeup water and by the use of small micron filters. Other impurity concentrations are maintained below specified limits by controlling the chemical quality of makeup water and chemical additives and by purification of the reactor coolant through the chemical and volume control system mixed bed demineralizer.

A soluble zinc compound may be added to the reactor coolant as a means to reduce radiation fields within the primary system. The zinc used may be either natural zinc or

zinc depleted of ^{64}Zn . When used, the target system zinc concentration is normally maintained to a concentration no greater than 40 ppb.

Zinc may be added to the reactor coolant system to reduce radiation fields and may later be added to reduce primary water stress corrosion cracking of Inconel-600 components.

5.2.3.2.2 Compatibility of Construction Materials with Reactor Coolant

All of the ferritic low alloy and carbon steels which are used in principal pressure retaining applications have corrosion resistant cladding on all surfaces that are exposed to the reactor coolant except for an area approximately 1.5 inches by 0.75 inches at approximate location 302.94° from vessel "0" and 384.89 inches down from the flange surface and an area approximately 0.53 inches by 0.3 inches at approximate location 1850 from vessel "0" and 385 inches down from the flange surface. The existence of these areas has been evaluated as acceptable. The corrosion resistance of the cladding material is at least equivalent to the corrosion resistance of Types 304 and 316 austenitic stainless steel alloys or nickel-chromium-iron alloy, martensitic stainless steel, and precipitation hardened stainless steel. The cladding of ferritic type base materials receives a post-weld heat treatment, as required by the ASME Code.

Ferritic low alloy and carbon steel nozzles have safe ends of either stainless steel forged or wrought materials, stainless steel weld metal analysis A-7 (designated A-8 in the 1974 Edition of the ASME Code), or nickel-chromium-iron alloy weld metal F-Number 43. The latter buttering material requires further safe ending with austenitic stainless steel base material after completion of the post-weld heat treatment when the nozzle is larger than a 4-inch nominal inside diameter and/or the wall thickness is greater than 0.531 inches.

All of the austenitic stainless steel and nickel-chromium-iron alloy base materials with primary pressure retaining applications are used in the solution anneal heat treat condition. These heat treatments are as required by the material specifications.

During subsequent fabrication, these materials are not heated above 800°F other than locally by welding operations. The solution annealed surge line material is subsequently formed by hot bending followed by a re-solution annealing heat treatment.

Components with stainless steel sensitized in the manner expected during component fabrication and installation will operate satisfactorily under normal plant chemistry conditions in pressurized water reactor systems because chlorides, fluorides, and oxygen are controlled to very low levels.

5.2.3.2.3 Compatibility with External Insulation and Environmental Atmosphere

In general, all of the materials listed in [Tables 5.2-2](#) and [5.2-3](#) which are used in principal pressure-retaining applications and which are subject to elevated temperature during system operation are in contact with thermal insulation that covers their outer surfaces.

The thermal insulation used on the RCPB is either the reflective stainless steel type or made of compounded materials which yield low leachable chloride and/or fluoride concentrations. The compounded materials in the form of blocks, boards, cloths, tapes, adhesives, cements, etc., are silicated to provide protection of austenitic stainless steels against stress corrosion which may result from accidental wetting of the insulation by spillage, minor leakage, or other contamination from the environmental atmosphere.

[Appendix 3A](#) includes a discussion which indicates the degree of conformance with Regulatory Guide 1.36, "Nonmetallic Thermal Insulation for Austenitic Stainless Steel."

In the event of coolant leakage, the ferritic materials will show increased general corrosion rates. Where minor leakage is anticipated from service experience, such as valve packing, pump seals, etc., only materials which are compatible with the coolant are used. These are as shown in [Tables 5.2-2](#) and [5.2-3](#). Ferritic materials exposed to coolant leakage can be readily observed as part of the inservice visual and/or nondestructive inspection program to assure the integrity of the component for subsequent service.

5.2.3.3 Fabrication and Processing of Ferritic Materials

5.2.3.3.1 Fracture Toughness

The fracture toughness properties of the RCPB components meet the requirements of the ASME Code, Section III, Paragraphs NB, NC, and ND-2300 as appropriate.

The fracture toughness properties of the reactor vessel materials are discussed in [Section 5.3](#).

Limiting steam generator and pressurizer RT_{NDT} temperatures are guaranteed at 60°F for the base materials and the weldments. These materials will meet the 50 ft-lb absorbed energy and 35 mils lateral expansion requirements of the ASME Code, Section III at 120°F. The actual results of these tests are provided in the ASME material data reports which are supplied for each component and submitted to the owner at the time of shipment of the component.

Calibration of temperature instruments and Charpy impact test machines are performed to meet the requirements of the ASME Code, Section III, Paragraph NB-2360.

Westinghouse has conducted a test program to determine the fracture toughness of low alloy ferritic materials with specified minimum yield strengths greater than 50,000 psi to

demonstrate compliance with Appendix G of the ASME Code, Section III. In this program, fracture toughness properties were determined and shown to be adequate for base metal plates and forgings, weld metal, and heat affected zone metal for higher strength ferritic materials used for components of the RCPB. The results of the program are documented in Reference 1, which has been submitted to the NRC for review.

5.2.3.3.2 Control of Welding

All welding is conducted utilizing procedures qualified according to the rules of Sections III and IX of the ASME Code. Control of welding variables, as well as examination and testing during procedure qualification and production welding, is performed in accordance with ASME Code requirements.

Appendix 3A includes discussions which indicate the degree of conformance of the ferritic materials components of the RCPB with Regulatory Guides 1.34, "Control of Electroslag Weld Properties," 1.43, "Control of Stainless Steel Weld Cladding of Low-Alloy Steel Components," 1.50, "Control of Preheat Temperature for Welding of Low-Alloy Steel," and 1.71, "Welder Qualification for Areas of Limited Accessibility."

5.2.3.4 Fabrication and Processing of Austenitic Stainless Steel

Sections 5.2.3.4.1 through 5.2.3.4.5 address Regulatory Guide 1.44, "Control of the Use of Sensitized Stainless Steel," and present the methods and controls utilized by Westinghouse to avoid sensitization and prevent intergranular attack of austenitic stainless steel components. Also, **Appendix 3A** includes a discussion which indicates the degree of conformance with Regulatory Guide 1.44.

5.2.3.4.1 Cleaning and Contamination Protection Procedures

It is required that all austenitic stainless steel materials used in the fabrication, installation, and testing of nuclear steam supply components and systems be handled, protected, stored, and cleaned according to recognized and accepted methods which are designed to minimize contamination which could lead to stress corrosion cracking. The rules covering these controls are stipulated in Westinghouse process specifications. As applicable, these process specifications supplement the equipment specifications and purchase order requirements of every individual austenitic stainless steel component or system which Westinghouse procures for the SNUPPS nuclear steam supply systems, regardless of the ASME Code classification.

The process specifications which define these requirements and which follow the guidance of the American National Standards Institute N-45 Committee specifications are as follows:

| <u>Process Number</u> | Specification |
|-----------------------|--|
| 82560HM | Requirements for Pressure Sensitive Tapes for Use on Austenitic Stainless Steels |
| 83336KA | Requirements for Thermal Insulation Used on Austenitic Stainless Steel Piping and Equipment |
| 83860LA | Requirements for Marking of Reactor Plant Components and Piping |
| 84350HA | Site Receiving Inspection and Storage Requirements for Systems, Material, and Equipment |
| 84351NL | Determination of Surface Chloride and Fluoride on Austenitic Stainless Steel Materials |
| 85310QA | Packaging and Preparing Nuclear Components for Shipment and Storage |
| 292722 | Cleaning and Packaging Requirements of Equipment for Use in the NSSS |
| 597756 | Pressurized Water Reactor Auxiliary Tanks Cleaning Procedures |
| 597760 | Cleanliness Requirements During Storage Construction, Erection and Start-Up Activities of Nuclear Power System |

Appendix 3A includes a discussion which indicates the degree of conformance of the austenitic stainless steel components of the RCPB with Regulatory Guide 1.37, "Quality Assurance Requirements for Cleaning of Fluid Systems and Associated Components of Water-Cooled Nuclear Power Plants."

5.2.3.4.2 Solution Heat Treatment Requirements

The austenitic stainless steels listed in **Tables 5.2-2, 5.2-3, and 5.2-4** are utilized in the final heat treated condition required by the respective ASME Code, Section II materials specification for the particular type of grade of alloy.

5.2.3.4.3 Material Testing Program

Westinghouse practice is that austenitic stainless steel materials of product forms with simple shapes need not be corrosion tested provided that the solution heat treatment is followed by water quenching. Simple shapes are defined as all plates, sheets, bars, pipe, and tubes, as well as forgings, fittings, and other shaped products which do not

have inaccessible cavities or chambers that would preclude rapid cooling when water quenched. When testing is required, the tests are performed in accordance with ASTM A 262, Practice A or E, as amended by Westinghouse Process Specification 84201MW.

5.2.3.4.4 Prevention of Intergranular Attack of Unstabilized Austenitic Stainless Steels

Unstabilized austenitic stainless steels are subject to intergranular attack (IGA) provided that three conditions are present simultaneously. These are:

- a. An aggressive environment, e.g., an acidic aqueous medium containing chlorides or oxygen
- b. A sensitized steel
- c. A high temperature

If any one of the three conditions described above is not present, intergranular attack will not occur. Since high temperatures cannot be avoided in all components in the NSSS, reliance is placed on the elimination of conditions a and b to prevent intergranular attack on wrought stainless steel components.

This is accomplished by:

- a. Control of primary water chemistry to ensure a benign environment.
- b. Utilization of materials in the final heat treated condition and the prohibition of subsequent heat treatments in the 800 and 1,500°F temperature range.
- c. Control of welding processes and procedures to avoid heat affected zone sensitization.
- d. Confirmation that the welding procedures used for the manufacture of components in the primary pressure boundary and of reactor internals do not result in the sensitization of heat affected zones.

Further information on each of these steps is provided in the following paragraphs:

The water chemistry in the RCS is controlled in **Chapter 16** and plant procedures to prevent the intrusion of aggressive species. Reference 5 describes the precautions taken to prevent the intrusion of chlorides into the system during fabrication, shipping, and storage. The use of hydrogen over pressure precludes the presence of oxygen during operation. The effectiveness of these controls has been demonstrated by laboratory tests and operating experience. The long-time exposure of severely sensitized stainless in early Westinghouse pressurized water reactors to reactor coolant environments has not resulted in any sign of intergranular attack. Reference 5 describes

the laboratory experimental findings and reactor operating experience. The additional years of operations since the issuance of Reference 5 have provided further confirmation of the earlier conclusions that severely sensitized stainless steels do not undergo any intergranular attack in Westinghouse pressurized water reactor coolant environments.

In spite of the fact that there never has been any evidence that pressurized water reactor coolant water attacks sensitized stainless steels, Westinghouse considers it good metallurgical practice to avoid the use of sensitized stainless steels in the nuclear steam supply system components. Accordingly, measures are taken to prohibit the purchase of sensitized stainless steels and to prevent sensitization during component fabrication. Wrought austenitic stainless steel stock used for components that are part of: 1) the RCPB, 2) systems required for reactor shutdown, 3) systems required for emergency core cooling, and 4) reactor vessel internals (relied upon to permit adequate core cooling for normal operation or under postulated accident conditions) is utilized in one of the following conditions:

- a. Solution annealed and water quenched, or
- b. Solution annealed and cooled through the sensitization temperature range within less than approximately 5 minutes

It is generally accepted that these practices will prevent sensitization. Westinghouse has verified this by performing corrosion tests on as-received wrought material.

The heat-affected zones of welded components must, of necessity, be heated into the sensitization temperature range, 800 to 1,500°F. However, severe sensitization, i.e., continuous grain boundary precipitates of chromium carbide, with adjacent chromium depletion, can be avoided by controlling welding parameters and welding processes. The heat input* and associated cooling rate through the carbide precipitation range are of primary importance. Westinghouse has demonstrated this by corrosion testing a number of weldments.

Of 25 production and qualification weldments tested, representing all major welding processes, and a variety of components, and incorporating base metal thicknesses from 0.10 to 4.0 inches, only portions of two were severely sensitized. Of these, one involved a heat input of 120,000 joules, and the other involved a heavy socket weld in relatively

* Heat input is calculated according to the formula:

$$H = \frac{(E)(I)(60)}{S}$$

Where:

H = joules/in.

E = volts

I = amperes

S = travel speed, in./min.

thin walled material. In both cases, sensitization was caused primarily by high heat inputs relative to the section thickness. In only the socket weld did the sensitized condition exist at the surface, where the material is exposed to the environment. The component has been redesigned, and a material change has been made to eliminate this condition.

The heat input in all austenitic pressure boundary weldments has been controlled by:

- a. Prohibiting the use of block welding
- b. Limiting the maximum interpass temperature to 350°F
- c. Westinghouse exercising approval rights on all welding procedures

5.2.3.4.5 Retesting Unstabilized Austenitic Stainless Steels Exposed to Sensitization Temperatures

As described in the previous section, it is not normal Westinghouse practice to expose unstabilized austenitic stainless steels to the sensitization range of 800 to 1,500°F during fabrication into components. If, during the course of fabrication, the steel is inadvertently exposed to the sensitization temperature range, 800 to 1,500°F, the material may be tested in accordance with ASTM A 262, as amended by Westinghouse Process Specification 84201MW, to verify that it is not susceptible to intergranular attack, except that testing is not required for:

- a. Cast metal or weld metal with a ferrite content of 5 percent or more,
- b. Material with a carbon content of 0.03 percent or less that is subjected to temperatures in the range of 800 to 1,500°F for less than 1 hour,
- c. Material exposed to special processing provided the processing is properly controlled to develop a uniform product and provided that adequate documentation exists of service experience and/or test data to demonstrate that the processing will not result in increased susceptibility to intergranular stress corrosion.

If it is not verified that such material is not susceptible to intergranular attack, the material will be resolution annealed and water quenched or rejected.

5.2.3.4.6 Control of Welding

The following paragraphs address Regulatory Guide 1.31, "Control of Ferrite Content in Stainless Steel Weld Metal," and present the methods used, and the verification of these methods, for austenitic stainless steel welding.

The welding of austenitic stainless steel is controlled to mitigate the occurrence of microfissuring or hot cracking in the weld. Although published data and experience have not confirmed that fissuring is detrimental to the quality of the weld, it is recognized that such fissuring is undesirable in a general sense. Also, it has been well documented in the technical literature that the presence of delta ferrite is one of the mechanisms for reducing the susceptibility of stainless steel welds to hot cracking. However, there is insufficient data to specify a minimum delta ferrite level below which the material will be prone to hot cracking. It is assumed that such a minimum lies somewhere between 0- and 3-percent delta ferrite.

The scope of these controls discussed herein encompasses welding processes used to join stainless steel parts in components designed, fabricated, or stamped in accordance with the ASME Code, Section III, Class 1, 2, and core support components. Delta ferrite control is appropriate for the above welding requirements, except where no filler metal is used or for other reasons such control is not applicable. These exceptions include electron beam welding, autogenous gas shielded tungsten arc welding, explosive welding, and welding using fully austenitic welding materials.

The fabrication and installation specifications require welding procedure and welder qualification in accordance with Section III, and include the delta ferrite determinations for the austenitic stainless steel welding materials that are used for welding qualification testing and for production processing. Specifically, the undiluted weld deposits of the "starting" welding materials are required to contain a minimum of 5-percent delta ferrite* as determined by chemical analysis and calculation, using the appropriate weld metal constitution diagrams in Section III. When new welding procedure qualification tests are evaluated for these applications, including repair welding of raw materials, they are performed in accordance with the requirements of Section III and Section IX.

The results of all the destructive and nondestructive tests are reported in the procedure qualification record in addition to the information required by Section III.

The "starting" welding materials used for fabrication and installation welds of austenitic stainless steel materials and components meet the requirements of Section III. The austenitic stainless steel welding material conforms to ASME weld metal analysis A-7 (designated A-8 in the 1974 Edition of the ASME Code), Type 308 or 308L for all applications. Bare weld filler metal, including consumable inserts, used in inert gas welding processes conform to ASME SFA 5.9, and are procured to contain not less than 5-percent delta ferrite according to Section III. Weld filler metal materials used in flux shielded welding processes conform to ASME SFA 5.4 or 5.9 and are procured in a wire-flux combination to be capable of providing not less than 5-percent delta ferrite in the deposit according to Section III. Welding materials are tested, using the welding energy inputs to be employed in production welding.

* The equivalent ferrite number may be substituted for percent delta ferrite.

Combinations of approved heat and lots of "starting" welding materials are used for all welding processes. The welding quality assurance program includes identification and control of welding material by lots and heats as appropriate. All of the weld processing is monitored according to approved inspection programs which include review of "starting" materials, qualification records and welding parameters.

Welding systems are also subject to quality assurance audit including calibration of gages and instruments; identification of "starting" and completed materials; welder and procedure qualifications; availability and use of approved welding and heat treating procedures; and documentary evidence of compliance with materials, welding parameters, and inspection requirements. Fabrication and installation welds are inspected using nondestructive examination methods according to Section III rules.

To assure the reliability of these controls, Westinghouse has completed a delta ferrite verification program, described in Reference 6, which has been approved as a valid approach to verify the Westinghouse hypothesis and is considered an acceptable alternative for conformance with the NRC Interim Position on Regulatory Guide 1.31. The Regulatory Staff's acceptance letter and topical report evaluation were received on December 30, 1974. The program results, which do support the hypothesis presented in Reference 6, are summarized in Reference 7.

Appendix 3A includes discussions which indicate the degree of conformance of the austenitic stainless steel components of the RCPB with Regulatory Guides 1.34, "Control of Electroslag Properties," and 1.71, "Welder Qualification for Areas of Limited Accessibility."

5.2.4 INSERVICE INSPECTION AND TESTING OF THE REACTOR COOLANT PRESSURE BOUNDARY

Inservice inspection and testing of pressure-retaining components, such as vessels, piping, pumps, valves, and bolting and supports within the reactor coolant pressure boundary, complies with the ASME Code, including addenda, per 10 CFR 50.55a(f) for inservice testing and 10 CFR 50.55a(g) for inservice inspection. Exceptions to compliance with ASME Code is obtained when specific written relief is granted by the NRC per 10 CFR 50.55a(a)(3), 10 CFR 50.55a(f)(6), or 10 CFR 50.55a(g)(6), or when Code Cases are incorporated per 10 CFR 50.55a(b)(5) or 10 CFR 50.55a(b)(6). The limitations and modifications that the NRC places on the ASME Code in 10 CFR 50.55a(b) are adhered to. The inservice testing of pumps and valves per the requirements of the ASME OM Code are discussed in **Section 3.9(B).6**.

Callaway initially submitted separate preservice and inservice inspection program documents, for pumps and valves, which complied with "NRC Staff Guidance for Complying with Certain Provision of 10 CFR 50.55a(g)--Inservice Inspection Requirements." Subsequent inservice inspection program documents are prepared in accordance with the 10-year update requirements in 10 CFR 50.55a and submitted to the NRC for initial approval. The inspection program documents identify the applicable

Section XI edition and addenda and provide the details for the areas subject to examination, method of examination, extent and frequency of examination, and applicable Code Cases. 'Relief Requests' seeking relief from applicable code requirements are submitted to the NRC and become part of the inservice inspection program upon approval by the NRC. The repair and replacement program identifies the applicable Section XI edition and addenda, applicable Code Cases and relief requests, and provides the administrative controls for performing repairs and replacements.

Since the plant will be required to meet the requirements of future editions of Section XI, insofar as practicable, an attempt was made during design to allow access for inspections and coverages anticipated to be required by later editions of the Code. The result of this effort has increased the areas on the RPV available to mechanized inservice inspection. Callaway has attempted to create an inservice inspection program and plant design that are consistent with the 10 CFR 50 philosophy of upgrading inspections.

5.2.4.1 Inspection of Class I Components

The system boundary subject to inspection includes all piping and components in quality Group A (ASME Boiler and Pressure Vessel Code, Section III, Class I).

The reactor pressure vessel (RPV), pressurizer, Class 1 portion of the steam generators, and all Class 1 piping, pumps, and valves are examined except for those areas where relief has been requested and granted.

The scope of examinations, inspections, and acceptance criteria meets the requirements outlined in Section XI of the ASME Boiler and Pressure Vessel Code, "Rules for Inservice Inspection of Nuclear Power Plant Components." In addition, the ultrasonic examination of ferritic, austenitic, and dissimilar metal components will be performed in accordance with IWA-2232.

The extent of selection of piping welds for examination is determined by the risk-informed ISI program (RI-ISI) implemented in accordance with ASME Section XI and 10 CFR 50.55a.

5.2.4.2 Arrangement and Accessibility

5.2.4.2.1 General

Access for the purpose of inservice inspection is defined as the design of the plant with the proper clearances for examination personnel and/or equipment to perform inservice examinations during a nuclear unit shutdown. During system and component arrangement design, careful attention was given to physical clearances to allow personnel and equipment to perform required inservice examinations. Access

requirements of the Code have been considered in the design of components, weld joint configuration, and system arrangement. An inservice inspection program design review was undertaken to identify any exceptions to the access requirements of the code with subsequent design modifications and/or inspection technique development to ensure Code compliance, as required. Additional exceptions may be identified and reported to the NRC after plant operations, as specified in 10 CFR 50.55a(g) (5)(iv). Space has been provided to handle and store insulation, structural members, shielding, calibration blocks, and similar material related to the inspection. Suitable hoists and other handling equipment are also provided. Lighting, sources of power, and services for the inspection equipment are provided at appropriate locations.

Access is provided for volumetric examination of the pressure-containing welds from the external surfaces of components and piping by means of removable insulation and removable shielding. Provisions for suitable access for inservice inspection examinations will minimize the time required for these inspections to be performed. Therefore, they will reduce the amount of radiation exposure to both plant and examination personnel. Working platforms have been provided at strategic locations in the plant to permit ready access to those areas of the reactor coolant pressure boundary which are designated as inspection points in the inservice inspection program. Areas without permanent platforms will be provided with temporary platforms and/or scaffolding, as required.

5.2.4.2.2 Access to Reactor Pressure Vessel

Access for inspection of the RPV will be as follows:

- a. Access to the inner surface of the RPV will be available during refueling outages when the vessel core barrel is removed. A remotely operated examination device designed to perform ultrasonic examinations from the inner surface of the vessel will be used to examine the vessel-to-flange weld, nozzle-to-shell welds, and the longitudinal circumferential, and meridional welds of the vessel. However, vessel welds below the 2,011-foot-6-inch cavity shelf elevation may be examined from the outer surface of the vessel. Selected areas of reactor cladding and the internal support attachments welded to the vessel wall will be accessible for remote visual examination when the core barrel is removed at the end of the 10-year inspection interval. A camera capable of remote positioning will be inserted into the RPV.
- b. If required, examination personnel will be able to install tracks for the examination of the nozzle and piping welds, the longitudinal welds in the upper shell course, and the flange-to-shell weld. These tracks can be lowered from the 2,021-foot-7-3/4-inch containment elevation through the opening between the vessel flange and the insulation. The mechanized equipment may be installed in a similar manner.

- c. The vessel flange seal surface will be accessible during refueling outages when the closure head is removed. The vessel-to-flange weld can be examined manually or mechanically from the flange seal surface, using ultrasonic techniques. The inside surface of the RPV will be available for a mechanized examination of the vessel-to-flange weld from the vessel side during refueling outages when the core barrel is removed. If examination of the vessel-to-flange weld is required when the core barrel has not been removed, the weld can be examined from the exterior surface of the vessel.
- d. Access to the exterior surface of the RPV below the 2,011-foot-6-inch cavity shelf elevation for augmented inservice inspection is available since an annular space has been provided between the vessel exterior surface and the insulation interior surface. This permits the insertion of remotely operated inspection devices between the insulation and the reactor vessel. Examination personnel can enter the area below the RPV through one approximately 3-foot-square access port in the insulation to install the pole track remote examination device. The bottom head insulation is designed to allow an examiner to walk on the insulation while installing the examination device. Access to the window is provided through the in-core instrumentation tunnel.

A 3-foot annular space between the exterior surface of the RPV and the interior surface of the insulation has been provided from the vessel closure flange elevation to the cavity shelf elevation. The clearance area provides sufficient access for examination personnel and equipment to perform any augmented inservice examinations on the exterior surfaces of the nozzle-to-shell, safe end, pipe-to-elbow, flange-to-shell, and longitudinal welds in the upper shell course of the vessel.

- e. The closure head will be dry stored during refueling, which will facilitate direct manual examination. Removable insulation will allow examination of the outside surfaces of the closure head. All reactor vessel nuts and washers will be removed to dry storage during refueling and may be examined at that time. The reactor vessel studs capable of being removed may be dry stored in racks. Required inservice examinations may be performed in the stud racks or reactor vessel studs may be removed from the stud racks for examination.

5.2.4.2.3 Pressurizer

The external surface is accessible for visual and volumetric inspection by removing the external insulation. Manways are provided to allow access for internal visual inspection. The insulation around the pressurizer heaters is provided with a means to identify component leakages during system hydrostatic and pressure testing.

5.2.4.2.4 Heat Exchangers and Steam Generators

The external surface is accessible for volumetric and visual inspection by removing portions of the vessel insulation. Manways in the steam generator channel head provide access for internal visual examinations and eddy current tests of steam generator tubes.

5.2.4.2.5 Piping Pressure Boundary

The physical arrangement of piping, pumps, and valves has been designed to allow personnel access to welds requiring inservice inspection. Modifications to the initial plant design have been incorporated where practical to provide proper inspection access. Removable insulation has been provided where required by the Code on those piping systems requiring ultrasonic and/or surface examinations. In addition, the placement of pipe hangers and supports with respect to these welds has been reviewed and modified where necessary to reduce the amount of plant support required in these areas during inspection. Working platforms are provided in areas required to facilitate the servicing of pumps and valves.

Temporary or permanent platforms and ladders will be provided, as necessary, to gain access to piping welds. A conscientious effort has been made to minimize the number of fitting-to-fitting welds within the inspection boundary. Welds requiring inspection have been located to permit ultrasonic examinations from at least one side, but, where component geometries permit, access from both sides of the weld is provided. The surfaces of the welds requiring ultrasonic examination by the Code have been prepared to permit effective examination.

5.2.4.2.6 Pump Pressure Boundaries

The internal pressure-retaining surfaces of the pumps are accessible for visual inspection by removing the pump internals. External surfaces of the pump casing are accessible for visual and volumetric examination by removing component insulation. Examination will be performed when the pumps are disassembled for maintenance purposes.

5.2.4.2.7 Valve Pressure Boundaries

Class 1 valves over 4-inch nominal size are accessible for disassembly for visual examination of internal pressure boundary surfaces.

5.2.4.3 Examination Techniques and Procedures

Techniques and procedures, including any special technique and procedure for visual, surface, and volumetric examinations, will be written in accordance with the requirements of Subarticle IWA-2200 and Table IWB-2500-1 of Section XI of the ASME Code, applicable year and addenda. The liquid penetrant or magnetic particle methods

will be utilized for surface examinations, radiographic (RT), and/or ultrasonic (UT) methods (either automated or manual) for volumetric examinations.

5.2.4.3.1 Equipment for Inservice Inspection

Procedures governing the use of the following examination devices will be qualified prior to examinations in the plant.

5.2.4.3.1.1 Ultrasonic Examination Equipment

Although the permanent tracks described in this section are still installed, they have never been used, due to advances in technology. The description of the permanently installed tracks is left in this section to document their existence for future use, if deemed necessary.

The remotely operated device for inservice inspection of the vessel and connected piping from their inner surfaces, as required, may be attached to the RPV at the flange surface. The device is capable of moving the transducers over the surface of the components in any direction.

The equipment for augmented inservice inspection of the reactor pressure vessel circumferential and vertical welds below the 2,011-foot-6-inch cavity elevation consists of remotely operated devices which can travel over the vessel shell or on permanently installed tracks between the vessel surface and the insulation. Tracks are located such that the devices requiring them are capable of moving ultrasonic transducers over all required lengths of the shell welds. Remote ultrasonic scanning equipment for examination of nozzle-to-vessel welds, safe ends, and pipe-to-elbow welds from the outer surface of the component can be mounted on the pipe or elbow. The nozzle-to-vessel weld examination equipment will provide radial and circumferential motion to the ultrasonic transducer while rotating about the nozzle. The pipe weld examination device will provide longitudinal and circumferential motion to the ultrasonic transducer while rotating about the pipe.

An electronic system with a receiver or data channel for each ultrasonic transducer will be used for acquiring and storing data when using remote automated examination equipment. Reflected signals may be transmitted through an ultrasonic instrument, gated, and multiplexed to initiate a digital recording. Scanning position will be indicated by encoders and subsequently logged by the data acquisition system. The key parameters of each reflector recorded include location, maximum signal amplitude, depth below the scanning surface, and length of reflector. However, similar or compatible systems of data acquisition may be utilized.

5.2.4.3.1.2 Surface Examination Equipment

Mechanized surface examination techniques will provide results which are at least equivalent to those obtainable by manual surface examination techniques.

5.2.4.3.1.3 Visual Examination Equipment

Remote visual examination techniques will provide a resolution capability which is at least equivalent to that obtainable by direct visual observation.

5.2.4.3.2 Coordination of Inspection Equipment with Access Provisions

Access to areas of the plant requiring inservice inspection is provided to allow the use of existing equipment, wherever practicable.

5.2.4.3.3 Manual Examination

In areas where manual ultrasonic examination is performed, all reportable indications will be mapped and records made of maximum signal amplitude, depth below the scanning surface, and length of the reflector. The data compilation format will be such as to provide for comparison of data from subsequent examinations. Radiographic techniques may be used where ultrasonic techniques are not applicable. In areas where manual surface or direct visual examinations are performed, all reportable indications will be mapped with respect to size and location in a manner to allow comparison of data from subsequent examinations.

5.2.4.4 Inspection Intervals

The inspection interval, as defined in Subarticle IWA-2400 of Section XI, is a 10 year interval of service. These inspection intervals represent calendar years after the reactor facility has been placed into commercial service. The interval may be extended by as much as one year to permit inspections to be concurrent with plant outages. The inspection schedule shall be in accordance with IWB-2400. Inservice examinations are performed during normal plant outages, such as refueling shutdowns or maintenance shutdowns occurring during the inspection interval. No examinations will be performed which require draining of the reactor vessel further than just below the nozzles or removal of the core solely for the purpose of accomplishing the examinations.

5.2.4.5 Examination Categories and Requirements

The extent of the examinations performed and the examination methods utilized are in accordance with Table IWB-2500-1 of ASME Section XI.

In lieu of the above for class 1, 2, and 3 piping welds, a risk-informed ISI program (RI-ISI) was implemented in accordance with ASME Section XI and 10 CFR 50.55a.

In addition, preservice inspections comply with IWB-2200.

5.2.4.6 Evaluation of Examination Results

Evaluation of examination results for Class 1 components are conducted in accordance with the requirements of Article IWB-3000 of the ASME Code, Section XI, 1998 Edition with 2000 Addenda. In addition, the recording and evaluation of examinations results for the reactor pressure vessel (RPV) are done as per Regulatory Guide 1.150, Revision 1.

5.2.4.7 System Leakage and Hydrostatic Tests

The hydrostatic test for the reactor pressure vessel and reactor coolant pressure boundary will be conducted in accordance with the requirements of Articles IWA-5000 and IWB-5000. System leakage tests will be conducted prior to startup following each reactor refueling outage, in accordance with Paragraph IWB-5221, as required by Table IWB-2500-1. A system hydrostatic test will be conducted at or near the end of each inspection interval in accordance with Paragraph IWB-5222, as required by Table IWB-2500-1. Examinations performed during these tests will be conducted without the removal of insulation.

5.2.5 REACTOR COOLANT PRESSURE BOUNDARY LEAKAGE DETECTION SYSTEMS

5.2.5.1 Design Bases

5.2.5.1.1 Safety Design Bases

There is no safety design basis for the reactor coolant pressure boundary leakage detection system.

5.2.5.1.2 Power Generation Design Bases

POWER GENERATION DESIGN BASIS ONE - For leaks of 1 gpm or greater, other than identified leakage sources, the reactor coolant boundary leakage detection systems are designed to detect leaks and determine the leakage rate (in accordance with Regulatory Guide 1.45 and 10 CFR 50, Appendix A, General Design Criterion 30). A comparison with the Regulatory Guide requirements is provided in **Table 5.2-6**.

POWER GENERATION DESIGN BASIS TWO - The leakage detection equipment is designed to continuously monitor the environmental conditions within the containment so that a background level is identified which is indicative of the normal level of leakage from primary systems and components. Significant upward deviation from normal containment environmental conditions provides positive indication in the control room of increases in leakage rates.

5.2.5.2 System Description

5.2.5.2.1 General Description

IDENTIFIED LEAKAGE DETECTION - Certain components of the reactor coolant pressure boundary may have small amounts of leakage and cannot, from a practical standpoint, be made leaktight. These identified sources of leakage are piped to the reactor coolant drain tank or the Pressurizer Relief Tank whose levels are indicated and alarmed in the control room. The annular gap between the O-rings in the reactor vessel head flange is tapped and piped to a temperature indicator and then to the reactor coolant drain tank. Reactor coolant leakage gives a high temperature indication and alarm. Additionally, the controlled leakage shaft seal system for the reactor coolant pumps is monitored by reactor coolant drain tank level indication and alarm.

UNIDENTIFIED LEAKAGE DETECTION - The reactor coolant pressure boundary leakage detection system consists of the sump level and flow monitoring system, the containment air particulate monitoring system, and the containment cooler condensate measuring system. The sump level and flow monitoring system indicates leakage by monitoring increases in sump level. The containment cooler condensate measuring system detects leakage from the release of steam or water to the containment atmosphere. The air particulate monitoring system detects leakage from the release of radioactive materials to the containment atmosphere. The containment gaseous radioactivity monitors could provide additional indication of leakage if significant reactor coolant gaseous activity is present from fuel cladding defects. The containment humidity measuring system is also available as an indirect indication of leakage to the containment.

Primary-to-secondary reactor coolant leakage, if it occurs, is detected by the following radioactivity monitors: the main condenser evacuation, the steam generator liquid, the steam generator blowdown processing, and the steam generator blowdown discharge ([Section 11.5.2](#)).

Reactor coolant pressure boundary leakage is also indicated by increasing charging pump flow rate compared with reactor coolant system inventory changes and by unscheduled increases in reactor makeup water usage.

INTERSYSTEM LEAKAGE - Leakage to any significant degree into the auxiliary systems connected to the RCPB is not expected to occur. Design and administrative provisions which serve to limit leakage include isolation valves designed for low seat leakage, periodic testing of RCPB check valves (see [Section 6.3.4.2](#)), and inservice inspection (see [Section 6.6](#)). Leakage will be detected by increasing the auxiliary system level, temperature, and pressure indications or lifting of the relief valves accompanied by increasing values of monitored parameters in the relief valve discharge path. These systems are isolated from the RCS by normally closed valves and/or check valves.

- a. Residual Heat Removal System (Suction Side) - The RHR system is isolated from the RCS on the suction side by motor-operated valves 8701A/B and 8702A/B. Leakage past these valves will be detected by lifting of relief valves 8708A or 8708B, accompanied by increasing pressurizer relief tank level, pressure, and temperature indications and alarms on the main control board.
- b. Safety Injection System/Accumulators - The accumulators are isolated from the RCS by check valves 8948A/B/C/D and 8956A/B/C/D. Leakage past these valves and into the accumulator subsystem will be detected by redundant control room accumulator pressure and level indications and alarms.
- c. Safety Injection System/RHR Discharge Subsystem - The RHR pump portion of the safety injection system is isolated from the RCS by check valves 8948A/B/C/D, 8818A/B/C/D, 8949B/C, 8841A/B, and normally closed motor-operated valve 8840. Leakage past these valves will eventually pressurize the RHR discharge header and result in lifting of the relief valves 8856A and 8856B or 8842. Relief valve lifting will be accompanied by control room indication and alarms of increasing boron recycle holdup tank levels.
- d. Safety Injection System/SI Pump Subsystem - The safety injection pump portion of the safety injection system is isolated from the RCS by check valves 8948A/B/C/D; EP-V010, V020, V030, V040; 8949A/B/C/D; EM-V001, V002, V003, V004; and normally closed motor-operated valves 8802A/B. Leakage past these valves will pressurize the safety injection pump discharge header, resulting in control room indication of increasing pressure and eventually lifting of relief valve 8851 or 8853A/B. Relief valve lifting will be accompanied by control room indication and alarms of increasing boron recycle holdup tank levels.
- e. Safety Injection System/ECCS Charging Pump Subsystem - The ECCS charging pump subsystem is isolated from the RCS by check valves BB-V001, V022, V040, V059, and EM-8815, and normally closed motor-operated valves EM-8801A/B. Leakage past these valves will pressurize the header between EM-8801A/B and normally closed motor-operated valves EM-8803A/B. If valves EM-8803A/B leak, the ECCS charging pump discharge piping could be pressurized. If an ECCS charging pump were not running, check valves BG-8481A/B would protect the suction side of the pumps. All piping and valves in this pathway from the discharge of the ECCS charging pumps to the RCS pressure boundary are safety-related and rated for RCS pressure. Thus, for a pathway to low pressure components, there would need to be a leakage through at least three check valves and two normally closed motor-operated gate valves. Any leakage through this pathway would be extremely unlikely and should

be very small. Any significant leakage to the suction of the ECCS centrifugal charging pumps could be detected by a change in charging flow rate.

- f. Waste Processing System - The waste processing system is isolated from the RCS by manual valves BB-V008, V028, V047, V066 and BB-V009, V029, V048, V067. Leakage past these valves will result in increasing the control room indication of reactor coolant drain tank level and reactor coolant drain tank pump flow.
- g. Head Gasket Monitoring Connections - Leakage past the reactor vessel head gasket(s) will result in temperature indication and alarm in the control room.
- h. Component Cooling Water - Leakage from the reactor coolant system to the component cooling water system, which services all components of the reactor coolant pressure boundary that require cooling, is detected by the component cooling water radioactivity monitoring system and/or increasing surge tank level. ([Section 11.5.2](#)).

Leakage to the containment atmosphere from the reactor coolant pressure boundary would cause a change in the containment airborne radioactivity which would be detected by the air particulate monitors. If the reactor is operating with a known rate of leakage, at a constant power level, with a constant reactor coolant activity and a constant purge rate, both the gross particulate and gross noble gas activities would reach an equilibrium level. Under these conditions, an abnormal increase in monitored activity would be the result of increased leakage. Such leakage is classified as unidentified until its source is determined.

During the expected modes of operation, the reactor coolant activity level fluctuates due to power variations and variations in letdown flow rate. However, significant increases in leakage can be detected.

Leakage detection systems have been designed to aid operating personnel, to the extent possible, in differentiating between possible sources of detected leakage within the containment and identifying the physical location of the leak.

The containment atmosphere particulate monitoring system provides the primary means of remotely determining the presence of reactor coolant leakage within the containment. Increases in containment airborne activity levels detected by either of the monitors indicate the reactor coolant pressure boundary as the source of leakage. Conversely, if the condensate measuring system detects increased containment moisture without a corresponding increase in airborne activity level, the indicated source of leakage would be judged to be a nonradioactive system, except during times when reactor coolant activity may be low.

Less sensitive methods of leakage detection, such as unexplained increases in reactor plant makeup requirements to maintain pressurizer level, also provide indication of the reactor coolant pressure boundary as a potential leakage source. Increases in the frequency of a particular containment sump pump operation or increases in the level in a particular sump facilitate localization of the source to components whose leakage would drain to that sump. Leakage rates of the magnitude necessary to be detectable by these latter methods are expected to be noted first by the more sensitive radiation and moisture detection equipment.

Normally, unidentified leakage from the reactor coolant pressure boundary is essentially zero. The reactor coolant system is an all welded system, with the exception of the connections on the pressurizer safety valves, reactor vessel head, and the pressurizer and steam generator manways, which are flanged. All connections to the reactor coolant system are welded. All isolation or check valves between the reactor coolant system and other systems have been designed for low seat leakage, and reactor coolant pressure boundary check valve backleakage is checked periodically. In general, valves in the reactor coolant system 2 inches and under are of the packless type. All valves larger than 2 inches have either dual packing with a leak-off connection to the reactor coolant drain tank between the two packings or a carbon spacer and 5 rings of packing.

The plant containment has the capability for a continuous purge of 4,000 cfm. The time to recirculate one containment free air volume through the containment air coolers is 4.57 minutes. The component operation for various leak detection systems, as discussed in [Section 5.2.5.2.3](#), is based on this containment purge and recirculation time.

MAXIMUM ALLOWABLE TOTAL LEAKAGE - The limits for the reactor coolant pressure boundary leakage are: identified, 10 gpm and unidentified, 1 gpm. When leakage has been identified, it will be evaluated by the operating staff to determine if operation can safely continue. Under these conditions, an allowable total leakage from known sources of 10 gpm has been established. Continued operation of the reactor with identified or unidentified leakage shall be in accordance with the Technical Specifications.

For normal chemical and volume control system operation, the charging pump flow rate is 87 gpm, which consists of 55 gpm being charged through the normal charging line and 32 gpm being supplied to the reactor coolant pump seals. Total flow leaving the reactor coolant system via the normal letdown path is 75 gpm, with the remaining 12 gpm returning via the seal water return line to the chemical and volume control system. The design flow rate of the normal charging pump is 130 gpm at the design head of 5900 feet, which, during normal operation, leaves adequate pump capacity to make up for reactor coolant pressure boundary leakage. The two 150-gpm ECCS centrifugal charging pumps are also used in charging service.

Maximum letdown flow is 120 gpm with an additional 12 gpm leaving via the seal water return line. A centrifugal charging pump with 150-gpm rated capacity (the NCP can deliver this flow rate at less than the design value of total developed head) provides an

adequate reserve capacity to make up for leakage. Thus, under normal or maximum letdown flow conditions, a 10-gpm maximum limit on reactor coolant pressure boundary leakage can be accommodated by operation of one charging pump.

The reactor coolant pressure boundary leakage detection system provides ample protection to assure that, in the unlikely event of a failure of the reactor coolant pressure boundary, small cracks will be detected prior to becoming large leaks. In particular:

- a. The sensitivity of the detection equipment is such that leaks can be identified when small, and the plant can be shut down. The limit on continued operation for unidentified leakage is 1 gpm. This is well within the detection capability of the reactor coolant pressure boundary leakage detection system.
- b. The time span for a crack to go from detectable size to critical size varies from 5 to more than 40 years. This assures adequate safety from a major loss-of-coolant accident.

The above methods are supplemented by visual and ultrasonic inspections of the reactor coolant pressure boundary during plant shutdown periods, in accordance with the inservice inspection program ([Section 5.2.4](#)).

5.2.5.2.2 Component Description

CONTAINMENT AIR PARTICULATE MONITOR - An air sample is drawn outside the containment into a closed system by a sample pump and is then consecutively passed through a particulate filter with detectors, an iodine filter with detector, and a gaseous monitor chamber with detector. The sample transport system includes:

- a. A pump to obtain the air sample
- b. A flow control valve to provide flow adjustment
- c. A flow meter to indicate the flow rate
- d. A flow alarm assembly to provide high and low flow alarm signals

The particulate filter is continuously monitored by a scintillation crystal with a photo multiplier tube which provides an output signal proportional to the activity collected on the filter. The particulate monitor has a range of 10^{-12} to $10^{-7} \mu\text{Ci}/\text{cc}$ and a minimum detectable concentration of $10^{-11} \mu\text{Ci}/\text{cc}$. The containment air particulate monitoring system is capable of performing its radioactive monitoring functions following an SSE. More details concerning the particulate monitors can be found in [Section 11.5.2.3.2.2](#).

CONTAINMENT GASEOUS RADIOACTIVITY MONITOR - The containment gaseous radioactivity monitor determines gaseous radioactivity in the containment by monitoring continuous air samples from the containment atmosphere. After passing through the gas monitor, the sample is returned via the closed system to the containment atmosphere.

Each sample is continuously mixed in a fixed, shielded volume where its activity is monitored. The monitor has a range of 10^{-7} to $10^{-2}\mu\text{Ci}/\text{cc}$ and a minimum detectable concentration of $2 \times 10^{-7}\mu\text{Ci}/\text{cc}$.

The containment gaseous radioactivity monitors are fully described in [Section 11.5.2.3.2.2](#).

The containment gaseous radioactivity monitoring system is capable of performing its radioactivity monitoring functions following an SSE.

CONTAINMENT PURGE MONITORS - The containment purge system radioactivity monitors ([Section 11.5.2.3.2.3](#)) serve as a backup to the containment air particulate and gaseous airborne radioactivity monitoring system while the purge is in operation.

CONTAINMENT COOLER CONDENSATE MONITORING SYSTEM - The condensate monitoring system permits measurements of the liquid runoff from the containment cooler units. It consists of a containment cooler drain collection header, a vertical standpipe, valving, and standpipe level instrumentation for each cooler.

The condensation from the containment coolers flows via the collection header to the vertical standpipe. A differential pressure transmitter provides standpipe level signals. The system provides measurements of low leakages by monitoring standpipe level increase versus time.

CONTAINMENT HUMIDITY MONITORING SYSTEM - The containment humidity monitoring system, utilizing temperature compensated humidity detectors, is provided to determine the water vapor content of the containment atmosphere.

An increase in the humidity of the containment atmosphere indicates release of water within the containment. The range of the containment humidity measuring system is 10-to 98-percent relative humidity at 80°F with a temperature range of 40 to 120°F.

CONTAINMENT SUMP LEVEL AND FLOW MONITORING SYSTEM - Since a leak in the primary system would result in reactor coolant flowing into the containment normal or instrument tunnel sumps, leakage would be indicated by a level increase in the sumps. Indication of increasing sump level is transmitted from the sump to the control room level indicator by means of a sump level transmitter. The system provides measurements of low leakages by monitoring level increase versus time.

CHARGING PUMP OPERATION - During normal operation, either the normal charging pump or an ECCS centrifugal charging pump will be in operation. If a gross loss of reactor coolant occurs which is not detected by the methods previously described, the flow rate of the normal charging pump, if operating, would indicate the leakage from the reactor coolant system. This leakage must be sufficient to cause a decrease in pressurizer or volume control tank level that is within the sensitivity range of the level indicators. The flow from the normal (or ECCS) charging pump would automatically increase to try to maintain pressurizer level. Charging pump discharge flow indication is provided in the control room.

SUMP PUMP OPERATION - Since a leak in the primary system may result in reactor coolant flowing into the containment normal or instrument tunnel sumps, gross leakage can be indicated by an increase in the frequency of operation of the containment normal or the containment instrument tunnel sump pumps. Pump operation can be monitored from the control room.

LIQUID INVENTORY - Larger leaks may also be detected by unscheduled increases in the amount of reactor coolant makeup water which is required to maintain the normal level in the pressurizer. Pressurizer level can be monitored in the control room. Total makeup water flow is also available from the plant computer.

5.2.5.2.3 Component Operation

CONTAINMENT AIR PARTICULATE MONITOR - Particulate activity is determined from the containment free volume and the coolant fission and corrosion product particulate activity concentrations. The sensitivity of the containment air particulate monitors for primary coolant leakage detection is dependent on both the primary coolant activity level and the background radiation level in containment which is dependent upon the power level, percent failed fuel, crud bursts, iodine spiking, and natural radioactivity brought in by the containment purge. Any increase of more than two standard deviations above the count rate for background would indicate a possible leak. The total particulate activity concentration above background, due to an abnormal leak and natural decay, increases almost linearly with time for the first several hours after the beginning of a leak. As shown in [Figure 5.2-2](#), with 0.1-percent failed fuel, containment background airborne particulate radioactivity equivalent to 10^{-4} percent/day, and a partition factor equal to 0.2, a 1-gpm leak would be detected in 1 hour. Larger leaks would be detected in proportionately shorter times (exclusive of sample transport time, which remains constant). The detection capabilities and response times are shown on [Figure 5.2-2](#).

Shortly after startup and also during steady operation with low levels of fuel defects, the level of radioactivity in the reactor coolant is lower than what was assumed in the original design bases calculation. Using a reactor coolant source term based on representative real-time data, with no fuel defects, it was determined that the containment air particulate monitors are capable of detecting a one gpm leak in one hour.

The leakage flow rate can be determined from the count rate when the specific background radioactivity present before the leakage begins is known. This method is limited by the fact that large uncertainties are possible when determining the associated leak rate by calculation. Therefore, in the event of an alarm or increasing trend on these monitors, a water inventory balance is performed to determine the equivalent RCS leak rate.

CONTAINMENT GASEOUS RADIOACTIVITY MONITOR - The containment atmosphere gaseous radioactivity monitor is less sensitive than the containment air particulate monitor but provides a positive indication of leakage in the event that reactor coolant gaseous activity exists as a result of fuel-cladding defects. Gaseous radioactivity is determined from the containment free volume and the gaseous activity concentration of the reactor coolant. Any increase more than two standard deviations above the count rate for background would indicate a possible leak. The total gaseous activity level above background (after 1 year of normal operation) increases almost linearly for the first several hours after the beginning of the leak. As specified in [Figure 5.2-2](#), with 0.1-percent failed fuel, containment background airborne gaseous radioactivity equivalent to 0.1 percent/day, and a partition factor equal to 1 (NUREG-0017 assumptions), a 1-gpm leak would be detected within 1 hour. Larger leaks would be detected in proportionately shorter times (exclusive of the sample transport time which remains constant). The detection capabilities and response times are shown on [Figure 5.2-2](#).

Analyses have shown that the pre-existing containment radioactive gaseous background levels for which reliable detection is possible is dependent upon the reactor power level, percent failed fuel, and natural radioactivity brought in by the containment purge. With primary coolant concentrations less than equilibrium levels, such as during reactor startup and operation with no fuel defects, the increase in detector count rate due to leakage will be partially masked by the statistical variation of the minimum detector background count rate, rendering reliable detection of a 1 gpm leak uncertain. The containment atmosphere gaseous radioactivity monitors were designed in accordance with the sensitivities specified in Regulatory Guide 1.45, "Reactor Coolant Pressure Boundary Leakage Detection Systems," its alarm setpoint is set to indicate a 1 gpm RCS leakage based on Regulatory Guide 1.45 assumptions, it is fully functioning in accordance with its design requirements, however, it has been removed as part of the reactor coolant pressure boundary leakage detection system due to its inability to promptly detect a 1 gpm RCS leakage within 1 hour with reduced radioactivity levels in the reactor coolant system. (Reference 8)

CONTAINMENT PURGE MONITORS - The containment purge monitors function the same as the containment air particulate and gaseous radioactivity monitors, except that the purge monitors sample from the containment purge exhaust line.

CONTAINMENT COOLER CONDENSATE MONITORING SYSTEM - The condensate flow rate is a function of containment humidity, essential service water temperature leaving the coolers, and containment purge rate. The water vapor dispersed by a 1 gpm

leak is much greater than the water vapor brought in with the outside air. Air brought in from the outside is heated to 50°F before it enters the containment.

After the air enters the containment, it is heated to 100-120°F so that the relative humidity drops. The water vapor brought in with the outside air does not build up in the containment since it is continually purged. The most important factor in condensing the water vapor is the temperature of the essential service water which is provided to the containment coolers. This water can vary between 38 - 100°F on the outlet of the coolers, depending on seasonal conditions.

Level changes of as little as 0.25 inches in the cooler condensate standpipes can be detected. Increases in the condensation rates over normal background are monitored by the Plant computer based upon level checks each minute in order to determine the unidentified leakage. **Figure 5.2-2** shows the detection capabilities of the system for various seasonal conditions with no airborne identified leakage. The system is capable of detecting a 1 gpm leak within 1 hour after water vapor has reached the coolers and started to condense. Normal background leakage will increase containment humidity to the point where condensation will more readily occur and, thereby, will improve the detection capabilities of this system.

The rate of leakage can be determined when the precise essential service water, outside air, and containment air temperatures and the outside relative humidity are known by use of psychrometric charts. A check of other instrumentation would be required to eliminate possible leakage from non-radioactive systems as a cause of an increase in condensate flow.

CONTAINMENT HUMIDITY MONITORING SYSTEM - Since the humidity level is influenced by several factors, a quantitative evaluation of an indicated leakage rate may be questionable and should be compared to observed increases in liquid flow from sumps and condensate flow from air coolers. Humidity level monitoring is used as an indirect indicating device to alert the operator to a potential problem.

The accuracy of the humidity detectors is ± 3 percent. A rapid increase of humidity over the background level by more than 10 percent can be taken as a probable indication of a leak.

CONTAINMENT SUMP LEVEL AND FLOW MONITORING SYSTEM - The detection capabilities of the containment normal sump and instrument tunnel sump are shown in **Figure 5.2-2**, assuming that the water from the leak has reached the sump.

The minimum detectable change in the containment normal sump level is 5 gallons and in the instrument tunnel sump level is 15 gallons. When the Instrument Tunnel Sump is completely dry, the initial minimum detectable level change is 25 gallons. The levels are scanned by the Plant computer once per minute, and the normal background rate of increase in sump level is subtracted to determine the leakage rate.

The actual reactor coolant leakage rate can be established from the increase above the normal rate of change of sump level after consideration of 35 percent of the high temperature leakage which initially evaporates but may be condensed by the containment coolers and then is routed to the sump. A check of other instrumentation would be required to eliminate possible leakage from nonradioactive systems as a cause of an increase in sump level.

CHARGING PUMP OPERATION - The normal charging pump normally operates at 132 gpm. For 75 gpm letdown the pump will send 87 gpm to the RCS and seals and 45 gpm in recirculation. For 120 gpm letdown the pump will send 132 to the RCS and seals. Any significant increase in the flow rate is a possible indication of a leak.

During some transient modes of operation it may be desirable to operate with only the 45 gpm letdown orifice in operation. During these conditions the normal charging pump will send 57 gpm to the RCS and seals and 45 gpm will be in recirculation. Any significant increase in the flow rate is a possible indication of a leak.

The leakage rate can be determined by the amount that the charging pump rate to the RCS increases above either 87 or 132 gpm depending on letdown flow to maintain constant pressurizer level.

SUMP PUMP OPERATION - Under normal conditions, the containment normal and instrument tunnel sump pumps will operate very infrequently. Gross leakage can be surmised from unusual frequency of pump operation. Sump level and pump running indication are provided in the control room to alert the operators.

The leakage rate can be determined from sump volumes and frequency of sump pump operation.

LIQUID INVENTORY - The operators can surmise gross leakage from changes in the reactor coolant inventory. Noticeable decreases in the pressurizer level not associated with known changes in operation will be investigated. Likewise, makeup water usage information which is available from the plant computer will be checked frequently for unusual makeup rates not due to plant operations.

5.2.5.3 Safety Evaluation

Inasmuch as this system has no safety design basis, no safety evaluation is provided. Criteria for the selection of safety design bases are stated in **Section 1.1.7**.

5.2.5.4 Tests and Inspections

Periodic testing of leakage detection systems is conducted to verify the operability and sensitivity of detector equipment. These tests include installation calibrations and alignments, periodic channel calibrations, functional tests, and channel checks. A

description of calibration and maintenance procedures and frequencies for the containment radioactivity monitoring system is presented in [Section 11.5.2](#).

The humidity detector and condensate measuring system are also periodically tested to ensure proper operation. The condensate measuring system is also tested to verify sensitivity.

Inservice inspection criteria, the equipment used, procedures involved, the frequency of testing, inspection, surveillance, and examination of the structural and leaktight integrity of reactor coolant pressure boundary components are described in detail in [Section 5.2.4](#).

5.2.5.5 Instrumentation Applications

The following indications are provided in the control room to allow operating personnel to monitor for leakage:

- a. Containment air particulate monitor - air particulate activity
- b. Containment gaseous activity monitor - gaseous activity
- c. Containment cooler condensate monitoring system - standpipe level
- d. Containment normal sump level and instrument tunnel sump level
- e. Containment humidity measuring system - containment humidity
- f. Gross leakage detection methods - Charging pump flow rate, let-down flow rate, pressurizer level and reactor coolant temperatures are available for the charging pump flow method. Containment sump levels and pump operation are available for the sump pump operation method. Totalized makeup water flow is available from the plant computer for liquid inventory.

5.2.6 REFERENCES

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2. Letter NS-CE-1730, dated March 17, 1978, C. Eicheldinger (Westinghouse) to J. F. Stoltz (NRC).
3. Cooper, L., Miselis, V. and Starek, R. M., "Overpressure Protection for Westinghouse Pressurized Water Reactors," WCAP-7769, Revision 1, June, 1972 (also letter NS-CE-622, dated April 16, 1975, C. Eicheldinger

(Westinghouse) to D. B. Vassallo (NRC), additional information on WCAP-7769, Revision I).

- 3a. J. E. Fontes, "Overpressure Protection Report for the Union Electric Co. Callaway Plant," Revision 3, dated 8/94. (SCP 94-143) Prepared for Amendment 128 (OL-1186) MSSV Setpoint Tolerance Change.
4. Burnett, T. W. T., et al., "LOFTRAN Code Description," WCAP-7907, October 1972.
5. Golik, M. A., "Sensitized Stainless Steel in Westinghouse PWR Nuclear Steam Supply Systems," WCAP-7477-L (Proprietary), March, 1970 and WCAP-7735 (Non-Proprietary), August 1971.
6. Enrietto, J. F., "Control of Delta Ferrite in Austenitic Stainless Steel Weldments," WCAP-8324-A, June 1975.
7. Enrietto, J. F., "Delta Ferrite in Production Austenitic Stainless Steel Weldments," WCAP-8693, January 1976.
8. NRC Letter, "Callaway Plant, Unit 1 - License Amendment Request to the Reactor Coolant System Leakage Detection Instrumentation Methodology (TAC NO. MC8220), May 16, 2006.

TABLE 5.2-1 APPLICABLE CODE ADDENDA FOR
REACTOR COOLANT SYSTEM COMPONENTS

| | | |
|-----------------------------|---|--|
| Reactor vessel | ASME III, 1971 Edition through Winter 1972 | |
| Reactor vessel closure head | ASME III, 2001 Edition through 2003 Addenda | |
| Steam generator | ASME III, 1989 Edition ASME XI 1995 Edition through 1996 Addenda | |
| Pressurizer | ASME III, 1974 Edition through Summer 1974 | |
| CRDM housing | ASME III, 2001 Edition through 2003 Addenda | |
| CRDM head adapter | ASME III, 2001 Edition through 2003 Addenda | |
| Reactor coolant pump | ASME III, 1971 Edition through Summer 1973 | |
| Reactor coolant pipe | ASME III, 1974 Edition through Winter 1975 | |
| Surge lines | ASME III, 1974 Edition through Winter 1975 | |
| Valves | | |
| Pressurizer safety | ASME III, 1974 Edition through Summer 1975 | |
| Motor operated | ASME III, 1974 Edition through Summer 1975 | |
| Manual (3 inch and larger) | ASME III, 1974 Edition through Summer 1975 | |
| Control | ASME III, 1974 Edition through Summer 1975 | |

**TABLE 5.2-2 CLASS 1 PRIMARY COMPONENTS
MATERIAL SPECIFICATIONS**

Reactor Vessel Components

| | | |
|--|---|--|
| Shell plates (other than core region) | SA-533, Grade A, B or C, Class 1 or 2 (vacuum treated) | |
| Shell plates (core region) | SA-533, Grade A or B, Class 1 (vacuum treated) | |
| Closure head forging | SA-508, Grade 3, Class 1 | |
| Shell, flange and nozzle forgings, nozzle safe ends | SA-508, Class 2 or 3; SA-182, Grade F304 or F316 | |
| CRDM and/or ECCS appurtenances, upper head | SB-167 (UNS N06690) and SA-479, Type 304/304L | |
| Instrumentation tube appurtenances, lower head | SB-166 or SB-167 and SA-182, Grade F304, F304L or F316 | |
| Closure studs, nuts, washers, inserts, and adaptors | SA-540, Class 3, Grade B23 or B24 (as modified by Code Case 1605) | |
| Core support pads | SB-166 with carbon less than 0.10 percent | |
| Monitor tubes and vent pipe | SA-312 or SA-376, Grade TP304 or TP316 or SB-166 or SB-167 or SA-182, Grade F316 | |
| Vessel supports, seal ledge, and heat lifting lugs | SA-516, Grade 70 (quenched and tempered) or SA-533, Grade A, B or C, Class 1 or 2 (vessel supports may be of weld metal buildup of equivalent strength of the nozzle material) | |
| Cladding and buttering | Stainless Steel Weld Metal Analysis A-8 and Ni-Cr-Fe Weld Metal F-Number 43 | |

Steam Generator Components

| | |
|---|------------------|
| Pressure forgings (including nozzles and tube sheet) | SA-508, Class 3a |
|---|------------------|

TABLE 5.2-2 (Sheet 2)

| | |
|---|---|
| Nozzle safe ends | SA-182F 316LN |
| Channel heads | SA-508 Class 3a |
| Tubes | SB-163 (Ni-Cr-Fe thermally treated) |
| Cladding and buttering | Stainless Steel Weld Metal Analysis A-8 and Ni-Cr-Fe Weld Metal F-Number 43 |
| Closure studs or bolts nuts washers | SA-193, Grade B16 SA-194, Grade 7 ASTM F436, Thru hardened |
| Pressurizer Components | |
| Pressure plates | SA-533, Grade A, Class 2 |
| Pressure forgings | SA-508, Class 2a |
| Nozzle safe ends | SA-182, Grade F316L |
| Cladding and buttering | Stainless Steel Weld Metal Analysis A-8 and Ni-Cr-Fe Weld Metal F-Number 43 |
| Closure studs or bolts nuts washers | SA-193, Grade B7 SA-194, Grade 7 ASTM F436, Thru hardened |
| Reactor Coolant Pump | |
| Pressure forgings | SA-182, Grade F304, F316, F347 or F348 |
| Pressure casting | SA-351, Grade CF8, CF8A or CF8M |
| Tube and pipe | SA-213; SA-376 or SA-312, Seamless, Grade TP304 or TP316 |
| Pressure plates | SA-240, Type 304 or 316 |
| Bar material | SA-479, Type 304 or 316 |
| Closure bolting | SA-193; SA-320; SA-540, SA-453, Grade 660, or Inconel 718, SB- 637 |
| Flywheel | SA-533, Grade B, Class 1 |

TABLE 5.2-2 (Sheet 3)

Reactor Coolant Piping

| | |
|---|--|
| Reactor coolant pipe | SA-351, Grade CF8A Centrifugal Casting |
| Reactor coolant fittings, branch nozzles | SA-351, Grade CF8A and SA-182, (Code Case 1423-2) Grade 316N |
| Surge line | SA-376, Grade TP304, TP316 or F304N |
| Auxiliary piping 1/2 through 12 inch and wall schedules 40S through 80S (ahead of second isolation valve) | ANSI B36.19 |
| All other auxiliary piping (ahead of second isolation valve) | ANSI B36.10 |
| Socket weld fittings | ANSI B16.11 |
| Piping flanges | ANSI B16.5 |
| Full Length CRDM | |
| Latch housing | SA-182M, Grade F304 |
| Rod travel housing | SA-182M, Grade F304 |
| Welding materials | Stainless Steel Weld Metal Analysis A-8 |

**TABLE 5.2-3 CLASS 1 AND 2 AUXILIARY COMPONENTS
MATERIAL SPECIFICATIONS**

Valves

| | |
|----------------------------|---|
| Bodies | SA-182, Grade F316 or SA-351, Grade CF8 or CF8M |
| Bonnets | SA-182, Grade F316 or SA-351, Grade CF8 or CF8M |
| | SA-479, Type XM-19 (solenoid- operated head vent valves only) |
| Discs | SA-182, Grade F316 or SA-564, Grade 630, or SA-351, Grade CF8 or CF8M |
| Stems | SA-182, Grade F316 or SA-564, Grade 630 |
| | 300 Series SST (solenoid-operated head vent valve rods only) |
| Pressure-retaining bolting | SA-453, Grade 660 |
| Pressure-retaining nuts | SA-453, Grade 660 or SA-194 Grade 6 |

Auxiliary Heat Exchangers

| | |
|--------------|--------------------------------|
| Heads | SA-240, Type 304 |
| Nozzle necks | SA-182, Grade F304 |
| Tubes | SA-213, Grade TP304 |
| Tube Sheets | SA-182, Grade F304 |
| Shells | SA-240 and SA-312, Grade TP304 |

Auxiliary Pressure Vessels, Tanks, Filters, etc.

| | |
|------------------|---|
| Shells and heads | SA-240, Type 304 or SA-264 (consisting of SA-537, Class 1 with Stainless Steel Weld Metal Analysis A-8 Cladding) |
|------------------|---|

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TABLE 5.2-3 (Sheet 2)

| | |
|-------------------------------|--|
| Flanges and nozzles | SA-182, Grade F304 and SA-105 or SA-350, Grade LF2 or LF3 with Stainless Steel Weld Metal Analysis A-8 Cladding |
| Piping | SA-312 and SA-240, Grade TP304 or TP316 Seamless |
| Pipe fittings | SA-403, Grade WP304 Seamless |
| Closure bolting and nuts | SA-193, Grade B7 and SA-194, Grade 2H |
| Auxiliary Pumps | |
| Pump casing and heads | SA-351, Grade CF8 or CF8M; SA-182, Grade F304 or F316 |
| Flanges and nozzles | SA-182, Grade F304 or F316; SA-403, Grade WP316L Seamless |
| Piping | SA-312, Grade TP304 or TP316 Seamless |
| Stuffing or packing box cover | SA-351, Grade CF8 or CF8M; SA-240, Type 304 or 304L or 316 |
| Pipe fittings | SA-403, Grade WP316L Seamless |
| Closure bolting and nuts | SA-193, Grade B6, B7 or B8M; SA-194, Grade 2H or 8M; SA-453 Grade 660, and Nuts, SA-194, Grade 2H, 6 and 8 M |

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TABLE 5.2-4 REACTOR VESSEL INTERNALS FOR
EMERGENCY CORE COOLING SYSTEMS

| | |
|-----------------|---|
| Forgings | SA-182, Grade F304 |
| Plates | SA-240, Type 304 |
| Pipes | SA-312, Grade TP304 Seamless or SA-376, Grade TP304 |
| Tubes | SA-213, Grade TP304 |
| Bars | SA-479, Type 304 and 410 |
| Castings | SA-351, Grade CF8 and CF8A |
| Bolting | SA-193, Grade B8M (65 MYS/90 MTS) Code Case 1618 Inconel-750; SA-461, Grade 688 |
| Nuts | SA-193, Grade B8 |
| Locking devices | SA-479, Type 304 |

**TABLE 5.2-5 RECOMMENDED REACTOR COOLANT
WATER CHEMISTRY LIMITS**

| | |
|---------------------------------------|--|
| Electrical conductivity | Determined by the concentration of boric acid and alkali present. |
| Solution pH | Determined by the concentration of boric acid and alkali present. |
| Oxygen ^(a) | 0.005 ppm, maximum |
| Chloride | 0.15 ppm, maximum |
| Fluoride | 0.15 ppm, maximum |
| Hydrogen ^(c) | 25 to 50 cc (STP)/kg H ₂ O |
| pH control agent (Li ⁷ OH) | Control Limits and Action Guidelines are listed in plant procedures. |
| Boric acid | Variable from 0 to ~4000 ppm as B |
| Silica | 1.0 ppm, maximum |
| Aluminum ^(b) | 0.05 ppm, maximum |
| Calcium + Magnesium ^(b) | 0.05 ppm, maximum |
| Magnesium ^(b) | 0.025 ppm, maximum |
| Zinc | Per Chemistry Program (maximum 40 ppb steady-state) |

NOTES:

- (a) Oxygen concentraton should be controlled by scavenging with hydrazine to less than 0.1 ppm in the reactor coolant prior to exceeding a temperature of 250°F. During power operation with the specified hydrogen concentration maintained in the coolant, the residual oxygen concentration does not exceed 0.005 ppm.
- (b) Aluminum, Calcium and Magnesium analyses are performed on major reactor makeup water sources such as the demineralized water storage tank which feeds the reactor makeup water storage tank and the boric acid storage tanks.
- (c) Hydrogen is maintained in the reactor coolant during plant operation per the EPRI PWR Primary Water Chemistry Guidelines. Twenty four hours prior to a scheduled reactor shutdown and cooldown, hydrogen may be reduced to 15 cc (STP)/kg water.

TABLE 5.2-6 DESIGN COMPARISON WITH REGULATORY GUIDE 1.45,
DATED MAY 1973, TITLED REACTOR COOLANT PRESSURE BOUNDARY
LEAKAGE DETECTION SYSTEMS

Regulatory Guide
1.45 Position

Union Electric

C. REGULATORY POSITION

The source of reactor coolant leakage should be identifiable to the extent practical. Reactor coolant pressure boundary leakage detection and collection systems should be selected and designed to include the following:

- | | |
|---|---|
| 1. Leakage to the primary reactor containment from identified sources should be collected or otherwise isolated so that: <ul style="list-style-type: none">a. the flow rates are monitored separately from unidentified leakage, andb. the total flow rate can be established and monitored. | 1. Complies. Flow to the RCDT and the PRT can be established, is monitored, and is separated from unidentified leakage. |
| 2. Leakage to the primary reactor containment from unidentified sources should be collected and the flow rate monitored with an accuracy of one gallon per minute (gpm) or better. | 2. Complies. The instrumentation provided is such that over a period of time (1 hour or more), the collected flow rate can be determined with an accuracy of better than 1 gallon per minute. |

TABLE 5.2-6 (Sheet 2)

| <u>Regulatory Guide</u> <u>1.45 Position</u> | <u>Union Electric</u> |
|--|---|
| 3. At least three separate detection methods should be employed and two of these methods should be (1) sump level and flow monitoring and (2) airborne particulate radioactivity monitoring. The third method may be selected from the following: <ul style="list-style-type: none"> a. monitoring of condensate flow rate from air coolers, b. monitoring of airborne gaseous radioactivity. Humidity, temperature, or pressure monitoring of the containment atmosphere should be considered as alarms or indirect indication of leakage to the containment. | 3. Complies. The methods provided are sump-level and flow (level versus time) monitoring, airborne particulate radioactivity monitoring, and containment cooler condensate monitoring. <p>Containment atmosphere humidity monitoring is also available as an indirect indication of leakage to the containment. As such, periodic testing of the sensitivity of the humidity monitoring system is not required.</p> |
| 4. Provisions should be made to monitor systems connected to the RCPB for signs of intersystem leakage. Methods should include radioactivity monitoring and indicators to show abnormal water levels or flow in the affected area. | 4. Complies. Refer to Sections 5.2.5.2.1, 9.3.3, and 11.5 |
| 5. The sensitivity and response time of each leakage detection system in regulatory position 3. above employed for unidentified leakage should be adequate to detect a leakage rate, or its equivalent, of one gpm in less than one hour. | 5. Complies, as described in Section 5.2.5.2.3 and as shown on Figure 5.2-2 . |

TABLE 5.2-6 (Sheet 3)

| <u>Regulatory Guide 1.45 Position</u> | <u>Union Electric</u> |
|---|---|
| 6. The leakage detection systems should be capable of performing their functions following seismic events that do not require plant shutdown. The airborne particulate radioactivity monitoring system should remain functional when subjected to the SSE. | 6. Complies. The airborne particulate radioactivity system is designed to remain functional when subjected to the SSE. Refer to Sections 11.5.2.3.2.2 and 11.5.2.3.2.3 . The remaining leakage detection systems can reasonably be expected to remain functional following seismic events of lesser severity than the SSE. However, no special qualification program is used to assure operability under such conditions. |
| 7. Indicators and alarms for each leakage detection system should be provided in the main control room. Procedures for converting various indications to a common leakage equivalent should be available to the operators. The calibration of the indicators should account for needed independent variables. | 7. Complies, as described in Sections 5.2.5.2.3 and 5.2.5.5 . |
| 8. The leakage detection systems should be equipped with provisions to readily permit testing for operability and calibration during plant operation. | 8. Complies. Refer to Section 5.2.5.4 . |
| 9. The technical specifications should include the limiting conditions for identified and unidentified leakage and address the availability of various types of instruments to assure adequate coverage at all times. | 9. Complies. Refer to the Technical Specifications |

5.3 REACTOR VESSEL

5.3.1 REACTOR VESSEL MATERIALS

5.3.1.1 Material Specifications

Material specifications are in accordance with the ASME Code requirements and are given in **Section 5.2.3**.

The ferritic materials of the reactor vessel beltline are restricted to the following maximum limits of copper, phosphorous, and vanadium to reduce sensitivity to irradiation embrittlement in service:

| <u>Element</u> | <u>Base Metal (percent)</u> | <u>As Deposited Weld Metal (percent)</u> |
|----------------|---------------------------------|--|
| Copper | 0.10 (Ladle) 0.12 (Check) | 0.10 |
| Phosphorous | 0.012 (Ladle) 0.017 (Check) | 0.015 |
| Vanadium | 0.05 (Check) | 0.05 (as residual) |

5.3.1.2 Special Processes Used for Manufacturing and Fabrication

- a. The vessel is Safety Class 1. Design and fabrication of the reactor vessel is carried out in strict accordance with ASME Code, Section III, Class 1 requirements. The closure head and nozzles are manufactured as forgings. The cylindrical portion of the vessel is made up of formed plates joined by full penetration longitudinal and girth weld seams. The bottom hemispherical head is made from dished plates. The reactor vessel parts are joined by welding, using the single or multiple wire submerged arc and the shielded metal arc processes.
- b. The use of severely sensitized stainless steel as a pressure boundary material has been prohibited and has been eliminated by either choice of material or programming the method of assembly.
- c. The surfaces of the guide studs are chrome plated to prevent possible galling of the mated parts.
- d. At all locations in the reactor vessel where stainless steel and Inconel are joined, the final joining weld beads are Inconel weld metal in order to prevent cracking.

- e. The location of full penetration weld seams in the upper closure head and vessel bottom head are restricted to areas that permit accessibility during inservice inspection.
- f. The stainless steel clad surfaces are sampled to assure that material composition requirements are met.
- g. Freedom from underclad cracking is assured by special evaluation of the procedure qualification for cladding applied on low alloy steel (SA-508, Class 2).
- h. Minimum preheat requirements have been established for pressure boundary welds, using low alloy material. The preheat is maintained until either an intermediate or full post-weld heat treatment is completed or until the completion of welding.

5.3.1.3 Special Methods for Nondestructive Examination

The nondestructive examination of the reactor vessel and its appurtenances is conducted in accordance with ASME Code, Section III requirements; also numerous examinations are performed in addition to ASME Code, Section III requirements. Nondestructive examination of the vessel is discussed in the following paragraphs and the reactor vessel quality assurance program is given in [Table 5.3-1](#).

5.3.1.3.1 Ultrasonic Examination

- a. In addition to the required ASME Code straight beam ultrasonic examination, angle beam inspection over 100 percent of one major surface of plate material is performed during fabrication to detect discontinuities that may be undetected by the straight beam examination.
- b. In addition to the ASME Code, Section III nondestructive examination, all full penetration ferritic pressure boundary welds in the reactor vessel are ultrasonically examined during fabrication. This test is performed upon completion of the welding and intermediate heat treatment but prior to the final post-weld heat treatment.
- c. After hydrotesting, all full penetration ferritic pressure boundary welds in the reactor vessel, as well as the nozzle to safe end welds, are ultrasonically examined. These inspections are also performed in addition to the ASME Code, Section III nondestructive examinations.

5.3.1.3.2 Penetrant Examinations

The partial penetration welds for the control rod drive mechanism head adaptors and the bottom instrumentation tubes are inspected by dye penetrant after the root pass, in

addition to code requirements. Core support block attachment welds are inspected by dye penetrant after the first layer of weld metal and after each 1/2 inch of weld metal. All clad surfaces and other vessel and head internal surfaces are inspected by dye penetrant after the hydrostatic test.

5.3.1.3.3 Magnetic Particle Examination

The magnetic particle examination requirements below are in addition to the magnetic particle examination requirements of Section III of the ASME Code.

All magnetic particle examinations of materials and welds are performed in accordance with the following:

- a. Prior to the final post-weld heat treatment - Only by the prod, coil, or direct contact method.
- b. After the final post-weld heat treatment - Only by the yoke method.

The following surfaces and welds are examined by magnetic particle methods. The acceptance standards are in accordance with Section III of the ASME Code.

Surface Examinations

- a. Magnetic particle examine all exterior vessel and head surfaces after the hydrostatic test.
- b. Magnetic particle examine all exterior closure stud surfaces and all nut surfaces after final machining or rolling. Continuous circular and longitudinal magnetization is used.
- c. Magnetic particle examine all inside diameter surfaces of carbon and low alloy steel products that have their properties enhanced by accelerated cooling. This inspection is performed after forming and machining (if performed) and prior to cladding.

Weld Examination

Magnetic particle examination of the weld metal build-up for vessel support welds, the closure head lifting lugs, and the refueling seal ledge to the reactor vessel after the first layer and each 1/2 inch of weld metal is deposited. All pressure boundary welds are examined after back chipping or back grinding operations.

5.3.1.4 Special Controls for Ferritic and Austenitic Stainless Steels

Welding of ferrite steels and austenitic stainless steels is discussed in **Section 5.2.3**. **Section 5.2.3** includes discussions which indicate the degree of conformance with

Regulatory Guide 1.44. **Appendix 3A** discusses the degree of conformance with Regulatory Guides 1.43, 1.50, 1.71, and 1.99.

5.3.1.5 Fracture Toughness

Assurance of adequate fracture toughness of ferritic materials in the reactor coolant pressure boundary (ASME Code, Section III, Class 1 components) is provided by compliance with the requirements for fracture toughness testing included in NB-2300 to Section III of the ASME Code and Appendix G of 10 CFR 50.

The initial Charpy V-notch minimum upper shelf fracture energy levels for the reactor vessel beltline (including welds) are 75 foot-pounds, as required per Appendix G of 10 CFR 50. Materials having a section thickness greater than 10 inches with an upper shelf of less than 75 foot-pounds are evaluated with regard to effects of chemistry (especially copper content), initial upper shelf energy, and fluence to assure that a 50-foot-pound shelf energy, as required by Appendix G of 10 CFR 50 is maintained throughout the life of the vessel. The specimens are oriented as required by NB-2300 of Section III of the ASME Code. The vessel fracture toughness data is provided in **Table 5.3-4** for Callaway Plant.

5.3.1.6 Material Surveillance

Prior to Refuel 20 at Callaway, the reactor vessel surveillance program was directed toward evaluation of the effect of radiation on the fracture toughness of reactor vessel steels, based on the transition temperature approach and the fracture mechanics approach. The program conformed to ASTM E-185 "Recommended Practice for Surveillance Tests for Nuclear Reactor Vessels," and 10 CFR 50, Appendix H.

The program used six specimen capsules that were put in place prior to plant start-up. The capsules were located in guide baskets welded to the outside of the neutron shield pads and positioned directly opposite the center portion of the core. The capsules were able to be removed or replaced only when the vessel head and upper internals were removed. The six capsules contained reactor vessel steel specimens oriented both parallel and normal (longitudinal and transverse) to the principal rolling direction of the limiting base material located in the core region of the reactor vessel and associated weld metal and weld heat-affected zone metal. In total, the six capsules contained 54 tensile specimens, 360 Charpy specimens, and 72 compact tension (CT) specimens. The evaluation of radiation damage was based on pre-irradiation and post-irradiation testing of Charpy V-notch and tensile specimens.

Each of the six capsules contains the following specimens:

| <u>Material</u> | <u>Number of Charpys</u> | <u>Number of Tensiles</u> | <u>Number of CTs</u> |
|--------------------------|--------------------------|---------------------------|----------------------|
| Limiting base material* | 15 | 3 | 4 |
| Limiting base material** | 15 | 3 | 4 |
| Weld metal*** | 15 | 3 | 4 |
| Heat-affected zone | 15 | - | - |

* Specimens oriented in the major rolling or working direction.

** Specimens oriented normal to the major rolling or working direction.

*** Weld metal to be selected per ASTM E-185.

After Refuel 20, the CT specimens, capsules, and material left from Charpy V-notch and tensile testing will be stored by the analyst to support future testing, reconstitution, or reinsertion, unless given NRC approval to discard. Archive material, which has never been irradiated and is sufficient for two additional capsules, will be retained beyond Refuel 20 as well. A description and location of the archived material is provided in WCAP-15151 (Reference 1A).

As part of the reactor vessel surveillance program prior to Refuel 20, dosimeters were placed in filler blocks drilled to contain them. The dosimeters permitted evaluation of the flux seen by the specimens and the vessel wall. In addition, thermal monitors made of low melting point alloys were included to monitor the maximum temperature of the specimens. The specimens were enclosed in a tight-fitting stainless steel sheath to prevent corrosion and ensure good thermal conductivity. The complete capsule was helium leak tested. As part of the surveillance program, a report of the residual elements in weight percent to the nearest 0.01 percent was made for surveillance material and as-deposited weld metal.

The fast neutron exposure of the specimens occurred at a faster rate than that experienced by the vessel wall, with the specimens being located between the core and the vessel. Since these specimens experienced accelerated exposure and were actual samples from the materials used in the vessel, the transition temperature shift measurements are representative of the vessel at a later time in life. Data from CT fracture toughness specimens provide additional information for use in determining allowable stresses for irradiated material.

Correlations between the calculations and measurements of the irradiated samples in the capsules, assuming the same neutron spectrum at the samples and the vessel inner

wall, are described in [Section 5.3.1.6.1](#). The anticipated degree to which the specimens perturbed the fast neutron flux and energy distribution is considered in the evaluation of the surveillance specimen data. Verification and possible readjustment of the calculated wall exposure is made by the use of data on all capsules withdrawn. The schedule for removal of the capsules for post-irradiation testing conformed to ASTM E-185 and Appendix H of 10 CFR 50 and is included as [Table 5.3-10](#).

The material surveillance program for radiation damage evaluation after Refuel 20 is described in [Section 5.3.1.6.3](#).

The following dosimeters and thermal monitors were included in each of the six capsules:

Dosimeters

Iron

Copper

Nickel

Cobalt-aluminum (0.15 percent Co)

Cobalt-aluminum (cadmium shielded)

U-238 (cadmium shielded)

Np-237 (cadmium shielded)

Thermal Monitors

97.5 percent Pb, 2.5 percent Ag (579°F melting point)

97.5 percent Pb, 1.75 percent Ag, 0.75 percent Sn (590°F melting point)

The material surveillance program for radiation damage evaluation after Refuel 20 is described in [Section 5.3.1.6.3](#).

5.3.1.6.1 Measurement of Integrated Fast Neutron ($E > 1.0$ MeV) Flux at the Irradiation Samples

Methodology for the measurement of Integrated Fast Neutron ($E > 1.0$ MeV) Flux at the Irradiation Samples is described in WCAP 14040 (Reference 1) and was approved by the NRC.

5.3.1.6.2 Section Deleted

5.3.1.6.3 Ex-Vessel Neutron Dosimetry

The Code of Federal Regulations, Title 10, Part 50, Appendix H, requires that neutron dosimetry be present to monitor the reactor vessel throughout plant life and that material specimens be used to measure damage associated with the end-of-life fast neutron exposure of the reactor vessel. The Ex-Vessel Neutron Dosimetry (EVND) Program at Callaway is designed to provide a verification of fast neutron exposure distributions within the reactor vessel wall and to establish a mechanism to enable long-term monitoring of those portions of the reactor vessel and vessel support structure that could experience significant radiation induced increases in reference nil ductility transition temperature (RT_{NDT}) over the service lifetime of the plant. When used in conjunction with dosimetry from internal surveillance capsules (discussed above) and with the results of neutron transport calculations, the reactor cavity neutron measurements allow the projection of embrittlement gradients through the reactor vessel wall with a minimum uncertainty.

Technical Description

To achieve the goals of the EVND Program, two types of measurements are made. Comprehensive sensor sets, including radiometric monitors (RMs), are employed at discrete locations within the reactor cavity to characterize the neutron energy spectrum variations axially and azimuthally over the beltline region of the reactor vessel. In addition, stainless steel gradient chains are used in conjunction with the encapsulated dosimeters to complete the mapping of the neutron environment between the discrete locations chosen for spectrum determinations.

In choosing sensor set locations for the EVND Program, advantage is taken of the octant symmetry typical of pressurized water reactors. That is, subject to access limitations, spectrum measurements are concentrated to obtain azimuthal flux distributions in a single forty-five degree sector. Placement of the discrete sensor sets is such that spectrum determinations are made at various locations (5, 15, 30, and 40 degrees) on the midplane of the active core to measure the spectrum changes caused by the varying amounts of water located between the core and the reactor vessel. The varied thickness of water is due to the stair step shape of the reactor core periphery relative to the cylindrical geometry of the reactor internals and vessel and to the local nature of the neutron pads. The remaining sensor sets may be positioned opposite the top and bottom of the active core or opposite key reactor vessel welds at particular azimuthal angles of interest. The intent is to measure axial variations in neutron spectrum over the core height, particularly near the top of the fuel where back-scattering of neutrons from primary loop nozzles and reactor vessel support structures can produce significant differences. At each of the azimuthal locations selected for spectrum measurements, stainless steel gradient chains extend over the full height of the active fuel.

Sensor Sets

The EVND Program employs advanced sensor sets that are recommended by and are designed to the latest ASTM neutron dosimetry standards. The sensor sets consist of the encapsulated dosimeters and gradient chains shown on [Table 5.3-11](#), which also lists the neutron reactions that are of interest.

5.3.1.7 Reactor Vessel Fasteners

The reactor vessel closure studs, nuts, and washers are designed and fabricated in accordance with the requirements of the ASME Code, Section III. The closure studs are fabricated of SA-540, Class 3, Grade B24. The closure stud material meets the fracture toughness requirements of the ASME Code, Section III and 10 CFR 50, Appendix G. Compliance with Regulatory Guide 1.65, "Materials and Inspections for Reactor Vessel Closure Studs," is discussed in [Appendix 3A](#). Nondestructive examinations are performed in accordance with the ASME Code, Section III. Bolting materials fracture toughness data is provided in [Table 5.3-7](#).

Refueling procedures require that the studs, nuts, and washers be removed from the refueling cavity and stored at convenient locations prior to refueling cavity flooding. Studs which cannot be removed are protected by enclosures and/or other means to prevent corrosive damage. Therefore, the removed reactor closure studs are never exposed to the borated refueling cavity water and remaining studs are protected. Additional protection against the possibility of incurring corrosion effects is assured by the use of a manganese base phosphate surfacing treatment.

The stud holes in the reactor flange are sealed with special plugs before removing the reactor closure, thus preventing leakage of the borated refueling water into the stud holes.

5.3.2 PRESSURE - TEMPERATURE LIMITS

5.3.2.1 Limit Curves

Startup and shutdown operating limitations will be based on the properties of the reactor pressure vessel beltline materials. Actual material property test data will be used. The methods outlined in Appendix G to Section III of the ASME Code will be employed for the shell regions in the analysis of protection against nonductile failure. The initial operating curves are calculated, assuming a period of reactor operation such that the beltline material will be limiting. The heatup and cooldown curves are given in the Pressure and Temperature Limits Report (PTLR).

Beltline material properties degrade with radiation exposure, and this degradation is measured in terms of the adjusted reference nil-ductility temperature, which includes a reference nil-ductility temperature shift (ΔRT_{NDT}).

Predicted ΔRT_{NDT} values are derived using two curves: the effect of fluence and copper content on the shift of ΔRT_{NDT} for the reactor vessel steels exposed to 550°F temperature curve and the maximum fluence at 1/4 T (thickness) and 3/4 T location (tips of the code reference flaw when flaw is assumed at inside diameter and outside diameter locations, respectively) curve. For a selected time of operation, this shift is assigned a sufficient magnitude so that no unirradiated ferritic materials in other components of the reactor coolant system (RCS) will be limiting in the analysis.

The operating curves including pressure-temperature limitations are calculated in accordance with 10 CFR 50, Appendix G and ASME Code, Section III, Appendix G, and WCAP-14040 (Reference 1) requirements.

The results of the material surveillance program described in [Section 5.3.1.6](#) will be used to verify that the ΔRT_{NDT} predicted from the effects of the fluence and copper content curve is appropriate and to make any changes necessary to correct the fluence and copper curves if ΔRT_{NDT} determined from the surveillance program is greater than the predicted ΔRT_{NDT} . Temperature limits for preservice hydrotests and inservice leak and hydrotests will be calculated in accordance with Appendix G of the ASME Code, Section III.

Compliance with Regulatory Guide 1.99 is discussed in [Appendix 3A](#).

5.3.2.2 Operating Procedures

The transient conditions that are considered in the design of the reactor vessel are presented in [Section 3.9\(N\).1.1](#). These transients are representative of the operating conditions that should prudently be considered to occur during plant operation. The transients selected form a conservative basis for evaluation of the RCS to insure the integrity of the RCS equipment.

Those transients listed as upset condition transients are given in [Table 3.9\(N\)-1](#). None of these transients will result in pressure-temperature changes which exceed the heatup and cooldown limitations, as described in [Section 5.3.2.1](#) and in the PTLR.

5.3.3 REACTOR VESSEL INTEGRITY

5.3.3.1 Design

The reactor vessel is cylindrical with a welded hemispherical bottom head and a removable, bolted, flanged, and gasketed hemispherical upper head. The reactor vessel flange and head are sealed by two hollow metallic O-rings. Seal leakage is detected by

means of two leakoff connections: one between the inner and outer ring and one outside the outer O-ring. The vessel contains the core, core support structures, control rods, and other parts directly associated with the core. The reactor vessel closure head contains head adaptors. These head adaptors are tubular members, attached by partial penetration welds to the underside of the closure head. The upper end of these adaptors are welded to the lower end of a CRDM latch housing or instrumentation port head adapter flange. Inlet and outlet nozzles are located symmetrically around the vessel. Outlet nozzles are arranged on the vessel to facilitate optimum layout of the RCS equipment. The inlet nozzles are tapered from the coolant loop vessel interfaces to the vessel inside wall to reduce loop pressure drop.

The bottom head of the vessel contains penetration nozzles for connection and entry of the nuclear incore instrumentation. Each nozzle consists of a tubular member made of either an Inconel or an Inconel-stainless steel composite tube. Each tube is attached to the inside of the bottom head by a partial penetration weld.

Internal surfaces of the vessel which are in contact with primary coolant are weld overlay with 0.125 inch minimum of stainless steel or Inconel except for an area approximately 1.5 inches by 0.75 at approximate location 302.94° from vessel "0" and 384.89 inches down from the flange surface and an area approximately 0.53 inches by 0.3 inches at approximate location 1850 from vessel "0" and 385 inches down from the flange surface. The existence of these areas has been evaluated as acceptable.

The reactor vessel is designed and fabricated in accordance with the requirements of the ASME Code, Section III. Principal design parameters of the reactor vessel are given in [Table 5.3-2](#). The reactor vessel is shown in [Figure 5.3-1](#).

There are no special design features which would prohibit the in-situ annealing of the vessel. If the unlikely need for an annealing operation was required to restore the properties of the vessel material opposite the reactor core because of neutron irradiation damage, a metal temperature greater than 650°F for a period of 168 hours maximum would be applied. Various modes of heating may be used, depending on the temperature required.

The reactor vessel materials surveillance program is adequate to accommodate the annealing of the reactor vessel. Sufficient specimens are available to evaluate the effects of the annealing treatment.

Cyclic loads are introduced by normal power changes, reactor trips, and startup and shutdown operations. These design base cycles are selected for fatigue evaluation and constitute a conservative design envelope for the projected plant life. Vessel analysis results in a usage factor that is less than 1.

The design specifications require analysis to prove that the vessel is in compliance with the fatigue and stress limits of the ASME Code, Section III. The loadings and transients specified for the analysis are based on the most severe conditions expected during

service. The heatup and cooldown rates imposed by the PTLR are 100°F in any one hour, except for cooldown of the pressurizer which is limited to 200°F in any one hour. In practice, these operations will occur more slowly. These rates are reflected in the vessel design specifications.

5.3.3.2 Materials of Construction

The materials used in the fabrication of the reactor vessel are discussed in [Section 5.2.3](#).

5.3.3.3 Fabrication Methods

The SNUPPS reactor vessel manufacturer is Combustion Engineering Corporation.

The replacement reactor vessel closure head manufacturer is AREVA.

The fabrication methods used in the construction of the reactor vessel are discussed in [Section 5.3.1.2](#).

5.3.3.4 Inspection Requirements

The nondestructive examinations performed on the reactor vessel are described in [Section 5.3.1.3](#).

5.3.3.5 Shipment and Installation

The reactor vessel is shipped in a horizontal position on a shipping sled with a vessel-lifting truss assembly. All vessel openings are sealed to prevent the entrance of moisture, and an adequate quantity of desiccant bags is placed inside the vessel. These are usually placed in a wire mesh basket attached to the vessel cover. All carbon steel surfaces, except for the vessel support surfaces and the top surface of the external seal ring, are painted with a heat-resistant paint before shipment.

The closure head is also shipped with a shipping cover and skid. The shipping cover encloses and protects the control rod mechanism housings. The shipping cover is sealed and pressurized with nitrogen to prevent the entrance of moisture and oxygen, and an adequate quantity of desiccant bags is placed inside. A lifting frame is provided for handling the vessel head.

5.3.3.6 Operating Conditions

Operating limitations for the reactor vessel are presented in [Section 5.3.2](#), as well as in the PTLR.

In addition to the analysis of primary components discussed in [Section 3.9\(N\).1.4](#), the reactor vessel is further qualified to ensure against unstable crack growth under faulted conditions. Actuation of the emergency core cooling system (ECCS) following a

loss-of-coolant accident produces relatively high thermal stresses in regions of the reactor vessel, which come into contact with ECCS water. Primary consideration is given to these areas, including the reactor vessel beltline region and the reactor vessel primary coolant nozzle, to ensure the integrity of the reactor vessel under this severe postulated transient.

For the beltline region, significant developments have recently occurred in order to address Pressurized Thermal Shock (PTS) events. On the basis of recent deterministic and probabilistic studies, taking U.S. PWR operating experience into account, the NRC staff concluded that conservatively calculated screening criterion values of less than 270°F for plate material and axial welds, and less than 300°F for circumferential welds, present an acceptably low risk of vessel failure from PTS events. These values were chosen as the screening criterion in the PTS Rule 10CFR50.61 for operating plants. Conservative equations chosen by the NRC staff for the calculation of RT_{PTS} for the purpose of comparison with the screening criterion are presented in paragraph (b) (2) of 10CFR50.61. Details of the analysis method and the basis for the PTS Rule can be found in SECY-82-465.

The reactor vessel beltline materials are specified in [Section 5.3.1](#). The design basis fluence of $3.29 \times 10^{19} \text{ n/cm}^2$, which is the design basis fluence at the vessel inner radius after 32 EFPY for the peak azimuthal location, was used for calculating the RT_{PTS} values. RT_{PTS} is the reference temperature as calculated by the method presented in paragraph (b) (2) of 10CFR50.61. The PTS Rule states that this method of calculating RT_{PTS} should be used in reporting values used to be compared to the above screening criterion. The screening criterion will not be exceeded using the method of calculation prescribed by the PTS Rule for the vessel design lifetime. The material properties, initial RT_{NDT} and end-of-life RT_{PTS} values are listed in [Table 5.3-9](#). The materials identified in [Table 5.3-9](#) are those materials that are exposed to high fluence levels at the beltline region of the reactor vessel and are, therefore, the subject of the PTS Rule. These materials, therefore, are a subset of the materials identified in [Section 5.2.3](#). The plant-specific calculated fluence at 35 EFPY for this peak azimuthal location is $2.02 \times 10^{19} \text{ n/cm}^2$.

Note: Based on the Callaway Plant performance, the plant is predicted to reach 35 EFPY at the end of its operating life. The principles and procedures of linear elastic fracture mechanics (LEFM) are used to evaluate thermal effects in the regions of interest. The LEFM approach to the design against failure is basically a stress intensity consideration in which criteria are established for fracture instability in the presence of a crack. Consequently, a basic assumption employed in LEFM is that a crack or crack-like defect exists in the structure. The essence of the approach is to relate the stress field developed in the vicinity of the crack tip to the applied stress on the structure, the material properties, and the size of defect necessary to cause failure.

The elastic stress field at the crack tip in any cracked body can be described by a single parameter designated as the stress intensity factor, K. The magnitude of the stress

intensity factor K is a function of the geometry of the body containing the crack, the size and location of the crack, and the magnitude and distribution of the stress.

The criterion for failure in the presence of a crack is that failure will occur whenever the stress intensity factor exceeds some critical value. For the opening mode of loading (stresses perpendicular to the major plane of the crack), the stress intensity factor is designated as K_I and the critical stress intensity factor is designated K_{IC} . Commonly called the fracture toughness, K_{IC} is an inherent material property which is a function of temperature and strain rate. Any combination of applied load, structural configuration, crack geometry, and size which yields a stress intensity factor K_{IC} for the material will result in crack instability.

The criterion of the applicability of LEFM is based on plasticity considerations at the postulated crack tip. Strict applicability (as defined by ASTM) of LEFM to large structures where plane strain conditions prevail requires that the plastic zone developed at the tip of the crack does not exceed 2.25 percent of the crack depth. In the present analysis, the plastic zone at the tip of the postulated crack can reach 20 percent of the crack depth. However, LEFM has been successfully used to provide conservative brittle fracture prevention evaluations, even in cases where strict applicability of the theory is not permitted due to excessive plasticity. Recently, experimental results from the Heavy Section Steel Technology (HSST) Program intermediate pressure vessel tests have shown that LEFM can be applied conservatively as long as the pressure component of the stress does not exceed the yield strength of the material. The addition of the elastically calculated thermal stresses, which results in total stresses in excess of the yield strength, does not affect the conservatism of the results, provided that these thermal stresses are included in the evaluation of the stress intensity factors. Therefore, for faulted conditions analyses, LEFM is considered applicable for the evaluation of the vessel inlet nozzle and beltline region.

In addition, it has been well established that the crack propagation of existing flaws in a structure subjected to cyclic loading can be defined in terms of fracture mechanics parameters. Thus, the principles of LEFM are also applicable to fatigue growth of a postulated flaw at the vessel inlet nozzle and beltline region.

Additional details on this method of analysis of reactor vessels under severe transients are given in Reference 2.

5.3.3.7 Inservice Surveillance

The internal and external surfaces of the reactor vessel are accessible for periodic inspection. Visual and/or nondestructive techniques are used. During refueling, the vessel cladding is capable of being inspected in certain areas between the closure flange and the primary coolant inlet nozzles, and, if deemed necessary, the core barrel is capable of being removed, making the entire inside vessel surface accessible.

The closure head is examined visually during each refueling. Optical devices permit a selective inspection of the cladding, control rod drive mechanism nozzles, and the gasket seating surface. The closure studs and nuts can be inspected periodically using visual, magnetic particle, and ultrasonic techniques.

The closure studs, nuts, washers, and the vessel flange seal surface, as well as the full penetration welds in the following areas of the installed reactor vessel, are available for nondestructive examination:

- a. Vessel shell - from the inside and outside surfaces
- b. Primary coolant nozzles - from the inside and outside surfaces*
- c. Closure head - from the inside and outside surfaces. Bottom head - from the inside and outside surfaces
- d. Field welds between the reactor vessel nozzle safe ends and the main coolant piping - from the inside and outside surfaces

The design considerations which have been incorporated into the system design to permit the above inspection are as follows:

- a. All reactor internals are completely removable. The tools and storage space required to permit these inspections are provided.
- b. The closure head is stored dry on the reactor operating deck during refueling to facilitate direct visual inspection.
- c. Reactor vessel studs, nuts, and washers can be removed to dry storage during refueling. Studs which cannot be removed are independently evaluated.
- d. Access is provided to the reactor vessel nozzle safe ends. The insulation covering the nozzle-to-pipe welds may be removed.
- e. Reactor cavity is designed to allow access to the outside surface of the vessel. Tracks are installed to allow mechanical equipment to inspect the vessel surface.

The reactor vessel presents access problems because of the radiation levels and remote underwater accessibility to this component. Because of these limitations on access to the reactor vessel, several steps have been incorporated into the design and

* Only partial outside diameter coverage is provided.

manufacturing procedures in preparation for the periodic nondestructive tests, which are required by the ASME inservice inspection code. These are:

- a. Shop ultrasonic examinations are performed on all internally clad surfaces to an acceptance and repair standard to assure an adequate cladding bond to allow later ultrasonic testing of the base metal from inside surface. The size of cladding bond defect allowed is 1/4 inch by 3/4 inch with the greater direction parallel to the weld in the region bounded by 2T (T = wall thickness) on both sides of each full penetration pressure boundary weld. Unbounded areas exceeding 0.442 square inches (3/4 inch diameter) in all other regions are rejected.
- b. The design of the reactor vessel shell is an uncluttered cylindrical surface to permit future positioning of the test equipment without obstruction.
- c. The weld deposited clad surface on both sides of the welds to be inspected is specifically prepared to assure meaningful ultrasonic examinations.
- d. During fabrication, all full penetration ferritic pressure boundary welds are ultrasonically examined in addition to Code examinations.
- e. After the shop hydrostatic testing, all full penetration ferritic pressure boundary welds, as well as the nozzle to safe end welds, are ultrasonically examined from both the inside and outside diameters in addition to ASME Code, Section III requirements.

The vessel design and construction enables inspection in accordance with the ASME Code, Section XI. The reactor vessel inservice inspection program is detailed in [Chapter 16](#), the Inservice Inspection Program, and the PTLR.

5.3.4 REFERENCES

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3. Lott, R.G., Vanichko, S.E., Locante, J., Schmertz, J.C., "Analysis of Capsule U From the Union Electric Company Callaway Plant Unit 1 Reactor Vessel Radiation Surveillance Program," WCAP-11374, Rev. 1, June 1987.

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4. Terck, E., Anderson, S.L., Madeyski, A., "Analysis of Capsule Y From the Union Electric Company Callaway Unit 1 Reactor Vessel Radiation Surveillance Program," WCAP-12946, June 1991.
5. Torek, E., Perock, J. D., Williams, J. F., "Analysis of Capsule V from the Union Electric Company Unit 1 Reactor Vessel Radiation Surveillance Program," WCAP-14895, July 1997.
6. Laubham, T. J., Roberts, G. K. Harik, E., "Analysis of Capsule X from AmerenUE Callaway Unit 1 Reactor Vessel Radiation Surveillance Program," WCAP-15400, June 2000.

**TABLE 5.3-1 REACTOR VESSEL QUALITY
ASSURANCE PROGRAM**

| | <u>RT*</u> | <u>UT*</u> | <u>PT*</u> | <u>MT*</u> |
|--|------------|------------|------------|------------|
| Forgings | | | | |
| Flanges | | Yes | | Yes |
| Studs and nuts | | Yes | | Yes |
| CRD latch housing | | Yes | Yes | |
| CRD head adapter tube | | Yes | Yes | |
| Instrumentation tube | | Yes | Yes | |
| Main nozzles | | Yes | | Yes |
| Nozzle safe ends | | Yes | Yes | |
| Plates | | Yes | | Yes |
| Weldments | | | | |
| Main seam | Yes | Yes | | Yes |
| CRD head adapter to closure head connection | | | Yes | |
| Instrumentation tube to bottom head connection | | | Yes | |
| Main nozzle | Yes | Yes | | Yes |
| Cladding | | Yes | Yes | |
| Nozzle to safe ends | Yes | Yes | Yes | |
| CRD latch housing to CRD head adapter tube | Yes | | Yes | |
| All full penetration ferritic pressure boundary welds accessible after hydrotest | | Yes | | Yes |
| Full penetration nonferritic pressure boundary welds accessible after hydrotest (Nozzle to safe ends) | | Yes | Yes | |
| Seal ledge | | | | Yes |
| Head lift lugs | | | | Yes |
| Core pad welds | | Yes | | |

TABLE 5.3-1 (Sheet 2)

- * RT - Radiographic
- UT - Ultrasonic
- PT - Dye Penetrant
- MT - Magnetic Particle

NOTE:

Base metal weld repairs as a result of UT, MT, RT, and/or PT indications shall be cleared by the same NDE technique/ procedure by which the indications were found. The repair shall meet all Section III requirements.

In addition, UT examination per the in-process/post-hydro UT requirements shall be performed on the following:

1. Base metal repairs in the core region.
2. Base metal repairs in the ISI zone (1/2 T).

TABLE 5.3-2 REACTOR VESSEL DESIGN PARAMETERS

| | |
|---|-------------|
| Design/operating pressure, psig | 2,485/2,235 |
| Design temperature, F | 650 |
| Overall height of vessel and closure head, bottom head outside diameter to top of control rod mechanism latch housing, ft-in. | 47-11.8 |
| Thickness of RPV head insulation, minimum, in. | 4.3 |
| Number of reactor closure head studs * | 54 |
| Diameter of reactor closure head/studs, minimum shank, in. | 6-13/16 |
| Outside diameter of flange, in. | 205 |
| Inside diameter of flange, in. | 167 |
| Outside diameter at shell, in. | 190-1/2 |
| Inside diameter at shell, in. | 173 |
| Inlet nozzle inside diameter, in. | 27-1/2 |
| Outlet nozzle inside diameter, in. | 29 |
| Clad thickness, minimum, in. | 1/8 |
| Lower head thickness, minimum, in. | 5-3/8 |
| Vessel beltline thickness, minimum, in. | 8-5/8 |
| Closure head thickness, minimum, in. | 7 |
| Nominal water volume, ft ³ | 3,700 |

* 54 Closure head studs are provided. 53 Studs are required to be tensioned for operation in modes 1 thru 4. (See ULNRC-1663 for supporting evaluation).

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TABLE 5.3-3 Deleted.

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TABLE 5.3-4 CALLAWAY UNIT 1 REACTOR VESSEL MATERIAL PROPERTIES

| <u>COMPONENT</u> | <u>CODE NO.</u> | <u>MATERIAL SPEC. NO.</u> | Cu (%) | P (%) | T _{NDT} (F) | RT _{NDT} (F) | <u>Avg. Upper Shelf</u> | |
|------------------------|-----------------|-------------------------------|-----------|----------|-------------------------|--------------------------|-------------------------|-----------------|
| | | | | | | | NMWD** (FT-LB) | MWD* (FT-LB) |
| Closure Head | 10DW96-1 | A508, G3, CL. 1 | 0.03 | 0.006 | -40 | -40 | 207 | - |
| Vessel Flange | R2701-1 | A508 CL. 2 | - | 0.010 | 40 | 40 | 123 | - |
| Inlet Nozzle | R2702-1 | A508 CL. 2 | - | 0.013 | 10 | 10 | 138 | - |
| Inlet Nozzle | R2702-2 | A508 CL. 2 | - | 0.011 | 10 | 10 | 141 | - |
| Inlet Nozzle | R2702-3 | A508 CL. 2 | - | 0.009 | -10 | -10 | 139 | - |
| Inlet Nozzle | R2702-4 | A508 CL. 2 | - | 0.010 | -10 | -10 | 134 | - |
| Outlet Nozzle | R2703-1 | A508 CL. 2 | - | 0.010 | -10 | -10 | 130 | - |
| Outlet Nozzle | R2703-2 | A508 CL. 2 | - | 0.009 | 10 | 10 | 108 | - |
| Outlet Nozzle | R2703-3 | A508 CL. 2 | - | 0.004 | 10 | 10 | 126 | - |
| Outlet Nozzle | R2703-4 | A508 CL. 2 | - | 0.006 | 0 | 0 | 122 | - |
| Nozzle Shell | R2706-1 | A533B, CL. 1 | 0.05 | 0.010 | 10 | 20 | 103 | - |
| Nozzle Shell | R2706-2 | A533B, CL. 1 | 0.06 | 0.009 | 0 | 30 | 88 | - |
| Nozzle Shell | R2706-3 | A533B, CL. 1 | 0.08 | 0.011 | 0 | 30 | 101 | - |
| Inter. Shell | R2707-1 | A533B, CL. 1 | 0.04 | 0.008 | -40 | 40 | 78 | 99 |
| Inter. Shell | R2707-2 | A533B, CL. 1 | 0.05 | 0.008 | -50 | 10 | 100 | 121 |
| Inter. Shell | R2707-3 | A533B, CL. 1 | 0.06 | 0.010 | -40 | -10 | 99 | 122 |
| Lower Shell | R2708-1 | A533B, CL. 1 | 0.07 | 0.006 | 0 | 50 | 82 | 95 |
| Lower Shell | R2708-2 | A533B, CL. 1 | 0.05 | 0.007 | -30 | 10 | 105 | 130 |
| Lower Shell | R2708-3 | A533B, CL. 1 | 0.07 | 0.006 | -10 | 20 | 101 | 122 |
| Bottom Head Torus | R2714-1 | A533B, CL. 1 | 0.15 | 0.010 | -20 | -20 | 139 | - |
| Bottom Head Dome | R2715-1 | A533B, CL. 1 | 0.17 | 0.011 | -40 | -40 | 152 | - |
| Inter. and lower shell | G2.03 | SAW | 0.04 | 0.008 | -60 | -60 | 143 | - |
| long. weld seams | | | | | | | | |
| Inter. to lower shell | E3.14 | SAW | 0.04 | 0.006 | -60 | -60 | 112 | - |
| girth weld seam | | | | | | | | |
| Weld HAZ | - | - | - | - | -80 | -70 | 144 | - |

*Major working direction

**Normal to major working direction

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TABLE 5.3-5 Deleted.

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TABLE 5.3-6 Deleted.

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TABLE 5.3-7 CALLAWAY UNIT 1 REACTOR VESSEL CLOSURE HEAD BOLTING MATERIAL PROPERTIES

| <u>Closure Head Studs</u> | | | | | | | | |
|---------------------------|--------------------|---------|---------------------------|---------------------------------|----------------|-----------------------|------------------------|------------------------------|
| Heat No. | Material Spec. No. | Bar No. | 0.2% Yield Strength (Ksi) | Ultimate Tensile Strength (Ksi) | Elongation (%) | Reduction in Area (%) | Energy at 10 F (FT LB) | Lateral Expansion (MILS) BHN |
| 84299 | SA540, B24 | 437 | 143.5 | 158.5 | 16.0 | 48.1 | 52, 51, 51 | 31, 27, 29 331 |
| 84299 | SA540, B24 | 437-1 | 138.0 | 155.0 | 17.0 | 51.4 | 51, 51, 53 | 29, 31, 30 341 |
| 84299 | SA540, B24 | 439 | 141.5 | 156.5 | 16.5 | 52.5 | 53, 54, 53 | 29, 30, 32 331 |
| 84299 | SA540, B24 | 439-1 | 140.5 | 154.5 | 16.0 | 49.5 | 55, 53, 52 | 33, 32, 29 331 |
| 83320 | SA540, B24 | 443 | 139.0 | 156.0 | 17.5 | 53.3 | 51, 50, 52 | 33, 29, 30 341 |
| 83320 | SA540, B24 | 443-1 | 141.0 | 157.0 | 17.5 | 54.1 | 49, 49, 49 | 29, 32, 30 331 |
| 83320 | SA540, B24 | 447 | 140.5 | 156.0 | 17.0 | 53.8 | 49, 50, 49 | 32, 30, 29 341 |
| 83320 | SA540, B24 | 447-1 | 144.0 | 159.0 | 17.5 | 52.1 | 49, 49, 49 | 32, 31, 30 331 |
| 83320 | SA540, B24 | 451 | 141.0 | 155.0 | 17.0 | 53.6 | 52, 51, 51 | 32, 30, 29 341 |
| 83320 | SA540, B24 | 451-1 | 141.0 | 156.0 | 17.5 | 52.2 | 51, 50, 51 | 30, 30, 31 341 |
| 83320 | SA540, B24 | 456 | 141.0 | 157.0 | 17.0 | 51.7 | 48, 50, 48 | 31, 31, 30 331 |
| 83320 | SA540, B24 | 456-1 | 139.8 | 154.0 | 17.0 | 53.5 | 49, 47, 47 | 33, 27, 30 331 |

| <u>Closure Head Nuts & Washers</u> | | | | | | | | |
|--|------------|-------|-------|-------|------|------|------------|----------------|
| | | | | | | | | |
| 63182 | SA540, B24 | 132 | 148.0 | 162.0 | 17.5 | 57.3 | 51, 52, 51 | 31, 32, 30 331 |
| 63182 | SA540, B24 | 132-1 | 148.7 | 162.0 | 17.0 | 54.7 | 49, 48, 49 | 29, 26, 29 331 |
| 63182 | SA540, B24 | 133 | 147.2 | 161.0 | 17.0 | 55.2 | 52, 50, 51 | 31, 30, 30 321 |
| 63182 | SA540, B24 | 133-1 | 149.2 | 162.5 | 17.5 | 54.7 | 51, 51, 49 | 29, 31, 27 331 |
| 63182 | SA540, B24 | 135 | 147.6 | 161.0 | 17.0 | 53.0 | 49, 49, 51 | 28, 29, 30 321 |
| 63182 | SA540, B24 | 135-1 | 143.2 | 157.0 | 17.5 | 55.2 | 55, 54, 52 | 33, 32, 31 321 |
| 63182 | SA540, B24 | 137 | 145.0 | 159.0 | 16.5 | 54.8 | 54, 54, 53 | 33, 33, 29 331 |
| 63182 | SA540, B24 | 137-1 | 147.0 | 160.0 | 17.0 | 55.7 | 54, 55, 54 | 34, 36, 33 321 |
| 63182 | SA540, B24 | 143 | 145.0 | 159.0 | 18.0 | 58.1 | 55, 54, 54 | 33, 32, 32 331 |
| 63182 | SA540, B24 | 143-1 | 147.0 | 160.0 | 17.0 | 57.3 | 54, 50, 52 | 33, 29, 30 321 |
| 63182 | SA540, B24 | 145 | 145.0 | 159.0 | 17.0 | 56.0 | 54, 54, 55 | 34, 35, 34 321 |
| 63182 | SA540, B24 | 145-1 | 146.2 | 159.7 | 17.0 | 57.0 | 56, 55, 54 | 36, 35, 36 331 |
| 63182 | SA540, B24 | 148 | 144.0 | 157.5 | 17.5 | 56.5 | 56, 55, 55 | 33, 34, 34 331 |
| 63182 | SA540, B24 | 148-1 | 148.6 | 162.0 | 17.0 | 55.6 | 52, 51, 52 | 33, 28, 30 321 |
| 63182 | SA540, B24 | 150 | 144.7 | 158.0 | 17.5 | 55.7 | 55, 55, 54 | 33, 30, 31 331 |
| 63182 | SA540, B24 | 150-1 | 145.7 | 160.0 | 17.0 | 56.5 | 53, 50, 52 | 33, 30, 31 331 |

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TABLE 5.3-8 Deleted.

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TABLE 5.3-9 CALLAWAY REACTOR VESSEL VALUES
FOR ANALYSIS OF POTENTIAL PRESSURIZED
THERMAL SHOCK EVENTS 10CFR50.61

| Material | Code No. | Cu% C-E | | Ni% C-E | | Initial RT _{NDT} (°F) | End of Life RT _{PTS} (°F) |
|--|----------|------------|-----|------------|-----|-----------------------------------|--|
| | | Anal Ave** | | Anal Ave** | | | |
| Intermediate Shell | R2707- 1 | .04 | .05 | .57 | .58 | 40 | 111 |
| | - 2 | .05 | .06 | .59 | .61 | 10 | 88 |
| | - 3 | .06 | .06 | .61 | .62 | - 10 | 68 |
| Lower Shell | R2708- 1 | .07 | .07 | .59 | .58 | 50 | 97* |
| | - 2 | .05 | .06 | .57 | .57 | 10 | 88 |
| | - 3 | .07 | .08 | .59 | .62 | 20 | 115 |
| Inter. and Lower Shell Long. Weld Seams | G2.03 | | .04 | | .06 | - 60 | 15.48* |
| Inter. to Lower Shell Girth Weld Seams | E3.14 | | .04 | | .04 | - 60 | 15.88* |
| Ave. for All Beltline Weld Metal | | - | .04 | - | .06 | - | - |

Note: See also [Table 5.3-4](#).

* Indicates numbers were calculated using surveillance capsule data.

**Average material/weld properties from WCAP 14894.

TABLE 5.3-10 REACTOR VESSEL MATERIAL
SURVEILLANCE PROGRAM - WITHDRAWAL SCHEDULE

| <u>CAPSULE NUMBER</u> | <u>VESSEL LOCATION</u> | <u>LEAD FACTOR^(a)</u> | <u>WITHDRAWAL TIME (EFPY)^(b)</u> |
|-----------------------|------------------------|----------------------------------|---|
| U | 58.5° | 4.42 | 1.05 (Removed) |
| Y | 241° | 3.85 | 4.6 (Removed) |
| V | 61° | 3.97 | 9.85 (Removed) |
| X | 238.5° | 4.34 | 12.4 ^(c) (Removed) |
| W | 121.5° | 4.29 | 25.8 (Removed) |
| Z | 301.5° | 4.29 | 16.53 (Removed) ^(d) |

- (a) Updated in Section 6 of Reference 6.
- (b) Effective Full Power Years (EFPY) from plant startup. Capsule Number U, Y, V, and X EFPYs referenced from WCAP-15400, Capsule Number W, Z EFPY generated by Callaway Reactor Engineering.
- (c) At 12.4 EFPY, the fluence at Capsule X is approximately equal to the calculated peak reactor vessel surface fluence at 51 EFPY.
- (d) Capsule Z removed during Refuel 13. Currently in long-term storage in spent fuel pool.

For additional information, see References 3, 4, 5, and 6.

**TABLE 5.3-11 NEUTRON DOSIMETRY
REACTIONS OF INTEREST**

| <u>MATERIAL</u> | <u>REACTION OF INTEREST</u> | <u>NEUTRON ENERGY RESPONSES^(a)</u> | <u>PRODUCT HALF-LIFE</u> | <u>DOSIMETER CAPSULE POSITION^(b)</u> | <u>GRADIENT CHAIN^(c)</u> |
|--|---|---|--------------------------|---|-------------------------------------|
| Copper | $^{63}\text{Cu}(\text{n},\alpha)^{60}\text{Co}$ | 4.53-11.0 MeV | 5.271 y | 2-Cd | No |
| Titanium | $^{46}\text{Ti}(\text{n},\text{p})^{46}\text{Sc}$ | 3.70-9.43 MeV | 83.79 d | 2-Cd | No |
| Iron | $^{54}\text{Fe}(\text{n},\text{p})^{54}\text{Mn}$ | 2.27-7.54 MeV | 312.3 d | 1-B & 2-Cd | Yes |
| Nickel | $^{58}\text{Ni}(\text{n},\text{p})^{58}\text{Co}$ | 1.98-7.51 MeV | 70.82 d | 2-Cd | Yes |
| $^{238}\text{U}^{\text{(d)}}$ | $^{238}\text{U}(\text{n,f})^{137}\text{Cs}$ | 1.44-6.69 MeV | 30.07 y | 3-Cd | No |
| ^{93}Nb | $^{93}\text{Nb}(\text{n},\text{n}')^{93m}\text{Nb}$ | 0.95-5.79 MeV | 16.13 y | 3-Cd | No |
| $^{237}\text{Np}^{\text{(d)}}$ | $^{237}\text{Np}(\text{n,f})^{137}\text{Cs}$ | 0.68-5.61 MeV | 30.07 y | 3-Cd | No |
| Cobalt-Al | $^{59}\text{Co}(\text{n,Y})^{60}\text{Co}$ | Thermal | 5.271 y | 1-B & 2-Cd | Yes |
| (a) Energies between which 90% of activity is produced (^{235}U fission spectrum). | | | | | |
| (b) "B" denotes bare iron and cobalt radiometric monitors, while "Cd" denotes cadmium-shielded radiometric monitors. Cadmium-shielded foils include foils of the following metals: copper, titanium, iron, nickel, niobium, and cobalt-aluminum. Cadmium-shielded fast fission reactions include ^{238}U and ^{237}Np in vanadium oxide encapsulated detectors. | | | | | |
| (c) These stainless steel bead chains connect and support the dosimeter capsules containing the radiometric monitors. The segmented chains provide iron, nickel, and cobalt reactions that are used to complete the determination of the axial and azimuthal gradients. The high purity iron, nickel, and cobalt-aluminum foils contained in the multiple foil sensor sets provide a direct correlation with the measured reaction rates from these gradient chains. Cross-comparisons permit the use of the gradient measurements to derive neutron flux distributions in the reactor cavity with a high level of confidence. | | | | | |
| (d) Vanadium-encapsulated ^{238}U and ^{237}Np fission monitors are currently unavailable. | | | | | |

5.4 COMPONENT AND SUBSYSTEM DESIGN

5.4.1 REACTOR COOLANT PUMPS

5.4.1.1 Design Bases

The reactor coolant pump provides an adequate core cooling flow rate for heat transfer to maintain a departure from nucleate boiling ratio (DNBR) greater than 1.17 within the parameters of operation. The required net positive suction head is by conservative pump design always less than that available by system design and operation. Sufficient pump rotation inertia is provided by a flywheel, in conjunction with the impeller and motor assembly, to provide adequate flow during coastdown. This forced flow following an assumed loss of pump power, and the subsequent natural circulation effect provides the core with adequate cooling flow.

The reactor coolant pump motor is tested, without mechanical damage, at overspeeds up to and including 125 percent of normal speed. The retention of integrity of the flywheel during a LOCA is demonstrated in Reference 1.

Steam/water tests planned jointly by Westinghouse, Framatone, and the French Atomic Energy Commission (CEA) are discussed in Reference 2. The ultimate use of the data from this testing will be to develop an empirical two-phase flow pump performance model. It is expected that this new model will confirm that the present pump model conservatively predicts performance in all LOCA conditions and thus increase the safety margin available in the emergency core cooling system (ECCS) and reactor coolant pump overspeed analyses.

The pump/motor system is designed for the SSE at the site.

5.4.1.2 Pump Description

5.4.1.2.1 Design Description

The reactor coolant pump is shown in [Figure 5.4-1](#). The reactor coolant pump design parameters are given in [Table 5.4-1](#). Code and material requirements are provided in [Section 5.2](#).

The reactor coolant pump is a vertical, single stage, controlled leakage, centrifugal pump designed to operate at high temperatures and pressures.

The pump consists of three major sections. They are the hydraulics, the seals, and the motor.

- a. The hydraulic section consists of the casing, thermal barrier, flange, impeller/diffuser, and diffuser adapter.

- b. The shaft seal section consists of three primary devices. They are number 1 controlled-leakage, film-riding face seal, and the number 2 and number 3 rubbing face seals. These seals are contained within the thermal barrier heat exchanger assembly and seal housing. Collectively, they provide a pressure breakdown from the reactor coolant system (RCS) pressure to ambient conditions. A fourth sealing device called a shutdown seal is housed within the number 1 seal area and is passively actuated by high temperature if seal cooling is lost.
- c. The motor is a drip-proof squirrel cage induction motor with a vertical solid shaft, an oil lubricated double-acting Kingsbury type thrust bearing, upper and lower oil lubricated radial guide bearings, and a flywheel.

Additional components of the pump are the shaft, pump radial bearing, thermal barrier heat exchanger, coupling, spool piece, and motor stand.

5.4.1.2.2 Description of Operation

Reactor coolant enters the suction nozzle, is directed to the impeller by the diffuser adapter, is pumped through the diffuser, and exits through the discharge nozzle.

Seal injection flow, under slightly higher pressure than the reactor coolant, enters the pump through a connection of the thermal barrier flange and is directed into the plenum between the thermal barrier housing and the shaft. The flow splits with a portion flowing down the shaft through the radial bearing and into the RCS; the remainder flows up the shaft through the seals.

Component cooling water is provided to the thermal barrier heat exchanger. During normal operation, the thermal barrier limits the heat transfer from hot reactor coolant to the radial bearing and to the seals. In addition, if a loss of seal injection flow should occur, the thermal barrier heat exchanger cools reactor coolant to an acceptable level before it enters the bearing and seal area.

The reactor coolant pump shaft sealing system can operate acceptably with either seal water injection or component cooling water alone for an unlimited time. As described in **Sections 9.2.2** and **9.3.4** the component cooling water and the seal water injection paths provide diverse cooling means which precludes seal failures due to any single failure or due to the effects of an SSE.

The reactor coolant pump motor bearings are of conventional design. The radial bearings are the segmented pad type, and the thrust bearing is a double-acting Kingsbury type. All are oil lubricated. Component cooling water is supplied to the external upper bearing oil cooler and to the integral lower bearing oil cooler. The reactor coolant pump motor bearings are qualified for 10 minutes operation without component cooling water with no resultant damage.

The motor is a water/air cooled, Class F thermalastic epoxy insulated, squirrel cage induction motor. The rotor and stator are of standard construction and are cooled by air.

Six resistance temperature detectors are imbedded in the stator windings to sense stator temperature. The top of the motor consists of a flywheel and an antireverse rotation device.

The internal parts of the motor are cooled by air. Integral vanes on each end of the rotor draw air in through cooling slots in the motor frame. This air passes through the motor with particular emphasis on the stator end turns. It is then routed to the external water/air heat exchangers, which are supplied with component cooling water. Each motor has two such coolers, mounted diametrically opposed to each other. In passing through the coolers, the air is cooled to below 122°F so that little heat is rejected to the containment from the motors.

Each of the reactor coolant pumps is equipped for continuous monitoring of reactor coolant pump shaft and frame vibration levels. Shaft vibration is measured by two relative shaft probes mounted on top of the pump seal housing; the probes are located 90 degrees apart in the same horizontal plane and mounted near the pump shaft. Frame vibration is measured by two velocity seismoprobes located 90 degrees apart in the same horizontal plane and mounted at the top of the motor support stand. Proximeters and converters linearize the probe output, which is displayed on a monitor in the control room. The monitor displays the vibration levels for both relative probes and both seismoprobes for each reactor coolant pump; manual selection allows the monitoring of gap voltages of individual probes. Indicator lights display alert and danger limits of vibration.

A removable shaft segment, the spool piece, is located between the motor coupling flange and the pump coupling flange; the spool piece allows removal of the pump seals with the motor in place. The pump internals, motor, and motor stand can be removed from the casing without disturbing the reactor coolant piping. The flywheel is available for inspection by removing the cover.

All parts of the pump in contact with the reactor coolant are austenitic stainless steel, except for seals, bearings, and special parts.

5.4.1.3 Design Evaluation

5.4.1.3.1 Pump Performance

The reactor coolant pumps are sized to deliver flow at rates which equal or exceed the flow rates required for core cooling. Initial RCS tests confirm the total delivery capability. Thus, assurance of adequate forced circulation coolant flow is provided prior to initial plant operation.

The estimated performance characteristic is shown in [Figure 5.4-2](#). The "knee" at about 45-percent design flow introduces no operational restrictions, since the pumps operate at full flow.

The reactor trip system assures that pump operation and core cooling capability are within the assumptions used for loss of flow analyses (See [Chapter 15.0](#)).

Long-term tests have been conducted on less than full scale prototype seals, as well as on full size seals. Operating plants continue to demonstrate the satisfactory performance of the controlled leakage shaft seal pump design.

The support of the stationary member of the number 1 seal ("seal ring") is such as to allow large deflections, both axial and tilting, while still maintaining its controlled gap relative to the seal runner. Even if all the graphite were removed from the pump bearing, the shaft could not deflect far enough to cause opening of the controlled leakage gap. The "spring-rate" of the hydraulic forces associated with the maintenance of the gap is high enough to ensure that the ring follows the runner under very rapid shaft deflections.

Testing of pumps with the number 1 seal entirely bypassed (full system pressure on the number 2 seal) shows that small (approximately 4 to 12 gpm) leakage rates would be maintained for a period of time sufficient to secure the pump. Even if the number 1 seal were to fail entirely during normal operation, the number 2 seal would maintain these small leakage rates if the proper action is taken by the operator. An increase in number 1 seal leakoff rate will warn the plant operator of number 1 seal damage. Following warning of excessive seal leakage conditions, the plant operator will take corrective actions. Gross leakage from the pump does not occur if these procedures are followed.

Loss of offsite power causes loss of power to the pump and causes a temporary stoppage in the supply of seal injection flow to the pump and also of the component cooling water flow to the pump and motor. The emergency diesel generators are started automatically due to loss of offsite power so that seal injection flow is provided by the ECCS charging pumps. Component cooling water flow is subsequently restored automatically, within 2 minutes. Load shedding and sequencing is discussed in [Section 8.3](#).

In the event of a loss of all AC power and/or loss of all seal cooling, the shutdown seal (SDS) will actuate on high seal cooling temperature to limit leakage from the RCP seal package. Leakage is limited when a thermal actuator retracts and causes the SDS piston ring and polymer ring to clamp down around the pump shaft.

5.4.1.3.2 Coastdown Capability

It is important to reactor protection that the reactor coolant flow is maintained for a short time after a pump trip in order to remove heat stored in the fuel elements of the core. In order to provide this flow after interruption of power to the pump, each reactor coolant pump is provided with a flywheel. The rotating inertia of the pump, motor, and flywheel is

employed during the coastdown period to continue the reactor coolant flow. An inadvertent early actuation of the SDS on the pump shaft, with the shaft still rotating, will not adversely impact RCP coastdown. The coastdown flow transients are provided in the figures in [Section 15.3](#). The coastdown capability of the pumps is maintained even under the most adverse case of a blackout coincident with the SSE. Core flow transients and figures are provided in [Section 15.3.1](#)

5.4.1.3.3 Bearing Integrity

The design requirements for the reactor coolant pump bearings are primarily aimed at ensuring a long life with negligible wear, so as to give accurate alignment and smooth operation over long periods of time. The surface-bearing stresses are held at a very low value, and even under the most severe seismic transients remain below stress values that can be adequately carried for short periods of time.

Because there are no established criteria for short-time stress-related failures in such bearings, it is not possible to make a meaningful quantification of such parameters as margins to failure, safety factors, etc. A qualitative analysis of the bearing design, embodying such considerations, gives assurance of the adequacy of the bearing to operate without failure.

Low oil levels in the lube oil sumps signal alarms in the control room. Each motor bearing contains embedded temperature detectors, and so initiation of failure, separate from loss of oil, is indicated and alarmed in the control room as a high bearing temperature. This requires pump shutdown. If these indications are ignored, and the bearing proceeded to failure, the low melting point of Babbitt metal on the pad surfaces ensures that sudden seizure of the shaft will not occur. In this event, the motor continues to operate, as it has sufficient reserve capacity to drive the pump under such conditions. However, the high torque required to drive the pump will require high current which will lead to the motor being shutdown by the electrical protection systems.

5.4.1.3.4 Locked Rotor

It may be hypothesized that the pump impeller might severely rub on a stationary member and then seize. This constitutes a loss-of-coolant flow in the loop. Analysis has shown that under such conditions, assuming instantaneous seizure of the impeller, the pump shaft fails in torsion just below the coupling to the motor, thus disengaging the flywheel and motor from the shaft. Following such a postulated seizure, the motor continues to run without any overspeed, and the flywheel maintains its integrity, as it is still supported on a shaft with two bearings. Flow transients are provided in the figures in [Section 15.3.3](#) for the assumed locked rotor.

There are no credible sources of shaft seizure other than impeller rubs. A sudden seizure of the pump bearing is precluded by graphite in the bearing. Any seizure in the seals results in a shearing of the antirotation pin in the seal ring. Further, an inadvertent actuation of the shutdown seal on the shaft has no significant effect on pump/shaft

rotation and will not interrupt core cooling flow provided by the RCP. The motor has adequate power to continue pump operation even after the above occurrences. Indications of pump malfunction in these conditions are initially by high temperature signals from the bearing water temperature detector, and excessive number 1 seal leakoff indications, and offscale number 1 seal leakoff indications respectively. Following these signals, pump vibration levels are checked. Excessive vibration, excessive number 1 seal leak-off, and high bearing inlet temperature indicate mechanical trouble. Administrative procedures provide for shutting down the affected pump or tripping the reactor based upon pre-established criterion.

5.4.1.3.5 Critical Speed

The reactor coolant pump shaft is designed so that its operating speed is below its first critical speed. This shaft design, even under the most severe postulated transient, gives low values of actual stress.

5.4.1.3.6 Missile Generation

Precautionary measures taken to preclude missile formation from primary coolant pump components assure that the pumps will not produce missiles under any anticipated accident condition. Each component of the primary pump motors has been analyzed for missile generation. Any fragments of the motor rotor would be contained by the heavy stator. The same conclusion applies to the pump impeller because the small fragments that might be ejected would be contained in the heavy casing. Further discussion and analysis of missile generation is contained in Reference 1.

5.4.1.3.7 Pump Cavitation

The minimum net positive suction head required by the reactor coolant pump at running speed is approximately a 192-foot head (approximately 85 psi). In order for the controlled leakage seal to operate correctly, it is necessary to require a minimum differential pressure of approximately 200 psi across the number 1 seal. This corresponds to a primary loop pressure at which the minimum net positive suction head is exceeded, and no limitation on pump operation occurs.

5.4.1.3.8 Pump Overspeed Considerations

For most turbine trips actuated by either the reactor trip system or the turbine protection system, the generator and reactor coolant pumps are maintained connected to the external network for 30 seconds to prevent any pump overspeed condition. The exceptions to this are turbine trips actuated by the turbine protection system for low bearing oil pressure, thrust bearing wear, turbine high vibration, high condenser backpressure, and manual trip pushbutton. These turbine trips have no time delay added to the trip circuit.

An electrical fault requiring immediate trip of the generator (with resulting turbine trip) could result in an overspeed condition. However, the turbine control system and the turbine overspeed protection system will limit the overspeed to less than 120 percent. As additional backup, the turbine protection system has a mechanical overspeed protection trip, usually set at about 110 percent (of turbine speed). In the cases where a turbine trip results in an immediate generator trip or a generator trip due to an electrical fault that de-energizes the pump busses, the reactor coolant pump motors will be transferred to offsite power within 6 to 10 cycles. Further discussion of pump overspeed considerations is contained in Reference 1.

5.4.1.3.9 Antireverse Rotation Device

Each of the reactor coolant pumps is provided with an antireverse rotation device in the motor. This antireverse mechanism consists of pawls mounted on the outside diameter of the flywheel, a serrated ratchet plate mounted on the motor frame, a spring return for the ratchet plate, and two shock absorbers.

At an approximate forward speed of 70 rpm, the pawls drop and bounce across the ratchet plate; as the motor continues to slow, the pawls drag across the ratchet plate. After the motor has slowed and come to a stop, the dropped pawls engage the ratchet plate and, as the motor tends to rotate in the opposite direction, the ratchet plate also rotates until it is stopped by the shock absorbers. The rotor remains in this position until the motor is energized again. When the motor is started, the ratchet plate is returned to its original position by the spring return. As the motor begins to rotate, the pawls drag over the ratchet plate. When the motor reaches sufficient speed, the pawls are bounced into an elevated position and are held in that position by friction resulting from centrifugal forces acting upon the pawls. While the motor is running at speed, there is no contact between the pawls and ratchet plate.

Considerable plant experience with the design of the antireverse rotation device has shown high reliability of operation.

5.4.1.3.10 Shaft Seal Leakage

During normal operation, leakage along the reactor coolant pump shaft is controlled by three shaft seals arranged in series so that reactor coolant leakage to the containment is essentially zero. Injection flow is directed to each reactor coolant pump via a seal water injection filter. It enters the pumps through a connection of the thermal barrier flange and flows to an annulus around the shaft inside the thermal barrier. Here the flow splits: a portion flows down the shaft to cool the bearing and enters the RCS; the remainder flows up the shaft through the seals. This flow provides a backpressure on the number 1 seal and a controlled flow through the seal. Above the seal, most of the flow leaves the pump via the number 1 seal discharge line. Minor flow passes through the number 2 seal and leakoff line. A back flush injection from a head tank flows into the number 3 seal between its "double dam" seal area. At this point, the flow divides with half flushing through one side of the seal and out the number 2 seal leakoff while the remaining half

flushes through the other side and out of the number 3 seal leakoff. This arrangement assures essentially zero leakage of reactor coolant or trapped gases from the pump.

In the event of a loss of all AC power and/or loss of all seal cooling, reactor coolant begins to travel along the RCP shaft and displace the cooler seal injection water. The shutdown seal (SDS) actuates once the number 1 seal package temperature reaches the SDS actuation temperature. SDS actuation controls shaft seal leakage and limits the loss of reactor coolant through the RCP seal package.

5.4.1.3.11 Seal Discharge Piping

The number 1 seal reduces the coolant pressure to that of the volume control tank. Water from each pump number 1 seal is piped to a common manifold, through the seal water return filter, and through the seal water heat exchanger where the temperature is reduced to that of the volume control tank. The number 2 and number 3 leakoff lines dump number 2 and 3 seal leakage to the reactor coolant drain tank and the containment sump, respectively.

5.4.1.4 Tests and Inspections

The reactor coolant pumps can be inspected in accordance with the ASME Code, Section XI, for inservice inspection of nuclear reactor coolant systems.

The pump casing is cast in one piece, eliminating welds in the casing. Support feet are cast integral with the casing to eliminate a weld region.

The design enables disassembly and removal of the pump internals for usual access to the internal surfaces of the pump casing.

The reactor coolant pump quality assurance program is given in **Table 5.4-2**.

5.4.1.5 Pump Flywheels

5.4.1.5.1 Pump Flywheel Integrity

The integrity of the reactor coolant pump flywheel is assured on the basis of the following design and quality assurance procedures.

5.4.1.5.2 Design Basis

The calculated stresses at operating speed are based on stresses due to centrifugal forces. The stress resulting from the interference fit of the flywheel on the shaft is less than 2,000 psi at zero speed, but this stress becomes zero at approximately 600 rpm because of radial expansion of the hub. The primary coolant pumps run at approximately 1,190 rpm and may operate briefly at overspeeds up to 109 percent (1,295 rpm) during loss of load. For conservatism, however, 125 percent of operating

speed was selected as the design speed for the primary coolant pumps. The flywheels are given a preoperational test of 125 percent of the maximum synchronous speed of the motor.

5.4.1.5.2.1 Fabrication and Inspection

The flywheel consists of two thick plates bolted together. The flywheel material is produced by a process that minimizes flaws in the material and improves its fracture toughness properties, such as vacuum degassing, vacuum melting, or electroslag remelting. Each plate is fabricated from SA-533, Grade B, Class 1 steel. Supplier certification reports are available for all plates and demonstrate the acceptability of the flywheel material on the basis of the requirements of Regulatory Guide 1.14.

Flywheel blanks are flame-cut from the SA-533, Grade B, Class 1 plates with at least 1/2 inch of stock left on the outer and bore radii for machining to final dimensions. The flywheel plates, both before and after assembly, are subjected to magnetic particle or liquid penetrant examination. Included in this examination are all surfaces within a minimum radial distance of 4 inches beyond the final machined bore. This includes the bore surface and the keyways. The finished flywheels, as well as the flywheel material (rolled plate), are subjected to 100-percent volumetric ultrasonic inspection, using procedures and acceptance standards specified in Section III of the ASME Code.

5.4.1.5.2.2 Material Acceptance Criteria

The reactor coolant pump motor flywheel conforms to the following material acceptance criteria:

- a. The nil-ductility transition temperature (NDTT) of the flywheel material is obtained by two drop weight tests (DWT) which exhibit "no-break" performance at 20°F in accordance with ASTM E-208. The above drop weight tests demonstrate that the NDTT of the flywheel material is no higher than 10°F.
- b. A minimum of three Charpy V-notch impact specimens from each plate shall be tested at ambient (70°F) temperature in accordance with the specification ASME SA-370. The Charpy V-notch (C_V) energy in both the parallel and normal orientation with respect to the rolling direction of the flywheel material is at least 50 foot pounds at 70°F, and, therefore, an RT_{NDT} of 10°F can be assumed. An evaluation of flywheel overspeed has been performed which concludes that flywheel integrity will be maintained (Ref. 1).

Thus, it is concluded that flywheel plate materials are suitable for use on the bases of the suppliers' certification data. The degree of compliance with Regulatory Guide 1.14 is further discussed in [Appendix 3A](#).

5.4.1.5.2.3 Accessability

The reactor coolant pump motors are designed so that, by removing the cover to provide access, the flywheel is available to allow an inservice inspection program in accordance with requirements of Section XI of the ASME Code and the recommendations of Regulatory Guide 1.14.

5.4.1.5.2.4 Spin Testing

Each flywheel assembly is spin tested at the design speed of the flywheel, i.e., 125 percent of the maximum synchronous speed of the motor.

5.4.1.5.3 Preservice Inspection

Post spin testing of reactor coolant pump flywheels is discussed in [Appendix 3A](#) under the response to Regulatory Guide 1.14.

5.4.1.5.4 Inservice Inspection

The reactor coolant pump flywheels will be inspected inservice in accordance with the recommendations given in Regulatory Guide 1.14, "Reactor Coolant Pump Flywheel Integrity," Revision 1, August 1975. A description of the inspections is included in Technical Specification 5.5.7.

5.4.2 STEAM GENERATORS

5.4.2.1 Design Bases

Steam generator design data are given in [Table 5.4-3](#). Code classifications of the steam generator components are given in [Section 3.2](#). Although the ASME classification for the secondary side is specified to be Class 2, all pressure-retaining parts of the steam generator, and thus both the primary and secondary pressure boundaries, are designed to satisfy the criteria specified in Section III of the ASME Code for Class 1 components. The design stress limits, transient conditions, and combined loading conditions applicable to the steam generator are discussed in [Section 3.9\(N\).1](#). Estimates of radioactivity levels anticipated in the secondary side of the steam generators during normal operation and the bases for the estimates are given in [Chapter 11.0](#). The accident analysis of a steam generator tube rupture is discussed in [Chapter 15.0](#).

The internal moisture separation equipment is designed to ensure that moisture carryover does not exceed 0.1 percent by weight under the following conditions:

- a. Steady state operation up to 100 percent of full load steam flow, with water at the normal operating level.

- b. Loading or unloading at a rate of 5 percent of full power steam flow per minute in the range from 15 to 100 percent of full load steam flow.
- c. A step load change of 10 percent of full power in the range from 15 to 100 percent full load steam flow.

The water chemistry on the reactor side is selected to provide the necessary boron content for reactivity control and to minimize corrosion of RCS surfaces. The water chemistry of the steam side and its effectiveness in corrosion control are discussed in [Chapter 10.0](#). Compatibility of steam generator tubing with both primary and secondary coolants is discussed further in [Section 5.4.2.3.2](#).

The steam generator is designed to prevent unacceptable damage from mechanical or flow-induced vibration. Tube support adequacy is discussed in [Section 5.4.2.5.3](#). The tubes and tube sheet are analyzed and confirmed to withstand the maximum accident loading conditions as they are defined in [Section 3.9\(N\).1](#). Further consideration is given in [Section 5.4.2.5.4](#) to the effect of tube wall thinning on accident condition stresses.

Access is provided to the primary side channel heads of the steam generator in order to permit inservice inspection and tube plugging/sleaving, when required. Access is provided to the shell side of the steam generator in the region of the tube sheet and flow distribution baffle in order to permit inservice inspection and removal of accumulated sludge.

5.4.2.2 Design Description

The steam generator is an Areva Model 73/19T, vertical shell and U-tube evaporator, with integral moisture separating equipment. [Figure 5.4-3](#) illustrates the design, indicating several of its design features which are described in the following paragraphs.

On the primary side, the reactor coolant flows through the inverted U-tubes, entering and leaving through nozzles located in the hemispherical bottom head of the steam generator. The head is divided into inlet and outlet chambers by a vertical divider plate extending from the apex of the head to the tube sheet.

Steam is generated on the shell side, flows upward, and exits through the outlet nozzle at the top of the vessel. Feedwater enters the steam generator at an elevation above the top of the U-tubes, through the feedwater nozzle. The water is distributed circumferentially around the steam generator by means of a feedwater ring and then flows downward through an annulus between the tube wrapper and shell. The distribution of feedwater is offset, with a greater volume of feedwater supplied to the other side of the tube bundle. The feedwater enters the ring via an anti-stratification helix inlet and it leaves through inverted "J-nozzle" tubes located that flow holes, which are at the top of the ring. These features are designed to prevent a condition which can result in water hammer occurrences in the feedwater piping. The steam water mixture from the tube bundle rises into the steam drum section, where 16 individual centrifugal moisture

separators remove most of the entrained water from the steam. The steam continues to the secondary separators, which remove most of the remaining moisture and provide a quality of at least 99.9 percent. The separated water is combined with entering feedwater to flow back down the annulus between the wrapper and the shell for recirculation through the steam generator. The dry steam exists from the steam generator through the outlet nozzle which is provided with a steam flow restriction.

A major design feature is the use of improved material for steam generator tubing. The tubing material is Inconel 690 Thermally Treated (TT) tubing. Improved fabrication processes were also used to increase tube reliability. The tube heat transfer surface area is approximately 80,000 ft².

The holes in the tube support plates of the Model 73/19T generator have three-lobe shape that provides three lands to support the tube laterally. The holes are fabricated by drilling, followed by broaching.

The tubes are seal welded to the tube sheet cladding. Fusion welds are performed in compliance with Section III and IX of the ASME Code and are dye penetrant inspected and leakproof tested. After welding, each tube is hydraulically expanded for the full depth of the tube sheet to the secondary surface to eliminate crevices between the tube and tube sheet.

The steam generators are fabricated from all forged components. The reactor coolant portion of the steam generator consists of a low alloy steel forged channel head with two integral nozzles connecting it to the reactor coolant system. The primary channel head is also self-draining which eliminates a channel head drain line and electro-polished to enhance decontamination efforts during inspections. The secondary portion of the steam generator consists of a boiling region and a steam drum, also fabricated from full forgings. The steam drum consists of two cylindrical shells, including the feedwater nozzle and two 16" diameter Manway openings.

The Model 73/19T steam generator has a mass circulation ratio of 4.0. The circulation ratio is the total mass flow through the tube bundle divided by the steam outlet mass flow. The benefits of a high circulation ratio include 1) a reduced precipitate deposit as a result of reduced quality and increased liquid velocity, 2) increased water level control during transients due to less void and lower volume displacement, and 3) an improved blowdown efficiency as the recirculated downcomer fluid is less diluted by relatively clean feedwater.

The Model 73/19T also has an integrated foreign object capture system and a grooved-ring nozzle dam retention system. The foreign object capture system acts as a filter for foreign objects in feedwater before the feedwater reaches the tubes. This system is used to preclude tube damage. The grooved-ring retention system is located in the primary channel head at the top of the entrance and exit nozzles. This ring provides for quick installation of nozzle dams to facilitate tube inspections.

5.4.2.3 Steam Generator Materials

5.4.2.3.1 Selection and Fabrication of Materials

All pressure boundary materials used in the steam generator are selected and fabricated in accordance with the requirements of Section III of the ASME Code. A general discussion of materials specifications is given in [Section 5.2.3](#), with types of materials listed in [Tables 5.2-2](#) and [5.2-3](#). Fabrication of reactor coolant pressure boundary materials is also discussed in [Section 5.2.3](#), particularly in [Section 5.2.3.3](#) and [5.2.3.4](#).

The steam generator materials are carbon steel, except for the tubes, tube sleeves, tube support plates, flow distribution baffle, antivibration bars, and the channel head divider plate. The interior surfaces of the reactor coolant channel head, nozzles, and manways are clad with austenitic stainless steel. The primary side of the tube sheet is weld clad with Inconel (ASME SFA-5.14). The tubes are Inconel-690, a nickel-chromium-iron alloy (ASME SB-163). The channel head divider plate is Inconel (SB-168). Tube support plates are ferritic stainless steel (Type 410).

Code cases used in material selection are discussed in [Section 5.2.1](#). The extent of conformance with Regulatory Guides 1.84 and 1.85 is discussed in [Appendix 3A](#).

During manufacture, cleaning is performed on the primary and secondary sides for the steam generator, in accordance with written procedures which follow the guidance of Regulatory Guide 1.37 and the ANSI Standard N45.2.1-1973, "Cleaning of Fluid Systems and Associated Components for Nuclear Power Plants." Onsite cleaning and cleanliness control also follow the guidance of Regulatory Guide 1.37, as discussed in [Appendix 3A](#). Cleaning process specifications are discussed in [Section 5.2.3.4](#).

The fracture toughness of the materials is discussed in [Section 5.2.3.3](#). Adequate fracture toughness of ferritic materials in the reactor coolant pressure boundary is provided by compliance with Appendix G of 10 CFR 50 and with Paragraph NB-2300 of Section III of the ASME Code. As discussed in [Section 5.4.2.1](#), consideration of fracture toughness is only necessary for materials in Class 1 components.

5.4.2.3.2 Compatibility of Steam Generator Tubing with Primary and Secondary Coolants

As mentioned in [Section 5.4.2.3.1](#), corrosion tests, which subjected the steam generator tubing material, Inconel-690 (ASME SB-163), to simulated steam generator water chemistry, have indicated that the loss due to general corrosion over the 40-year plant life is insignificant, compared to the tube wall thickness. Testing to investigate the susceptibility of heat exchanger construction materials to stress corrosion in caustic and chloride aqueous solutions has indicated that Inconel-690 has excellent resistance to general and pitting type corrosion in severe operating water conditions. Many reactor years of successful operation have shown the same low general corrosion rates as indicated by the laboratory tests.

Adoption of the all volatile treatment (AVT) chemistry control program eliminates the possibility for recurrence of the tube wall thinning phenomenon related to phosphate chemistry control.

Successful AVT operation requires maintenance of low concentration of impurities in the steam generator water, thus reducing the potential for formation of highly concentrated solutions in low flow zones, which is the precursor of corrosion. By restriction of the total alkalinity in the steam generator and prohibition of extended operation with free alkalinity, the AVT control program minimizes the possibility for occurrence of intergranular corrosion in localized areas due to excessive levels of free caustic.

Additional extensive operating data are presently being accumulated with the conversion to AVT chemistry. A comprehensive program of steam generator inspections, in accordance with the Technical Specification, will ensure detection and correction of any unanticipated degradation that might occur in the steam generator tubing.

Another corrosion-related phenomenon, termed tube denting, was first discovered during the April 1975 steam generator inspection at the Surry Unit No. 2 plant. This discovery was evidenced by eddy current signals resembling those produced by scanning dents and by difficulty in passing the standard eddy current probe through the tubes at the intersections with the support plates. Subsequent to the initial finding, steam generator inspections at other operating plants revealed indications of denting to various degrees.

An intensive program of investigations, which has included removal of dented tubes and tube/support plate samples from affected steam generators and laboratory tests of heated crevices and model boilers, has revealed that the source of tube denting is corrosion of the carbon steel tube support plate (TSP) in the crevices between the tube and TSP. The corrosion rate in these locations is apparently accelerated by deposition of impurities from the secondary fluid, caused by low flow velocity and superheated fluid in the crevice. The corrosion product has a larger volume than the base metal. The results are simultaneous reduction of the tube diameter, dilation of the hole in the TSP, and secondary effects (e.g., TSP distortions) related to dilation of the TSP holes. Denting has been most pronounced in plants having a history of chloride contamination resulting from condenser leakage. The presence of acid chloride has been found to be a common factor in tube denting produced in laboratory tests. Measures to inhibit denting concentrate on providing a more corrosion resistant TSP material and on eliminating conditions conducive to corrosion at the tube support locations (e.g., chemical impurities in the secondary fluid and localized superheat).

The tube support plates used in the Model 73/19T steam generator are Type 410 ferritic stainless steel which has been shown in laboratory tests to be resistant to corrosion in the AVT environment. When corrosion of ferritic stainless steel does occur, the volume of the corrosion products is equivalent to the volume of the parent material. Thus, substitution of Type 410 ferritic stainless steel for carbon steel used in previous steam generators substantially reduces the potential for tube denting.

Other features of the Model 73/19T generator further reduce the potential for tube denting. The trifoil geometry of the tube support plates is less susceptible to the accumulation of corrosion products which cause tube denting. The trifoil geometry also results in a reduced fluid pressure drop across the tube support plates and, therefore, a higher recirculation ratio and higher fluid velocities in the tube bundle.

Operating experience, verified in numerous steam generator inspections, indicates that the tube degradation associated with phosphate water treatment is not occurring where only AVT has been utilized. Adherence to the AVT chemical specifications and close monitoring of the condenser integrity will assure the continued good performance of the steam generator tubing.

5.4.2.3.3 Control of Secondary-Side Impurities

Several provisions exist in the SNUPPS plants to limit the accumulations of impurities in the steam generator, either by limiting ingress or by facilitating removal. The materials of construction of the secondary system are such as to minimize the formation of corrosion products. The materials include stainless steel tubing in all feedwater heaters and Corten tubing in the moisture-separator-reheaters. A full-flow condensate demineralizer system is provided. A piping connection is provided from the feedwater heater, ahead of the steam generators, to the condenser hot well. During startup, this connection is used to circulate secondary system water through the condensate demineralizers. The flow circulation removes suspended corrosion products that may have accumulated during extended shutdowns.

For removal of impurities, the blowdown system has a capacity slightly in excess of 1 percent of full-load feedwater flow. As described in [Section 5.4.2.2](#) and [5.4.2.3.2](#), the design of the Model 73/19T steam generator is expected to result in an increased efficiency of impurity removal by the blowdown system.

The feedwater system materials are discussed in [Section 10.4.7](#), the steam generator blowdown system is discussed in [Section 10.4.8](#), and the condensate demineralizer system is discussed in [Section 10.4.6](#). Instrumentation to monitor secondary side water chemistry is described in [Section 9.3.2](#).

During shutdowns, sludge lancing may be used to remove accumulated material. In sludge lancing, a hydraulic jet is inserted through an access opening (handhole) to loosen sludge deposits, which are removed by means of a suction pump.

5.4.2.4 Steam Generator Inservice Inspection

The steam generator and associated insulation is designed to permit inspection of Class 1 and 2 parts, including individual tubes. The design includes a number of openings to provide access to both the primary and secondary sides of the steam generator, and the inspection program followed complies with Section XI of the ASME Code, including addenda per 10 CFR 50.55a (g) with certain exceptions whenever specific written relief

is granted by the NRC per 10 CFR 50.55a (g) (6). These openings include four manways, two for access to both chambers of the reactor coolant channel head inlet and outlet sides and two in the steam drum for inspection and maintenance of the moisture separators, six 6-inch handholes above the top of the tube sheet, and 12 2-inch inspection ports located between each tube support plate elevation. Access to the tube U-bend is provided through the deck plates and wrapper canopy. For proper functioning of the steam generator, some of the deck plate openings are covered with welded, but removable, hatch plates. Inspection/access to the primary side is provided by two 16-inch manways located in the channel head.

The insulation in the area of circumferential welds, including tube-sheet-to-head or shell welds, primary nozzle-to-vessel head welds and nozzle-to-head inside radiused sections; primary nozzle-to-safe end welds; integrally welded vessel supports, circumferential butt welds, and nozzle-to-vessel welds on the secondary side is removable. The pressure-retaining bolting can be removed for examination. Manways in the primary head allow direct visual examination of the head cladding. The manways allow sufficient access for the installation of the remotely operated eddy current equipment capable of performing inservice inspections.

5.4.2.4.1 Compliance with Section XI of the ASME Code

Eddy current examinations of steam generator tubing/sleeves are performed in accordance with Appendix IV to Section XI of the ASME Boiler and Pressure Vessel Code.

Other Class 1 and Class 2 components of the steam generators are examined in accordance with the requirements of the ASME Boiler and Pressure Vessel Code, Section XI. The inservice inspection program of Class 1 components of the steam generators is described in [Section 5.2.4](#). The inservice inspection of Class 2 components of the steam generators is discussed in [Section 6.6](#).

5.4.2.4.2 Program for Inservice Inspection of Steam Generator Tubing

Steam generator tubing is inspected in accordance with Technical Specifications. This guide covers the inspection equipment, baseline inspections, tube selection, sampling and frequency of inspection, methods of recording, and required actions based on findings. The design of the steam generators permits inservice inspection, plugging and/or sleeving, if required, of each tube. Regulatory Guide 1.121 and the Technical Specifications provide recommendations concerning tube plugging.

The remotely operated equipment is capable of examining the entire length of the tubes.

All original examination data, results, and reports are stored in a fireproof facility and in an atmosphere controlled to minimize deterioration. The data is stored in a limited-access facility and retained for the operating life of the plant.

Standards consisting of similar as-manufactured steam generator tubing with known imperfections are used to establish sensitivity and to calibrate the equipment. Where practical, these standards include reference flaws that simulate the length, depth, and shape of actual imperfections that are characteristic of past experience.

Personnel engaged in taking or interpreting data are tested and qualified in accordance with ANSI/ASNT CP-189 and supplements designated by the Edition and Addenda of Section XI used during the examination. Procedures governing the above examinations are qualified prior to examination in the plant.

All of the tubes or tube sleeves in the steam generators shall be inspected by eddy current prior to service to establish a baseline condition of the tubing.

The sample selection and testing of tubes, the inspection intervals, and the actions to be taken if defects are identified will follow the Steam Generator Program in the Technical Specifications.

5.4.2.5 Design Evaluation

Seismic and LOCA loads are discussed in [Section 3.9\(N\)](#).

5.4.2.5.1 Forced Convection of Reactor Coolant

The limiting case for heat transfer capability is the "nominal 100-percent design" case. The steam generator effective heat transfer coefficient is based on the coolant conditions of temperature and flow for this case. The best estimate for the heat transfer coefficient applied in steam generator design calculations and plant parameters selection is 1406 Btu/hr-ft²-°F. The coefficient incorporates a specified fouling factor resistance of 0.00005 hr-ft²-°F/Btu, which is the value selected to account for the differences in the measured and calculated heat transfer performance as well as provide the margin indicated above. Although margin for tube fouling is available, operating experience to date has not indicated that steam generator performance decreases over a long-time period. Adequate tube area is selected to ensure that the full design heat removal rate is achieved.

5.4.2.5.2 Natural Circulation of Reactor Coolant

The driving head created by the change in coolant density as it is heated in the core and rises to the outlet nozzle initiates convection circulation. This circulation is enhanced by the fact that the steam generators, which provide a heat sink, are at a higher elevation than the reactor core, which is the heat source. Natural circulation is sufficient for the removal of decay heat during hot shutdown and cooldown in the event of a loss of forced circulation.

5.4.2.5.3 Mechanical and Flow-Induced Vibration Under Normal Operation

The possibility of vibratory failure of tubes due to either mechanical or flow-induced excitation has been thoroughly evaluated. This evaluation includes detailed analysis of the tube support systems as well as an extensive research program with tube vibration model tests.

In evaluating possible failure due to vibration, consideration is given to such sources of excitation as those generated by the primary fluid flowing within the tubes. The effects of these as well as any other mechanically induced vibrations are considered to be negligible and should cause little concern.

Another source of possible vibratory failure in heat exchanger components is hydrodynamic excitation by the secondary fluid on the outside of the tubes.

Consideration of secondary flow-induced vibration involves two types of flow, parallel and cross, and it is evaluated in three regions:

- a. At the entrance of the downcomer feed to the tube bundle (cross flow)
- b. Along the straight sections of the tube (parallel flow)
- c. In the curved tubed section of the U-bend (cross flow)

For the case of parallel flow, analysis is done to determine the vibratory deflections in order to verify that the flow velocities are sufficiently below those required for damaging fatigue or impacting vibratory amplitude. Thus, the support system is deemed adequate to preclude parallel flow excitation.

For the case of cross-flow excitation, several possible mechanisms of tube vibration exist. For the Model 73/19T steam generator design and conditions, only two of these mechanisms are deemed significant enough to merit extensive consideration: 1) turbulence and 2) fluidelastic vibration. The steam generator is analyzed to ensure that the turbulence flow velocity is acceptable and that unstable fluidelastic vibration does not exist. In order to achieve this, adequate tube supports must be provided. An evaluation using the specific parameters for the Model 73/19T steam generator confirms the integrity of the support system.

Assurance against damaging flow induced tube vibration has been accomplished by a combination of analysis and testing. Cross and parallel flow velocities were calculated from thermal-hydraulic analysis of the secondary flow. Three possible vibrational mechanisms, vortex shedding, fluidelastic excitation, and turbulence were studied.

Tests carried out on the tube bundle geometry showed no vortex shedding for small pitch ratios.

For fluidelastic excitation, the ratios of the effective cross flow velocity to the critical velocity were calculated. The results indicate that no critical excitation will occur during steady state conditions as well as operational transients.

Turbulence responses are low and therefore risk of fatigue due to turbulent flow is excluded.

5.4.2.5.4 Allowable Tube Wall Thinning Under Accident Conditions

An evaluation is performed to determine the extent of tube wall thinning that can be tolerated under accident conditions. The worst-case loading conditions are assumed to be imposed upon uniformly thinned tubes, at the most critical location in the steam generator. Under such a postulated design basis accident, vibration is of short enough duration that there is no endurance problem to be considered. The steam generator tubes, existing originally at their minimum wall thickness and reduced by a conservative general corrosion and erosion loss, can be shown to provide an adequate safety margin, that is, sufficient wall thickness, in addition to the minimum required for a maximum stress less than the allowable stress limit, as it is defined by the ASME Code.

5.4.2.6 Quality Assurance

The steam generator nondestructive examination program is given in [Table 5.4-4](#).

Radiographic inspection and acceptance standards are in accordance with the requirements of Section III of the ASME Code.

Liquid penetrant inspection is performed on weld deposited tube sheet cladding, channel head cladding, divider plate to tube sheet and to channel head weldments, tube-to-tube sheet weldments, and weld deposit cladding. Liquid penetrant inspection and acceptance standards are in accordance with the requirements of Section III of the ASME Code.

Magnetic particle inspection is performed on the tube sheet forging, channel head casting, nozzle forgings, and the following weldments:

- a. Nozzle to shell
- b. Support brackets
- c. Instrument connection (secondary)
- d. Temporary attachments after removal
- e. All accessible pressure retaining welds after hydrostatic test

Magnetic particle inspection and acceptance standards are in accordance with the requirements of Section III of the ASME Code.

Ultrasonic tests are performed on the tube sheet forging, tube sheet cladding, secondary shell and head plate, and nozzle forgings.

The heat transfer tubing is subjected to eddy current testing.

Hydrostatic tests are performed in accordance with Section III of the ASME Code.

5.4.3 REACTOR COOLANT PIPING

5.4.3.1 Design Bases

The RCS piping is designed and fabricated to accommodate the system pressures and temperatures attained under all expected modes of plant operation or anticipated system interactions. Stresses are maintained within the limits of Section III of the ASME Code. Code and material requirements are provided in [Section 5.2](#).

Materials of construction are specified to minimize corrosion/ erosion and ensure compatibility with the operating environment. The piping in the RCS is Safety Class 1 and is designed and fabricated in accordance with ASME Code, Section III, Class 1 requirements.

Stainless steel pipe conforms to ANSI B36.19 for sizes 1/2 inch through 12 inches and wall thickness Schedules 40S through 80S. Stainless steel pipe outside of the scope of ANSI B36.19 conforms to ANSI B36.10.

The minimum wall thicknesses of the loop pipe and fittings are no less than those calculated using the ASME Code, Section III, Class 1 formula of Paragraph NB-3641.1(3) with an allowable stress value of 17,550 psi. The pipe wall thickness for the pressurizer surge line is Schedule 160. The minimum pipe bend radius is 5 nominal pipe diameters, and ovality does not exceed 6 percent.

All butt welds, branch connection nozzle welds, and boss welds are of a full penetration design.

Full structural weld overlays (FSWOLs) have been installed on the dissimilar metal welds and adjacent stainless steel welds of the pressurizer surge, spray, safety and relief nozzles.

Processing and minimization of sensitization are discussed in [Section 5.2.3](#)

Flanges conform to ANSI B16.5.

Socket weld fittings and socket joints conform to ANSI B16.11.

Inservice inspection is discussed in [Section 5.2.4](#).

5.4.3.2 Design Description

The RCS piping includes those sections of piping interconnecting the reactor vessel, steam generator, and reactor coolant pump. It also includes the following:

- a. Charging line and alternate charging line from the system isolation valve up to the branch connections on the reactor coolant loop
- b. Letdown line and excess letdown line from the branch connections on the reactor coolant loop to the system isolation valve
- c. Pressurizer spray lines from the reactor coolant cold legs to the spray nozzle on the pressurizer vessel
- d. Residual heat removal lines to or from the reactor coolant loops up to the designated check valve or isolation valve
- e. Safety injection lines from the designated check valve to the reactor coolant loops
- f. Accumulator lines from the designated check valve to the reactor coolant loops
- g. Loop fill, loop drain, sample*, and instrument* lines to or from the designated isolation valve to or from the reactor coolant loops
- h. Pressurizer surge line from one reactor coolant loop hot leg to the pressurizer vessel inlet nozzle
- i. Resistance temperature detector scoop element, pressurizer spray scoop, sample connection* with scoop, reactor coolant temperature element installation boss, and the temperature element thermowell itself
- j. All branch connection nozzles attached to reactor coolant loops
- k. Pressure relief lines from nozzles on top of the pressurizer vessel up to and through the power operated pressurizer relief valves and pressurizer safety valves

* Lines with a 3/8-inch (liquid service) or less flow restricting orifice qualify as Safety Class 2. In the event of a break in one of these Safety Class 2 lines, the normal makeup system is capable of providing makeup flow while maintaining pressurizer water level.

- I. Seal injection water lines to the reactor coolant pump to the designated check valve (injection line)
- m. Auxiliary spray line from the isolation valve to the pressurizer spray line header
- n. Sample lines* from pressurizer to the isolation valve
- o. Reactor vessel head vent lines* to the isolation valves

Principal design data for the reactor coolant piping are given in [Table 5.4-5](#).

Details of the materials of construction and codes used in the fabrication of reactor coolant piping and fittings are discussed in [Section 5.2](#).

The reactor coolant piping and fittings which make up the loops are austenitic stainless steel. Pipe and fittings are cast, seamless without longitudinal or electroslag welds, and comply with the requirements of the ASME Code, Section II (Parts A and C), Section III, and Section IX. All smaller piping which is part of the RCS, such as the pressurizer surge line, spray and relief line, loop drains and connecting lines to other systems, are also austenitic stainless steel. The nitrogen supply line for the pressurizer relief tank is carbon steel. All joints and connections are welded, except for the pressurizer code safety valves, where flanged joints are used. A thermal sleeve is installed on the pressurizer spray line nozzle.

All piping connections from auxiliary system are above the horizontal centerline of the reactor coolant piping, with the exception of:

- a. Residual heat removal pump suction lines, which are 45 degrees down from the horizontal centerline. This enables the water level in the RCS to be lowered in the reactor coolant pipe while continuing to operate the residual heat removal system, should this be required for maintenance.
- b. Loop drain lines.
- c. The differential pressure taps for flow measurement, which are downstream of the steam generators of the first 90-degree elbow.
- d. The pressurizer surge line, which is attached at the horizontal centerline.
- e. Two of the three scoops in each resistance temperature detector hot leg connection.
- f. The hot leg sample connections, the loop 3 thermowell, and the loop 4 boron injection connection, all located on the horizontal centerline.

- g. The connections for measurement of water level in the RCS during refueling and maintenance operation.

Penetrations into the coolant flow path are limited to the following:

- a. The spray line inlet connections extend into the cold leg piping in the form of a scoop so that the velocity head of the reactor coolant loop flow adds to the spray driving force.
- b. The reactor coolant sample system taps protrude into the main stream to obtain a representative sample of the reactor coolant.
- c. The hot leg connections to the resistance temperature detectors have scoops which extend into the reactor coolant to collect a representative temperature sample for the individual hot leg resistance temperature detectors.
- d. The wide range temperature detectors are located in resistance temperature detector wells that extend into both the hot and cold legs of the reactor coolant pipes.

One hot leg and one cold leg temperature reading are provided from each coolant loop to use for protection. Narrow range, thermowell-mounted Resistance Temperature Detectors (RTDs) are provided for each coolant loop. In the hot legs, sampling scoops are used because the flow is stratified. That is, the fluid temperature is not uniform over a cross section of the hot leg. One dual element RTD is mounted in a thermowell in each of the three sampling scoops associated with each hot leg. The scoops extend into the flow stream at locations 120° apart in the cross sectional plane. Each scoop has five orifices which sample the hot leg flow along the leading edge of the scoop. Outlet ports are provided in the scoops to direct the sampled fluid past the sensing element of the RTDs. One of each of the RTD's dual elements is used while the other is an installed spare. Three readings from each hot leg are averaged to provide a hot leg reading for that loop.

One dual element RTD is mounted in a thermowell associated with each cold leg. No flow sampling is needed because coolant flow is well mixed by the reactor coolant pumps. One RTD element is used while the other is an installed spare.

The thermowells are pressure boundary parts which completely enclose the RTD. They have been shop hydrotested to 1.25 times the RCS design pressure. The external design pressure and temperature are the RCS design temperature and pressure. The RTD is not part of the pressure boundary. The scoop, thermowell, and thermowell/scoop assembly have been analyzed to the ASME Boiler and Pressure Vessel Code, Section III, Class 1. The effects of seismic and flow-induced loads were considered in the design.

Signals from the temperature detectors are used to compute the reactor coolant ΔT (temperature of the hot leg, T_{hot} , minus the temperature of the cold leg, T_{cold}) and an average reactor coolant temperature (T_{avg}). The T_{avg} for each loop is indicated on the main control board.

5.4.3.3 Design Evaluation

Piping load and stress evaluation for normal operating loads, seismic loads, blowdown loads, and combined normal, blowdown, and seismic loads is discussed in [Section 3.9\(N\)](#).

5.4.3.3.1 Material Corrosion/Erosion Evaluation

The water chemistry is selected to minimize corrosion. A periodic analysis of the coolant chemical composition is performed to verify that the reactor coolant quality meets the specifications (see [Section 5.2.3](#)).

Periodic analysis of the coolant chemical composition is performed to monitor the adherence of the system to desired reactor coolant water quality listed in [Table 5.2-5](#). Maintenance of the water quality to minimize corrosion is accomplished, using the chemical and volume control system and sampling system which are described in [Chapter 9.0](#).

The design and construction are in compliance with the ASME Code, Section XI. Pursuant to this, all pressure containing welds out to the second valve that delineates the RCS boundary are accessible for examination and are fitted with removable insulation.

5.4.3.3.2 Sensitized Stainless Steel

Sensitized stainless steel is discussed in [Section 5.2.3](#).

5.4.3.3.3 Contaminant Control

Contamination of stainless steel and Inconel by copper, low melting temperature alloys, mercury, and lead is prohibited. Thread lubricants are approved in accordance with applicable procedures. Prior to application of thermal insulation, the austenitic stainless steel surfaces are cleaned and analyzed to halogen limits as defined by Westinghouse Process Specifications.

5.4.3.4 Tests and Inspections

The RCS piping quality assurance program is given in [Table 5.4-6](#).

Volumetric examination is performed throughout 100 percent of the wall volume of each pipe and fitting in accordance with the applicable requirements of Section III of the ASME

Code for all pipe 27-1/2 inches and larger. All unacceptable defects are eliminated in accordance with the requirements of the same section of the code.

A liquid penetrant examination is performed on both the entire outside and inside surfaces of each finished fitting, in accordance with the criteria of the ASME Code, Section III. Acceptance standards are in accordance with the applicable requirements of the ASME Code, Section III.

The pressurizer surge line conforms to SA-376, Grade 304, 304N, or 316 with supplementary requirements S2 (transverse tension tests) and S6 (ultrasonic test). The S2 requirement applies to each length of pipe. The S6 requirement applies to 100 percent of the piping wall volume.

The end of pipe sections, branch ends, and fittings are machined back to provide a smooth weld transition adjacent to the weld path.

5.4.4 MAIN STEAM LINE FLOW RESTRICTOR

5.4.4.1 Design Basis

The outlet nozzle of the steam generator is provided with a flow restrictor designed to limit steam flow in the unlikely event of a break in the main steam line. A large increase in steam flow will create a backpressure which limits further increase in flow. The flow restrictor performs the following functions: Rapid rise in containment pressure is prevented, the rate of heat removal from the reactor coolant is such as to keep the cooldown rate within acceptable limits, thrust forces on the main steam line piping are reduced, and stresses on internal steam generator components, particularly the tube sheet and tubes, are limited. The restrictor is configured to minimize the unrecovered pressure loss across the restrictor during normal operation.

5.4.4.2 Design Description

The flow restrictor consists of seven Inconel (ASME SB-166) venturi inserts which are installed in holes in an integral low alloy steel forging. The inserts are arranged with one venturi at the centerline of the outlet nozzle and the other six equally spaced around it. After insertion into the low alloy steel forging holes, the Inconel venturi nozzles are welded to the Inconel cladding on the inner surface of the forging.

5.4.4.3 Design Evaluation

The flow restriction design has been analyzed to assure its structural adequacy. The equivalent throat diameter of the steam generator outlet is 16 inches, and the resultant pressure drop through the restrictor at 100-percent steam flow is approximately 3.8 psig. This is based on a design flow rate of 3.99×10^6 lb/hr (see Tables 5.1-1 and 10.3-2 for uprated steam flow rates). Materials of construction and manufacturing of the flow restrictor are in accordance with Section III of the ASME Code.

5.4.4.4 Tests and Inspections

Since the restrictor is not a part of the steam system boundary, no tests and inspection beyond those during fabrication are anticipated.

5.4.5 MAIN STEAM LINE ISOLATION SYSTEM

The main steam line isolation system is discussed in [Section 10.3](#).

5.4.6 REACTOR CORE ISOLATION COOLING SYSTEM

This section is not applicable to SNUPPS.

5.4.7 RESIDUAL HEAT REMOVAL SYSTEM

5.4.7.1 Design Bases

The residual heat removal system (RHRS) functions to remove heat from the RCS when RCS pressure and temperature are below approximately 400 psig and 350°F, respectively. Heat is transferred from the RHRS to the component cooling water system.

Portions of the RHRS also serve as portions of the ECCS during the injection and recirculation phases of a LOCA (see [Section 6.3](#)).

The RHRS also is used to transfer refueling water between the refueling cavity and the refueling water storage tank at the beginning and end of the refueling operations. The RHRS is designed to be isolated from the RCS whenever the RCS pressure exceeds the RHRS design pressure.

5.4.7.2 Design Description

5.4.7.2.1 Functional Design

RHRS design parameters are listed in [Table 5.4-7](#). Nuclear plants employing the same RHRS design as the SNUPPS units are given in [Section 1.3](#).

During normal approaches to cold shutdown, the RHRS is placed in operation approximately 4 hours after reactor shutdown when the temperature and pressure of the RCS are below approximately 350°F and 400 psig, respectively. Assuming that two heat exchangers and two pumps are in service and that each heat exchanger is supplied with component cooling water at design flow and temperature, the RHRS is designed to reduce the temperature of the reactor coolant from 350°F to 140°F within 14.9 hours (See [Figure 5.4-9](#)). The time required, under these conditions, to reduce reactor coolant temperature from 350°F to 212°F is 2.8 hours based on a 50°F/hr cooldown rate. The heat load handled by the RHRS during the cooldown transient includes residual and decay heat from the core and reactor coolant pump heat. The design heat load is based

on the decay heat fraction that exists at 20 hours following reactor shutdown from an extended run at full power. The design heat load used here and in [Section 9.2.5](#) (UHS) is based on the decay heat generation rate of 78.9×10^6 Btu/hr. Based on the MODE 4 ECCS standby alignment requirements of Technical Specification 3.5.3 imposed on one RHR train, as well as procedural requirements related to preventing void formation associated with exceeding saturation conditions in the RHR suction lines from the RWST, the assumption of a two-train cooldown starting at the RHR cut-in conditions does not reflect plant operating practice.

Assuming that only one heat exchanger and pump are in service and that the heat exchanger is supplied with component cooling water at design flow and temperature, the RHRS is capable of reducing the temperature of the reactor coolant from 350°F at 12 hours after shutdown to 200°F at 30.6 hours after shutdown (See [Figure 5.4-10](#)). The time required under these conditions to reduce reactor coolant temperature from 350°F to 212°F is approximately 10 hours.

The RHRS is isolated from the RCS on the suction side by two motor-operated valves in series on each suction line. Each motor-operated valve is interlocked to prevent its opening if RCS pressure is greater than 360 psig. A control room alarm will actuate if an RHR suction isolation valve is not fully closed and RCS pressure is greater than the design pressures for RHR system operation. The RHRS is isolated from the RCS on the discharge side by two check valves in each return line. Also provided on the discharge side is a normally open, motor-operated valve downstream of each RHRS heat exchanger. (These check valves and motor-operated valves are not considered part of the RHRS. They are shown as part of the ECCS, see [Figure 6.3-1](#).)

Each inlet line to the RHRS is equipped with a pressure relief valve designed to relieve the combined flow of all the charging pumps at the relief valve set pressure. These relief valves also protect the system from inadvertent overpressurization during plant cooldown or startup and provide LTOP for the RCS during low temperature water solid operation. Each discharge line from the RHRS to the RCS is equipped with a pressure relief valve designed to relieve the maximum possible backleakage through the valves isolating the RHRS from the RCS.

The RHRS is provided for a single nuclear power unit, and is not shared among nuclear power units.

The RHRS is designed to be fully operable from the control room for normal operation. Manual operations required of the operator are: opening the suction isolation valves, positioning the flow control valves downstream of the RHRS heat exchangers, and starting the residual heat removal pumps. By nature of its redundant two-train design, the RHRS is designed to accept all major component single failures with the only effect being an extension in the required cooldown time. For two low probability electrical system single failures, i.e., failure in the suction isolation valve interlock circuitry or diesel generator failure in conjunction with loss of offsite power, operator action outside the control room is required to open the suction isolation valves. Manual actions are

discussed in further detail in [Sections 5.4.7.2.7](#) and [5.4.7.2.8](#). Spurious operation of a single motor-operated valve can be accepted without loss of function, as a result of the redundant two-train design.

Missile protection, protection against dynamic effects associated with the postulated rupture of piping, and seismic design are discussed in [Sections 3.5, 3.6, and 3.7\(B\)](#), and [3.7\(N\)](#) respectively.

5.4.7.2.2 Piping and Instrumentation Diagrams

The RHRS, as shown in [Figures 5.4-7](#) (piping and instrumentation diagram) and [5.4-8](#) (process flow diagram), consists of two residual heat exchangers, two residual heat removal pumps, and the associated piping, valves, and instrumentation necessary for operational control. The inlet lines to the RHRS are connected to the hot legs of two reactor coolant loops, while the return lines are connected to the cold leg of each of the reactor coolant loops. These return lines are also the ECCS low head injection lines (see [Figure 6.3-1](#)). EJ-HV-8716A and B and EJ-HV-8809A and B are maintained open during operating modes 1-3 in order that either RHR pump is able to inject to all four RCS cold legs.

The RHRS suction lines are isolated from the RCS by two motor-operated valves in series located inside the containment. Each discharge line is isolated from the RCS by two check valves in series located inside the containment and by a normally open motor-operated valve located outside the containment. (The check valves and the motor-operated valve on each discharge line are shown as part of the ECCS, see [Figure 6.3-1](#)).

During RHRS operation, reactor coolant flows from the RCS to the residual heat removal pumps, through the tube side of the residual heat exchangers, and back to the RCS. The heat is transferred to the component cooling water circulating through the shell side of the residual heat exchangers.

Coincident with operation of the RHRS, a portion of the reactor coolant flow may be diverted from downstream of the residual heat exchangers to the chemical and volume control system (CVCS) low pressure letdown line for cleanup and/or pressure control. By regulating the diverted flowrate and the charging flow, the RCS pressure may be controlled. Pressure regulation is necessary to maintain the pressure range dictated by the fracture prevention criteria requirement of the reactor vessel, by the number 1 seal differential pressure, and by net positive suction head requirements of the reactor coolant pumps.

The RCS cooldown rate is manually controlled by regulating the reactor coolant flow through the tube side of the RHR heat exchangers. The flow control valve in the bypass line around each RHR heat exchanger automatically maintains a constant return flow to the RCS. Instrumentation is provided to monitor system pressure, temperature, and total flow.

The RHR system is also used for filling the refueling cavity before refueling. After refueling operations, water is pumped back to the refueling water storage tank until the water level is brought down to the flange of the reactor vessel. The remainder of the water is removed via a drain connection at the bottom of the refueling canal.

When the RHR system is in operation, the water chemistry is the same as that of the reactor coolant. Provision is made for the nuclear sampling system to extract samples from the flow of reactor coolant downstream of the residual heat exchangers. A local sampling point is also provided on each residual heat removal train between the pump and heat exchanger.

The RHR system functions in conjunction with the high head portion of the ECCS to provide direct injection of borated water from the refueling water storage tank into the RCS cold legs during the injection phase following a LOCA. During normal operation, the RHR system is aligned to inject borated water upon receipt of a safety injection signal. EJ-HV-8716A and B and EJ-HV-8809A and B are maintained open during operating modes 1-3 in order that either RHR pump is able to inject to all four RCS cold legs.

In its capacity as the low head portion of the ECCS, the RHR system also provides long-term recirculation capability for core cooling following the injection phase of a LOCA. This function is accomplished by aligning the RHR system to take fluid from the containment sump, cool it by circulation through the residual heat exchangers, and supply it to the core directly as well as via the ECCS centrifugal charging pumps and safety injection pumps.

The use of the RHR system as part of the ECCS is more completely described in [Section 6.3](#).

The RHR pumps, in order to perform their ECCS function, are interlocked to start automatically on receipt of a safety injection signal (see [Section 6.3](#)).

The RHR suction isolation valves in each inlet line from the RCS are separately interlocked to prevent both their being opened when RCS pressure is greater than 360 psig. A control room alarm will actuate if an RHR suction isolation valve is not fully closed and RCS pressure is greater than the design pressures for RHR system operation. These interlocks are described in more detail in [Sections 5.4.7.2.5](#) and [7.6.2](#).

The RHR suction isolation valves are also interlocked to prevent their being opened unless the isolation valves in the following lines are closed:

- a. Recirculation lines from the residual heat exchanger outlets to the suctions of the safety injection pumps and ECCS centrifugal charging pumps
- b. RHR pump suction lines from the refueling water storage tank
- c. RHR pump suction lines from the containment sump

The motor-operated valves in the RHR miniflow bypass lines are interlocked to open when the RHR pump discharge flow is less than approximately 816 gpm at 300°F (783 gpm at 68°F) and close when the flow exceeds approximately 1650 gpm at 300°F (1582 gpm at 68°F).

5.4.7.2.3 Equipment and Component Descriptions

The materials used to fabricate RHRS components are in accordance with the applicable code requirements. All parts of the components in contact with borated water are fabricated or clad with austenitic stainless steel or equivalent corrosion-resistant material. Component parameters are given in [Table 5.4-8](#).

Residual Heat Removal Pumps

Two pumps are installed in the RHRS. The pumps are sized to deliver reactor coolant flow through the RHR heat exchangers to meet the plant cooldown requirements. The use of two separate RHR trains assures that cooling capacity is only partially lost should one pump become inoperative.

The RHR pumps are protected from overheating and loss of discharge flow by miniflow bypass lines. A valve located in each miniflow line is regulated by a signal from the flow indicating switch located in each pump discharge header. The control valves open when the RHR pump discharge flow is less than approximately 816 gpm at 300°F (783 gpm at 68°F) and close when the flow exceeds approximately 1650 gpm at 300°F (1582 gpm at 68°F).

A pressure sensor in each pump discharge header provides a signal for an indicator in the control room. A high pressure alarm is also actuated by the pressure sensor.

The two pumps are vertical, centrifugal units with mechanical seals on the shafts. All pump surfaces in contact with reactor coolant are austenitic stainless steel or equivalent corrosion resistant material.

The RHR pumps also function as the low head safety injection pumps in the ECCS (see [Section 6.3](#) for further information and for the residual heat removal pump performance curves).

Residual Heat Exchangers

Two residual heat exchangers are installed in the system. The heat exchanger design is based on heat load and temperature differences between reactor coolant and component cooling water existing 20 hours after reactor shutdown when the temperature difference between the two systems is small.

The installation of two heat exchangers in separate and independent residual heat removal trains assures that the heat removal capacity of the system is only partially lost if one train becomes inoperative.

The residual heat exchangers are of the shell and U-tube type. Reactor coolant circulates through the tubes, while component cooling water circulates through the shell. The tubes are welded to the tube sheet to prevent leakage of reactor coolant.

The residual heat exchangers also function as part of the ECCS (see [Section 6.3](#)).

Residual Heat Removal System Valves

Valves that perform a modulating function are equipped with two sets of packings and an intermediate leakoff connection that discharges to the drain header.

Manual and motor-operated valves have backseats to facilitate repacking and to limit stem leakage when the valves are open. Leakage connections are provided where required by valve size and fluid conditions.

Encapsulation

The RHR suction lines from the containment recirculation sumps are each provided with a single motor-operated gate valve outside the containment. This valve, including its operator, is encapsulated in a pressure vessel which is leaktight at containment design pressure. The piping from the sump to the valve is also encapsulated in a concentric guard pipe which is leaktight. A leaktight seal is provided so that neither the compartment nor the guard pipe is connected directly to the sump or containment atmosphere. Component parameters for the encapsulation tank are given in [Table 5.4-8](#).

The valve provides a barrier outside the containment to prevent loss of sump water should a leak develop in the recirculation loop. Should a leak develop in the valve body or in the pipe between the valve and the sump, the sump fluid is contained by the leaktight seal and/or by the guard pipe.

Each encapsulated gate valve is installed with a pathway from the valve bonnet to the RHR system piping. This pathway ensures that the internal valve bonnet pressure will never be greater than the RHR system pressure, and thus preclude the formation of pressure locking conditions for these valves.

With this system, no single failure of either an active or a passive component will prevent the recirculation phase or adversely affect the integrity of the containment.

5.4.7.2.4 System Operation

Reactor Startup

Generally, while at cold shutdown condition, decay heat from the reactor core is being removed by the RHRS. The number of pumps and heat exchangers in service depends upon the heat load at the time.

At initiation of the plant startup, the RCS is filled, and the pressurizer heaters are energized. The RHRS is operating and is connected to the CVCS via the low pressure letdown line for purification and/or to control reactor coolant pressure. During this time, the RHRS acts as an alternate letdown path. The manual valves downstream of the residual heat exchangers leading to the letdown line of the CVCS are opened. The control valve in the line from the RHRS to the letdown line of the CVCS is then manually adjusted in the control room to permit letdown flow.

RCS pressure control is maintained via the RHRS and the low pressure letdown line until the pressurizer steam bubble is formed. Indication of steam bubble formation is provided in the control room by the damping out of the RCS pressure fluctuations and by pressurizer level indication for solid plant operation, or by saturation temperature for vacuum fill.

After the pressurizer steam bubble is formed and the reactor coolant pumps are started, the RHRS is isolated from the RCS. RCS pressure is then controlled by normal letdown and the pressurizer spray and pressurizer heaters.

Power Generation and Hot Standby Operation

During power generation and hot standby operation, the RHRS is not in service but is aligned for operation as part of the ECCS. EJ-HV-8716A and B and EJ-HV-8809A and B are maintained open during operating modes 1-3 in order that either RHR pump is able to inject to all four RCS cold legs.

Normal Reactor Cooldown

Reactor cooldown is defined as the operation which brings the reactor from no-load temperature and pressure to cold conditions.

The initial phase of reactor cooldown is accomplished by transferring heat from the RCS to the steam and power conversion system through the use of the steam generators and dumping steam to the condenser.

When the reactor coolant temperature and pressure are reduced below approximately 350°F and 400 psig, approximately 4 hours after reactor shutdown, the second phase of cooldown starts with the RHRS being placed in operation.

Startup of the RHRS includes a warmup period during which time reactor coolant flow through the heat exchangers is limited to minimize thermal shock. The rate of heat removal from the reactor coolant is manually controlled by regulating the coolant flow

through the residual heat exchangers. By adjusting the control valves downstream of the residual heat exchangers, the mixed mean temperature of the return flows is controlled.

Coincident with the manual adjustment, each heat exchanger bypass valve is automatically regulated to give the required total flow.

The reactor cooldown rate is limited by RCS equipment cooling rates based on allowable stress limits, as well as the operating temperature limits of the component cooling water system. As the reactor coolant temperature decreases, the reactor coolant flow through the residual heat exchangers is increased by adjusting the control valve in each heat exchanger's tube side outlet line.

As cooldown continues, pressure control is accomplished by regulating the charging flow rate and the rate of letdown from the RHRSS to the CVCS.

After the reactor coolant pressure is reduced and the temperature is 140°F or lower, the RCS may be opened for refueling or maintenance.

Refueling

Residual heat removal pumps are utilized during refueling to pump borated water from the refueling water storage tank to the refueling cavity. During this operation, the RHRSS isolation valve(s) in the suction line(s) from the RCS are closed, and the isolation valve(s) to the refueling water storage tank are opened.

The reactor vessel head is lifted off the reactor vessel. The refueling water is then pumped into the reactor vessel through the normal RHRSS return lines and into the refueling cavity through the open reactor vessel.

After the water level reaches the normal refueling level, the RHRSS suction isolation valve(s) for the RCS are opened, the refueling water storage tank supply valve(s) is(are) closed, and residual heat removal is resumed.

During refueling, the RHRSS is maintained in service with the number of pumps and heat exchangers in operation as required by the heat load.

Following refueling, the RHR pumps are used to drain the refueling cavity to the top of the reactor vessel flange by pumping water from the RCS to the refueling water storage tank. The vessel head is then replaced and the normal RHRSS flowpath re-established. The remainder of the water is removed from the refueling canal via a drain connection in the bottom of the canal.

5.4.7.2.5 Control

Each inlet line to the RHRSS is equipped with a pressure relief valve sized to relieve the combined flow of all the charging pumps at the relief valve set pressure. These relief

valves also protect the system from inadvertent overpressurization during plant cooldown or startup and provide LTOP for the RCS during low temperature water solid operation. Each valve has a relief flow capacity of 986 gpm at a set pressure of 450 psig.

Each discharge line from the RHR system to the RCS is equipped with a pressure relief valve to relieve any backleakage through the valves separating the RHR system from the RCS. Each valve has a relief flow capacity of 20 gpm at a set pressure of 600 psig. These relief valves are located in the ECCS (see [Figure 6.3-1](#)).

The fluid discharged by the suction side relief valves is collected in the pressurizer relief tank. The fluid discharged by the discharge side relief valves is collected in the recycle holdup tank of the boron recycle system.

The design of the RHR system includes two motor-operated gate isolation valves in series on each inlet line between the high pressure RCS and the lower pressure RHR system. They are closed during normal operations, and are only opened for residual heat removal during a plant cooldown after the RCS pressure is reduced below approximately 400 psig and RCS temperature is reduced to approximately 350°F. During a plant startup, the inlet isolation valves are shut after drawing a bubble in the pressurizer and prior to increasing RCS pressure above 600 psig. These isolation valves are provided with "prevent-open" interlocks which are designed to prevent possible exposure of the RHR system to normal RCS operating pressure. The inlet isolation valves in each subsystem are separately and independently interlocked with pressure signals to prevent their being opened whenever the RCS pressure is greater than 360 psig. A control room alarm will actuate if an RHR suction isolation valve is not fully closed and RCS pressure is greater than the design pressures for RHR system operation.

The use of two independently powered, motor-operated valves in each of the two inlet lines, along with two independent pressure interlock signals for each function, assures a design which meets applicable single failure criteria. These protective interlock designs, in combination with plant operating procedures, provide diverse means of accomplishing the protective function. For further information on the instrumentation and control features, see [Section 7.6.2](#).

The RHR inlet isolation valves are provided with red-green position indicator lights on the main control board.

Isolation of the low pressure RHR system from the high pressure RCS is provided on the discharge side by two check valves in series. These check valves are located in the ECCS, and their testing is described in [Section 6.3.4.2](#).

5.4.7.2.6 Applicable Codes and Classifications

The entire RHR system is designed as Safety Class 2, with the exception of the suction isolation valves, which are Safety Class 1. Class 1 discharge valves are discussed in [Section 6.3](#). Component codes and classifications are given in [Section 3.2](#).

5.4.7.2.7 System Reliability Considerations

General Design Criterion 34 requires that a system to remove residual heat be provided. The safety function of this required system is to transfer fission product decay heat and other residual heat from the core at a rate sufficient to prevent fuel or pressure boundary design limits from being exceeded. Safety grade systems are provided in the plant design, both nuclear steam supply system (NSSS) scope and balance-of-plant (BOP) scope, to perform this function. The NSSS scope safety grade systems which perform this function for all plant conditions, except a LOCA are: the RCS and steam generators, which operate in conjunction with the auxiliary feedwater system and the steam generator safety and power-operated relief valves; and the RHRS, which operates in conjunction with the component cooling water and service water systems. The BOP scope safety grade systems which perform this function for all plant conditions, except a LOCA, are: the auxiliary feedwater system; the steam generator safety and power-operated relief valves, which operate in conjunction with the RCS and the steam generators; and the component cooling water and service water systems, which operate in conjunction with the RHRS. For LOCA conditions, the safety grade system which performs the function of removing residual heat from the reactor core is the ECCS, which operates in conjunction with the component cooling water system and the essential service water system.

The auxiliary feedwater system, along with the steam generator safety and power-operated relief valves, provides a completely separate, independent, and diverse means of performing the safety function of removing residual heat, which is normally performed by the RHRS when RCS temperature is less than 350°F.

The auxiliary feedwater system is capable of performing this function for an extended period of time following plant shutdown.

The RHRS is provided with two residual heat removal pumps and heat exchangers arranged in two separate, independent flow paths. To assure reliability, each residual heat removal pump is connected to a different vital bus. Each train is isolated from the RCS on the suction side by two motor-operated valves in series with each valve receiving power via a separate motor control center and from a different vital bus. Each suction isolation valve is also interlocked and alarmed to prevent exposure of the RHRS to the normal operating pressure of the RCS (see [Section 5.4.7.2.5](#)). RHR system piping and components have the potential to develop voids and pockets of entrained gases. Preventing and managing gas intrusion and accumulation in the pump suction and pump discharge piping, however, supports proper operation of the RHR system and may also prevent water hammer, pump cavitation, and pumping of noncondensable gas into the reactor vessel.

RHRS operation for normal conditions and for major failures is accomplished completely from the control room. The redundancy in the RHRS design provides the system with the capability to maintain its cooling function even with a major single failure, such as

failure of a residual heat removal pump, valve, or heat exchanger without impact on the redundant train's continued heat removal.

Although such major system failures are within the system design basis, there are other less significant failures which can prevent opening of the residual heat removal suction isolation valves from the control room. Since these failures are of a minor nature, improbable to occur, and easily corrected outside the control room, with ample time to do so, they have been realistically excluded from the engineering design basis. Such failures are not likely to occur during the limited time period in which they can have any effect (i.e., when opening the suction isolation valves to initiate residual heat removal operation). However, even if they should occur, they have no adverse safety impact and can be readily corrected. In such a situation, the auxiliary feedwater system and the steam generator power-operated relief valves can be used to perform the safety function of removing residual heat and, in fact, can be used to continue the plant cooldown below 350°F, until the RHRS is made available.

One example of this type of a failure is the interlock circuitry which is designed to prevent exposure of the RHRS to the normal operating pressure of the RCS (see [Section 5.4.7.2.5](#)). In the event of such a failure, RHRS operation can be initiated by defeating the "prevent-open" interlock through corrective action at the solid state protection system cabinet or at the individual affected motor control centers.

The other type of failure which can prevent opening the residual heat removal suction isolation valves from the control room is a failure of an electrical power train. Such a failure is extremely unlikely to occur during the few minutes out of a year's operating time during which it can have any consequence. If such an unlikely event should occur, several alternatives are available. The most realistic approach would be to obtain restoration of offsite power, which can be expected to occur in less than 1/2 hour. Other alternatives are to restore the emergency diesel generator to operation or to bring in an alternative power source.

The only impact of either of the above types of failures is some delay in initiating residual heat removal operation, while action is taken to open the residual heat removal suction isolation valves. This delay has no adverse safety impact because of the capability of the auxiliary feedwater system and steam generator power-operated relief valves to continue to remove residual heat, and, in fact, to continue plant cooldown.

A failure mode and effects analysis of the RHRS for normal plant cooldown is provided as [Table 5.4-9](#).

5.4.7.2.8 Manual Actions

The RHRS is designed to be fully operable from the control room for normal operation. Manual operations required of the operator are: opening the suction isolation valves, positioning the flow control valves downstream of the RHRS heat exchangers, and starting the residual heat removal pumps.

Manual actions required outside the control room, under conditions of single failure, are discussed in [Section 5.4.7.2.7](#).

5.4.7.3 Performance Evaluation

The performance of the RHR system in reducing reactor coolant temperature is evaluated through the use of heat balance calculations on the RCS, and the component cooling water system at stepwise intervals following the initiation of RHR operation. Heat removal through the RHR and component cooling water heat exchangers is calculated at each interval by use of standard water-to-water heat exchanger performance correlations. The resultant fluid temperatures for the RHR and component cooling water system are calculated and used as input to the next interval's heat balance calculation.

Assumptions utilized in the series of the heat balance calculations describing plant RHR cooldown are as follows:

- a. RHR operation is initiated 4 hours after reactor shutdown (12 hours after shutdown for single train cooldown).
- b. RHR operation begins at a reactor coolant temperature of 350°F.
- c. Thermal equilibrium is maintained throughout the RCS during the cooldown.
- d. Component cooling water temperature at the CCW heat exchanger outlet during cooldown is limited to a maximum of 120°F.
- e. Expected cooldown rates of 50°F per hour are not exceeded.

Cooldown curves calculated using this method are provided for the case of all residual heat removal components operable ([Figure 5.4-9](#)) and for the case of a single train residual heat removal cooldown ([Figure 5.4-10](#)).

5.4.7.4 Preoperational Testing

Preoperational testing of the RHR system is addressed in [Chapter 14.0](#).

5.4.7.5 Gas Management

The RHR system is operable when it is sufficiently filled with water. The Technical Specifications include Surveillance Requirements for verifying systems are sufficiently full of water. Voiding may occur, however, due to the accumulation of entrained gas; acceptance criteria are established for the volume of accumulated gas at susceptible locations. If accumulated gas is discovered that exceeds the acceptance criterion for the susceptible location (or if the volume of accumulated gas at one or more susceptible

locations exceeds an acceptance criterion for gas volume at the suction or discharge of a pump), the Technical Specification Surveillance Requirement is not met and past operability reviews are initiated. If it is determined by subsequent evaluation that the RHR system was not rendered inoperable by the accumulated gas (i.e., the system was sufficiently filled with water), the Surveillance Requirement may be declared met. Accumulated gas should be eliminated or brought within the acceptance criteria limits.

RHR system locations susceptible to gas accumulation are monitored and, if gas is found, the gas volume is compared to the acceptance criteria for the location. Susceptible locations in the same system flow path that are subject to the same gas intrusion mechanisms may be verified by monitoring a representative subset of susceptible locations. Monitoring may not be practical for locations that are inaccessible due to radiological or environmental conditions, the plant configuration, or personnel safety. For these locations, alternative methods (e.g., operating parameters, remote monitoring) may be used to monitor the susceptible location. Monitoring is not required for susceptible locations where the maximum potential accumulated gas void volume has been evaluated and determined to not challenge system operability. The accuracy of the method used for monitoring the susceptible locations and trending of the results must be sufficient to assure system operability between surveillance performances.

5.4.8 REACTOR WATER CLEANUP SYSTEM

This section is not applicable to SNUPPS.

5.4.9 MAIN STEAM LINE AND FEED WATER PIPING

Discussion pertaining to the main steam line and feedwater piping are contained in the following sections:

- a. Main Steam Line Piping - [Section 10.3](#).
- b. Main Feedwater Piping - [Section 10.4.7](#).
- c. Auxiliary Feedwater Piping - [Section 10.4.9](#).
- d. Inservice Inspection of a, b, and c - [Section 6.6](#).

5.4.10 PRESSURIZER

5.4.10.1 Design Bases

The pressurizer provides a point in the RCS where liquid and vapor are maintained in equilibrium under saturated conditions for control of pressure of the RCS during steady state operations and transients.

The volume of the pressurizer is equal to, or greater than, the minimum volume of steam, water, or total of the two which satisfies all of the following requirements:

- a. The combined saturated water volume and steam expansion volume is sufficient to provide the desired pressure response to system volume changes.
- b. The water volume is sufficient to prevent the heaters from being uncovered during a step load increase of 10 percent at full power.
- c. The steam volume is large enough to accommodate the surge resulting from a 50-percent reduction of full load with automatic reactor control and a 40-percent steam dump without the water level reaching the high level reactor trip point.
- d. The steam volume is large enough to prevent water relief through the safety valves following a loss of load with the high water level initiating a reactor trip, without reactor control or steam dump.
- e. The pressurizer will not empty following reactor trip and turbine trip.
- f. The emergency core cooling will not be activated because of a reactor trip and turbine trip.

The surge line is sized to minimize, to an acceptable value, the pressure drop between the RCS and the safety valves with maximum discharge flow from the safety valves.

The surge line and the thermal sleeves are designed to withstand the thermal stresses resulting from volume surges of water of different temperatures, which occur during operation.

5.4.10.2 Design Description

5.4.10.2.1 Pressurizer and Surge Line

The pressurizer is a vertical, cylindrical vessel with hemispherical top and bottom heads constructed of carbon steel, with austenitic stainless steel cladding on all internal surfaces exposed to the reactor coolant. Stainless steel is used on all surfaces in contact with the reactor coolant.

The general configuration of the pressurizer is shown in [Figure 5.4-11](#). The design data of the pressurizer are given in [Table 5.4-10](#). Codes and material requirements are provided in [Section 5.2](#).

The pressurizer surge line connects the pressurizer to one reactor hot leg, thus enabling continuous coolant volume pressure adjustments between the RCS and the pressurizer.

The surge line nozzle and removable electric heaters are located in the bottom of the pressurizer. The heaters are removable for maintenance or replacement.

The pressurizer surge line nozzle diameter is given in [Table 5.4-10](#), and the pressurizer surge line dimensions are shown in [Figure 5.1-1](#), Sheet 2.

A thermal sleeve is provided in the surge line nozzle to minimize thermal stresses. A retaining screen is located above the nozzle to prevent foreign matter from entering the RCS. Baffles in the lower section of the pressurizer prevent an insurge of cold water from flowing directly to the steam/water interface and assist in mixing.

Spray line nozzles, relief and safety valve connections are located in the top head of the pressurizer vessel. Spray flow is modulated by automatically controlled air-operated valves. The spray valves also can be operated manually by a switch in the control room.

A small continuous spray flow is provided through a manual bypass valve around the power-operated spray valves to assure that the boron concentration in the pressurizer is not dissimilar from that in the reactor coolant and to prevent excessive cooling of the spray piping.

During an outsurge of water from the pressurizer, flashing of water to steam and generation of steam by automatic actuation of the heaters keep the pressure above the minimum allowable limit. During an insurge from the RCS, the spray system, which is fed from two cold legs, condenses steam in the vessel to prevent the pressurizer pressure from reaching the setpoint of the power-operated relief valves for normal design transients. Heaters are energized on high water level during insurge to heat the subcooled surge water that enters the pressurizer from the reactor coolant loop.

Material specifications are provided in [Table 5.2-2](#) for the pressurizer, pressurizer relief tank, and the surge line. Design transients for the components of the RCS are discussed in [Section 3.9\(N\).1](#). Additional details on the pressurizer design cycle analysis are given in [Section 5.4.10.3](#).

5.4.10.2.2 Pressurizer Instrumentation

Refer to [Chapter 7.0](#) for details of the instrumentation associated with pressurizer pressure, level, and temperature.

Temperatures in the spray lines from the cold legs of two loops are measured and indicated. Alarms from these signals are actuated to warn the operator of low spray water temperature or indicate insufficient flow in the spray lines.

Temperatures in the pressurizer safety and relief valve discharge lines are measured and indicated. An increase in a discharge line temperature is an indication of leakage or relief through the associated valve.

5.4.10.3 Design Evaluation

5.4.10.3.1 System Pressure

Whenever a steam volume is present within the pressurizer, the RCS pressure is governed by conditions in the pressurizer.

A design basis safety limit is that RCS pressure does not exceed the maximum transient value allowed under the ASME Code, Section III.

Evaluation of plant conditions of operation, which follow, indicate that this safety limit is not reached.

During startup and shutdown, the rate of temperature change in the RCS is controlled by the operator. Heatup rate is controlled by energy input from the reactor coolant pumps and by the pressurizer electrical heating capacity. This heatup rate takes into account the continuous spray flow provided to the pressurizer. When the reactor core is in cold shutdown, the heaters are de-energized.

If the pressurizer is filled water solid during system heatup or near the end of the second phase of plant cooldown, RCS pressure is maintained by the letdown flow rate via the RHRs.

5.4.10.3.2 Pressurizer Performance

The normal operating water volume at full load conditions is given in [Table 5.4-10](#).

5.4.10.3.3 Pressure Setpoints

The RCS design and operating pressure, together with the safety, power relief, and pressurizer spray valves setpoints and the protection system pressure setpoints, are listed in [Table 5.4-11](#). The design pressure allows for operating transient pressure changes. The selected design margin considers core thermal lag, coolant transport times and pressure drops, instrumentation and control response characteristics, and system relief valve characteristics.

5.4.10.3.4 Pressurizer Spray

Two separate, automatically controlled spray valves with remote manual overrides are used to initiate pressurizer spray. In parallel with each spray valves is a manual throttle valve which permits a small continuous flow through both spray lines to reduce thermal stresses and thermal shock when the spray valves open and to help maintain uniform water chemistry and temperature in the pressurizer. Temperature sensors with low alarms are provided in each spray line to alert the operator to insufficient bypass flow. The layout of the common spray line piping routed to the pressurizer forms a water seal which prevents the steam buildup back to the control valves. The spray rate is selected

to prevent the pressurizer pressure from reaching the operating setpoint of the power relief valves during a step reduction in power level of 10 percent of full load.

The pressurizer spray lines and valves are large enough to provide the required spray flow rate under the driving force of the differential pressure between the surge line connection in the hot leg and the spray line connection in the cold leg. The spray line inlet connections extend into the cold leg piping in the form of a scoop in order to utilize the velocity head of the reactor coolant loop flow to add to the spray driving force. The spray valves and spray line connections are arranged so that the spray will operate when one reactor coolant pump is not operating. The line may also be used to assist in equalizing the boron concentration between the reactor coolant loops and the pressurizer.

A flow path from the CVCS to the pressurizer spray line is also provided. This path provides auxiliary spray to the vapor space of the pressurizer during cooldown when the reactor coolant pumps are not operating. The thermal sleeves on the pressurizer spray connection and the spray piping are designed to withstand the thermal stresses resulting from the introduction of cold spray water.

5.4.10.4 Tests and Inspections

The pressurizer is designed and constructed in accordance with the ASME Code, Section III.

To implement the requirements of the ASME Code, Section XI the following welds are designed and constructed to present a smooth transition surface between the parent metal and the weld metal. The weld surface is ground smooth for ultrasonic inspection.

- a. Support skirt to the pressurizer lower head
- b. Surge nozzle to the lower head
- c. Nozzles to the safety, relief, and spray lines
- d. Nozzle to safe end attachment welds
- e. All girth and longitudinal full penetration welds
- f. Manway attachment welds

The liner within the safe end nozzle region extends beyond the weld region to maintain a uniform geometry for ultrasonic inspection.

Peripheral support rings are furnished for the removable insulation modules.

The pressurizer quality assurance program is given in **Table 5.4-12**.

5.4.11 PRESSURIZER RELIEF DISCHARGE SYSTEM

5.4.11.1 Design Bases

The pressurizer relief discharge system collects, cools, and directs for processing the steam and water discharged from safety and relief valves in the containment. The system consists of the pressurizer relief tank, the safety and relief valve discharge piping, the relief tank internal spray header and associated piping, the tank nitrogen supply, the vent to containment, and the drain to the waste processing system.

The system design is based on the requirement to absorb a discharge of steam equivalent to 110 percent of the full power pressurizer steam volume. The steam volume requirement is approximately that which would be experienced if the plant were to suffer a complete loss of load accompanied by a turbine trip but without the resulting reactor trip. A delayed reactor trip is considered in the design of the system.

The minimum volume of water in the pressurizer relief tank is determined by the energy content of the steam to be condensed and cooled, by the assumed initial temperature of the water, and by the desired final temperature of the water volume. The initial water temperature is assumed to be 120°F, which corresponds to the design maximum expected containment temperature for normal conditions. Provision is made to permit cooling the tank should the water temperature rise above 120°F during plant operation. The design final temperature is 200°F, which allows the content of the tank to be drained directly to the waste processing system without cooling.

A safety-related flowpath downstream of the excess letdown heat exchanger is provided to direct a cooled flow to the PRT. This flow path may be used if the normal and excess letdown paths are unavailable or if it is desired to contain the reactor coolant inside the containment. Another flowpath is provided for the controlled release of fluid from the PRT to the containment normal sump.

The vessel saddle supports and anchor bolt arrangement are designed to withstand the loadings resulting from a combination of nozzle loadings acting simultaneously with the vessel seismic and static loadings.

5.4.11.2 System Description

The piping and instrumentation diagram for the pressurizer relief discharge system is given in [Figure 5.1-1](#), Sheet 2.

Codes and materials of the pressurizer relief tank and associated piping are given in [Section 5.2](#). Design data for the tank are given in [Table 5.4-13](#).

The steam and water discharged from the various safety and relief valves inside the containment is routed to the pressurizer relief tank if the discharged fluid is of reactor

grade quality. **Table 5.4-14** provides an itemized list of valves discharging to the tank, together with references to the corresponding piping and instrumentation diagrams.

The tank normally contains water and a predominantly nitrogen atmosphere. In order to obtain effective condensing and cooling of the discharged steam, the tank is installed horizontally with the steam discharged through a sparger pipe located near the tank bottom and under the water level. The sparger holes are designed to ensure a resultant steam velocity close to sonic. The water in the tank may be discharged to allow increased capacity for RC letdown via the excess letdown path. In this mode, the water is cooled before it enters the tank.

The tank is also equipped with an internal spray and a drain which are used to cool the water following a discharge. Cold water is drawn from the reactor makeup water system, or the contents of the tank are circulated through the reactor coolant drain tank heat exchanger of the waste processing system and back into the spray header.

The nitrogen gas blanket is used to control the atmosphere in the tank and to allow room for the expansion of the original water plus the condensed steam discharge. The tank gas volume is calculated, using a final pressure based on an arbitrary design pressure of 100 psig. The design discharge raises the worst case initial conditions to 50 psig, a pressure low enough to prevent fatigue of the rupture discs. Provision is made to permit the gas in the tank to be periodically analyzed to monitor the concentration of hydrogen and/or oxygen.

The contents of the tank can be drained to the waste holdup tank in the waste processing system or the recycle holdup tank in the boron recycle system via the reactor coolant drain tank pumps in the waste processing system. Under emergency conditions, the tank contents can be drained to the containment normal sump.

5.4.11.2.1 Pressurizer Relief Tank

The general configuration of the pressurizer relief tank is shown in **Figure 5.4-12**. The tank is a horizontal, cylindrical vessel with elliptical dished heads. The vessel is constructed of austenitic stainless steel, and is overpressure protected in accordance with the ASME Code, Section VIII, Division 1, by means of two safety heads with stainless steel rupture discs. The PRT saddle supports are designed to withstand the loadings resulting from a combination of nozzle loadings acting simultaneously with the vessel seismic and static loadings.

A flange nozzle is provided on the tank for the pressurizer discharge line connection to the sparger pipe. The tank is also equipped with an internal spray connected to a cold water inlet and with a bottom drain, which are used to cool the tank following a discharge.

5.4.11.3 Design Evaluation

The pressurizer relief discharge system does not constitute part of the reactor coolant pressure boundary per 10 CFR 50, Section 50.2, since all of its components are downstream of the RCS safety and relief valves. Thus, General Design Criteria 14 and 15 are not applicable. Furthermore, complete failure of the auxiliary systems serving the pressurizer relief tank will not impair the capability for safe plant shutdown.

The design of the system piping layout and piping restraints is consistent with the hazards protection requirements indicated in [Appendix 3.B](#). The safety and relief valve discharge piping is restrained so that the integrity and operability of the valves are maintained in the event of a rupture. Regulatory Guide 1.67 is not applicable, since the system is not an open discharge system.

The pressurizer relief discharge system is capable of handling the design discharge of steam without exceeding the design pressure and temperature of the pressurizer relief tank.

The volume of water in the pressurizer relief tank is capable of absorbing the heat from the assumed discharge, maintaining the water temperature below 200°F. If a discharge exceeding the design basis should occur, the relief device on the tank would pass the discharge through the tank to the containment.

The rupture discs on the relief tank have a relief capacity equal to or greater than the combined capacity of the pressurizer safety valves. The tank design pressure is twice the calculated pressure resulting from the design basis safety valve discharge described in [Section 5.4.11.1](#). The tank and rupture discs holders are also designed for full vacuum to prevent tank collapse if the content cools following a discharge without nitrogen being added.

The discharge piping from the pressurizer safety and relief valves to the relief tank is sufficiently large to prevent backpressure at the safety valves from exceeding 20 percent of the setpoint pressure at full flow.

5.4.11.4 Instrumentation Requirements

The pressurizer relief tank pressure transmitter provides an indication of pressure relief tank pressure. An alarm is provided to indicate high tank pressure.

The pressurizer relief tank level transmitter supplies a signal for an indicator with high and low level alarms. The temperature of the water in the pressurizer relief tank is indicated, and an alarm actuated by high temperature informs the operator that cooling of the tank contents is required.

5.4.11.5 Tests and Inspections

The system components are subject to nondestructive and hydrostatic testing during construction, in accordance with Section VIII, Division 1 of the ASME Code.

During plant operation, periodic visual inspections and preventive maintenance are conducted on the system components according to normal industrial practice.

5.4.12 VALVES

5.4.12.1 Design Bases

As noted in **Section 5.2**, all valves out to and including the second valve normally closed or capable of automatic or remote closure, larger than 3/4 inch, are ANS Safety Class 1, and ASME III, Code Class 1 valves. All 3/4-inch or smaller valves in lines connected to the RCS are Class 2, since the interface with the Class 1 piping is provided with suitable orificing for such valves. Design data for the RCS valves are given in **Table 5.4-15**.

For a check valve to qualify as part of the RCS, it must be located inside the containment system. When the second of two normally open check valves is considered part of the RCS (as defined in **Section 5.1**), means are provided to periodically assess back-flow leakage of the first valve when closed.

To ensure that the valves will meet the design objectives, the materials of construction minimize corrosion/erosion and ensure compatibility with the environment. Leakage is minimized to the extent practicable by design.

5.4.12.2 Design Description

All manual, motor operated, and throttling control valves are provided with either double-packed stuffing boxes and intermediate lantern ring leakoff connections which are piped to a closed collection system when so equipped, or a four or five ring packing configuration and carbon spacer (if required). Both packing configurations minimize leakage to atmosphere to the extent practicable by design.

Gate valves at the engineered safety features interface are wedge design and are essentially straight through. The wedges are flex-wedge or solid. All gate valves have backseats.

Globe valves are "T" and "Y" styles. Check valves are swing type for sizes 2-1/2 inches and larger. All check valves which contain radioactive fluid are stainless steel, and do not have body penetrations other than the inlet, outlet, and bonnet. The check hinge is serviced through the bonnet.

All operating parts are contained within the valve body. The disc has limited rotation to provide a change of seating surface and alignment after each valve opening.

5.4.12.3 Design Evaluation

The design requirements for Class 1 valves, as discussed in [Section 5.2](#), limit stresses to levels which ensure the structural integrity of the valves. In addition, the testing programs described in [Section 3.9\(N\)](#) demonstrate the ability of the valves to operate, as required, during anticipated and postulated plant conditions.

Reactor coolant chemistry parameters are specified in the design specifications to assure the compatibility of valve construction materials with the reactor coolant. To ensure that the reactor coolant continues to meet these parameters, the chemical composition of the coolant will be analyzed periodically.

The above requirements and procedures, coupled with the previously described design features for minimizing leakage, ensure that the valves will perform their intended functions, as required during plant operation.

5.4.12.4 Tests and Inspections

The tests and inspections discussed in [Section 3.9\(N\)](#) are performed to ensure the operability of the active valves.

There are no full-penetration welds within the valve body walls. Valves are accessible for disassembly and internal visual inspection, to the extent practical. Plant layout configurations determine the degree of inspectability. The valve nondestructive examination program is given in [Table 5.4-16](#). Inservice inspection is discussed in [Section 5.2.4](#).

5.4.13 SAFETY AND RELIEF VALVES

5.4.13.1 Design Bases

Given that the steam generator safety valves open when steam pressure reaches the steam side safety setting, the combined capacity of the pressurizer safety valves can accommodate the maximum pressurizer surge resulting from complete loss of load, without reactor trip or any operator action.

The pressurizer power-operated relief valves are designed to limit pressurizer pressure to a value below the fixed high pressure reactor trip setpoint. They are designed to fail to the closed position on loss of power.

5.4.13.2 Design Description

The pressurizer safety valves are of the pop type. The valves are spring loaded, open by direct fluid pressure action, and have backpressure compensation features.

The pipe connecting each pressurizer nozzle to its safety valve is shaped in the form of a loop seal. Condensate resulting from normal heat losses accumulates in the loop. The water prevents any leakage of hydrogen gas or steam through the safety valve seats. If the pressurizer pressure exceeds the set pressure of the safety valves, they start lifting, and the water from the seal discharges during the actuation period.

For any increases made to core differential pressure or pressurization rates from core reload or plant modifications, the loop seal purge time for the pressurizer safety valves will be re-examined. A complete discussion of the loop seal purge time can be found in Reference 4.

The pressurizer power-operated relief valves are solenoid actuated valves which respond to a signal from a pressure sensing system or to manual control. Motor-operated valves are provided to isolate the power-operated relief valves if excessive leakage develops or if the PORV fails to close.

Temperatures in the pressurizer safety and relief valve discharge lines are measured and indicated. An increase in a discharge line temperature is an indication of leakage or relief through the associated valve.

The power-operated relief valves provide the safety-related means for reactor coolant system depressurization to achieve cold shutdown.

Design parameters for the pressurizer safety and power relief valves are given in **Table 5.4-17**.

5.4.13.3 Design Evaluation

The pressurizer safety valves prevent RCS pressure from exceeding 110 percent of system design pressure, in compliance with the ASME Code, Section III.

The pressurizer power relief valves prevent actuation of the fixed reactor high pressure trip for all design transients up to and including the design step load decreases with steam dump. The relief valves also limit undesirable opening of the spring loaded safety valves.

5.4.13.4 Tests and Inspections

All safety and relief valves are subjected to hydrostatic tests, seat leakage tests, operational tests, and inspections, as required. For safety valves that are required to function during a faulted condition, additional tests are performed. These tests are described in **Section 3.9(N)**. There are no full penetration welds within the valve body walls. Valves are accessible for disassembly and internal visual inspection.

5.4.14 COMPONENT SUPPORTS

5.4.14.1 Design Bases

Component supports allow unrestrained lateral thermal movement of the loop during plant operation and provide restraint to the loops and components during accident and seismic conditions. The loading combinations and design stress limits are discussed in **Section 3.9(N).1.4**. Support design is in accordance with the ASME Code, Section III, Subsection NF. The design maintains the integrity of the RCS boundary for normal, seismic, and accident conditions and satisfies the requirements of the piping code. Results of piping and supports stress evaluation are presented in **Section 3.9(N)**.

5.4.14.2 Design Description

The support structures are welded structural steel sections. Linear type structures (tension and compression struts, columns, and beams) are used in all cases, except for the reactor vessel supports, which are plate-type structures. Attachments to the supported equipment are nonintegral type that are bolted to or bear against the components. The supports-to-concrete attachments are either anchor bolts or embedded fabricated assemblies.

The supports permit unrestrained thermal growth of the supported systems but restrain vertical, lateral, and rotational movement resulting from seismic and pipe break loadings. This is accomplished using spherical bushings in the columns for vertical support and girders, bumper pedestals, and tie-rods for lateral support.

To compensate for manufacturing and construction tolerances, adjustment in the support structures is provided to ensure proper erection alignment and fit-up. This is accomplished by shimming or grouting at the supports-to-concrete interface and by shimming at the supports-to-equipment interface.

The supports for the various components are described in the following paragraphs.

5.4.14.2.1 Reactor Pressure Vessel

Supports for the reactor vessel (**Figure 5.4-13**) are individual air cooled rectangular box structures beneath the vessel nozzles bolted to the primary shield wall concrete. Each box structure consists of a horizontal top plate that receives loads from the reactor vessel shoe, a horizontal bottom plate which transfers the loads to the primary shield wall concrete, and connecting vertical plates which bear against an embedded support. The supports are air cooled to maintain the supporting concrete temperature within acceptable levels.

5.4.14.2.2 Steam Generator

As shown in [Figure 5.4-14](#), the steam generator supports consist of the following elements:

a. Vertical support

Four individual columns provide vertical support for each steam generator. These are bolted at the top to the steam generator and at the bottom to the concrete structure. Spherical ball bushings at the top and bottom of each column allow unrestrained lateral movement of the steam generator during heatup and cooldown. The column base design permits both horizontal and vertical adjustment of the steam generator for erection and adjustment of the system.

b. Lower lateral support

Lateral support is provided at the generator tube sheet by fabricated steel girders and struts. These are bolted to the compartment walls and include bumpers that bear against the steam generator but permit unrestrained movement of the steam generator during changes in system temperature. Stresses in the beams caused by wall displacement during compartment pressurization are considered in the design.

c. Upper lateral support

The upper lateral support of the steam generator is provided by a ring band at the operating deck. One-way acting limit stops restrain sudden seismic or blowdown induced motion, but permit the normal thermal movement of the steam generator. Movement perpendicular to the thermal growth direction of the steam generator is prevented by shear keys.

5.4.14.2.3 Reactor Coolant Pump

Three individual columns, similar to those used for the steam generator, provide the vertical support for each pump. Lateral support for seismic and blowdown loading is provided by three lateral tension tie bars. The pump supports are shown in [Figure 5.4-15](#).

5.4.14.2.4 Pressurizer

The supports for the pressurizer, as shown in [Figures 5.4-16](#) and [5.4-17](#), consist of:

a. A steel ring between the pressurizer skirt and the supporting concrete slab. The ring serves as a leveling and adjusting member for the pressurizer,

and may also be used as a template for positioning the concrete anchor bolts.

- b. The upper lateral support consists of struts cantilevered off the compartment walls that bear against the "seismic lugs" provided on the pressurizer.

5.4.14.2.5 Pipe Restraints

- a. Crossover leg

Restraint at each elbow of the reactor coolant pipe between the pump and the steam generator (crossover leg) is not required for postulated breaks due to implementation of leak-before-break methodology. The horizontal and vertical shim plates from the elbow of the saddle block were removed to deactivate the two crossover leg elbow restraints as shown in [Figure 5.4-18](#). The RCS vertical crossover leg pipe whip restraint was deactivated by removal of the tie rod and associated pins as shown in [Figure 5.4-19](#).

- b. Hot leg

The hot leg restraint located near the 50 degree elbow in the reactor coolant system hot leg was also removed due to implementation of leak-before-break methodology. It was deactivated by removal of the pipe saddle and shim packs as shown on [Figure 5.4-20](#).

- c. Hot leg and cold leg lateral restraints

A restraint on each reactor coolant system hot leg and cold leg is located near the reactor vessel safe-end to reactor coolant system piping weld with the reactor vessel primary shield wall to prevent excessive displacement of either the hot leg or the cold leg following a postulated guillotine break at the reactor vessel safe-end to piping weld. These restraints are shown in [Figure 5.4-21](#).

5.4.14.3 Design Evaluation

Detailed evaluation ensures the design adequacy and structural integrity of the reactor coolant loop and the primary equipment supports system. This detailed evaluation is made by comparing the analytical results with established criteria for acceptability. Structural analyses are performed to demonstrate design adequacy for safety and reliability of the plant in case of a large or small seismic disturbance and/or LOCA conditions. Loads which the system is expected to encounter often during its lifetime (thermal, weight, and pressure) are applied, and stresses are compared to allowable values as described in [Section 3.9\(N\).1.4](#).

The safe shutdown earthquake and design basis LOCA, resulting in a rapid depressurization of the system, are required design conditions for public health and safety. The methods used for the analysis of the safe shutdown earthquake and LOCA conditions are given in **Sections 3.9(N).1.4.**

5.4.14.4 Tests and Inspections

Nondestructive examinations are performed in accordance with the procedures of the ASME Code, Section V, except as modified by the ASME Code, Section III, Subsection NF.

5.4.15 REFERENCES

1. "Reactor Coolant Pump Integrity in LOCA," WCAP-8163, September, 1973.
2. Eggleston, F. T., "Safety-Related Research and Development for Westinghouse Pressurized Water Reactor, Program Summaries - Winter 1977 - Summer 1978," WCAP-8768, Revision 2, October, 1978.
3. Deleted.
4. Barrett, G. O., et al., "Pressurizer Safety Valve Set Pressure Shift," WCAP-12910, March 1991.

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**TABLE 5.4-1 REACTOR COOLANT PUMP
DESIGN PARAMETERS**

| | |
|--|---|
| Unit design pressure, psig | 2,485 |
| Unit design temperature, °F | 650 (a) |
| Unit overall height, ft | 26.93 |
| Seal water injection, gpm | 8 |
| Seal water return, gpm | 3 |
| Cooling water flow, gpm | 366 |
| Maximum continuous cooling water inlet temperature | 105 |
| | |
| Pump | |
| Capacity, gpm | 100,200 ± 2000 (hot) |
| Developed head, ft | 290 ± 10 (hot) |
| NPSH required, ft | Figure 5.4-2 |
| Suction temperature, °F | 556.6 |
| Pump discharge nozzle, inside diameter, in. | 27-1/2 |
| Pump suction nozzle, inside diameter, in. | 31 |
| Speed, rpm | 1,187 |
| Water volume (casing), ft ³ | 78.6 |
| Weight total (including pump casing, motor, and motor supports), dry, lb | 204,035 (b) |
| | |
| Motor | |
| Type | Drip proof, squirrel cage induction, water/ air cooled |
| Power, hp | 7,000 |
| Voltage, Volts | 13,200 |
| Phase | 3 |
| Frequency, Hz | 60 |
| Insulation class | Class F, thermalastic epoxy insulation |

TABLE 5.4-1 (Sheet 2)

Starting

| | |
|---|--------------------------|
| Current | 1,600 amp @ 13,200 Volts |
| Input, hot reactor coolant | 265 ± 5 amp |
| Input, cold reactor coolant | 336 ± 7 amp |
| Pump moment of inertia, maximum (lb-ft ²) | |
| Flywheel | 64,000 |
| Shaft | 745 |
| Impeller | 1,980 |
| Rotor core | 27,700 |
| Runner | 675 |
| Coupling | 190 |
| (a) Design temperature of pressure-retaining parts of the pump assembly exposed to the reactor coolant and injection water on the high pressure side of the controlled leakage seal shall be that temperature determined for the parts for the primary loop temperature of 650°F. | |
| (b) Approximately 206,000 lbs. if studs and nuts are utilized in the main flange joint. | |

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TABLE 5.4-2 REACTOR COOLANT PUMP
QUALITY ASSURANCE PROGRAM

| | <u>RT*</u> | <u>UT*</u> | <u>PT*</u> | <u>MT*</u> |
|---------------------------|------------|------------|------------|------------|
| Castings | Yes | | Yes | |
| Forgings | | | | |
| Main shaft | | Yes | | Yes |
| Main studs | | Yes | | Yes |
| Flywheel (rolled plate) | | Yes | | |
| Weldments | | | | |
| Circumferential | Yes | | Yes | |
| Instrumentant connections | | | Yes | |

- * RT - Radiographic
- UT - Ultrasonic
- PT - Dye penetrant
- MT - Magnetic particle

TABLE 5.4-3 STEAM GENERATOR DESIGN DATA

| | | |
|--|------------------------|--|
| Design pressure, reactor coolant side, psig | 2,485 | |
| Design pressure, steam side, psig | 1,185 | |
| Design pressure, primary to secondary, psi | 1,600 | |
| Design temperature, reactor coolant side, °F | 650 | |
| Design temperature, steam side, °F | 600 | |
| Design temperature, primary to secondary, °F | 650 | |
| Total heat transfer surface area, ft ² | 78,946 | |
| Maximum moisture carryover, wt percent | 0.10 | |
| Overall height, ft-in. | 68-4 | |
| Number of U-tubes | 5,872 | |
| U-tube nominal diameter, in. | 0.75 | |
| Tube wall nominal thickness, in. | 0.0429 | |
| Number of manways | 4 | |
| Inside diameter of manways, in. | 16 | |
| Number of handholes | 6 | |
| Design fouling factor, ft ² -hr-F/Btu | 0.00005 | |
| Steam flow (per unit), lb/hr | 3.99 x 10 ⁶ | |
| Nominal primary side water volume, ft ³ | | |
| No load | 1,345.9 | |
| Full load | 1,345.9 | |
| Nominal secondary side water volume, ft ³ | | |
| No load | 3,322 | |
| Full load | 2,358 | |

**TABLE 5.4-4 STEAM GENERATOR QUALITY
ASSURANCE PROGRAM**

| | <u>RT^(a)</u> | <u>UT^(a)</u> | <u>PT^(a)</u> | <u>MT^(a)</u> | <u>ET^(a)</u> | |
|---|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|--|
| Tube Sheet | | | | | | |
| Forging | | Yes | | Yes | | |
| Cladding | | Yes ^(b) | Yes | | | |
| Channel Head (if fabricated) | | | | | | |
| Fabrication | Yes ^(c) | Yes ^(d) | | Yes | | |
| Cladding | | | Yes | | | |
| Secondary Shell and Head (forgings) | | Yes | | | | |
| Tubes | | Yes | | | Yes | |
| Nozzles (Forgings) | | Yes | | Yes | | |
| Weldments | | | | | | |
| Shell, circumferential | Yes | | | Yes | | |
| Cladding (channel head/tube sheet joint cladding restoration) | | | Yes | | | |
| Primary nozzles to fab head | Yes | | | Yes | | |
| Manways to fab head | Yes | | | Yes | | |
| Steam and feedwater nozzle to shell | Yes | | | Yes | | |
| Support brackets | | | | Yes | | |
| Tube to tube sheet | | | Yes | | | |
| Instrument connections (primary and secondary) | | | | Yes | | |
| Temporary attachments after removal | | | | Yes | | |

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TABLE 5.4-4 (Sheet 2)

| | <u>RT</u> ^(a) | <u>UT</u> ^(a) | <u>PT</u> ^(a) | <u>MT</u> ^(a) | <u>ET</u> ^(a) |
|---|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| After hydrostatic test (all major pressure boundary welds and complete cast channel head - where accessible) | | | | Yes | |
| Nozzle safe ends (if weld deposit) | Yes | | Yes | | |
| (a) RT - Radiographic UT - Ultrasonic PT - Dye penetrant MT - Magnetic particle ET - Eddy Current | | | | | |
| (b) Flat surfaces only | | | | | |
| (c) Weld deposit | | | | | |
| (d) Base material only | | | | | |

**TABLE 5.4-5 REACTOR COOLANT PIPING
DESIGN PARAMETERS**

| | |
|--|-------------|
| Reactor inlet piping, inside diameter, in. | 27-1/2 |
| Reactor inlet piping, nominal wall thickness, in. | 2.32 |
| Reactor outlet piping, inside diameter, in. | 29 |
| Reactor outlet piping, nominal wall thickness, in. | 2.45 |
| Coolant pump suction piping, inside diameter, in. | 31 |
| Coolant pump suction piping, nominal wall thickness, in. | 2.60 |
| Pressurizer surge line piping, nominal pipe size, in. | 14 |
| Pressurizer surge line piping, nominal wall thickness, in. | 1.406 |
| Nominal water volume, all four loops including surge line, ft ³ | 1,225 |
| Reactor Coolant Loop Piping | |
| Design/operating pressure, psig | 2,485/2,235 |
| Design temperature, °F | 650 |
| Pressurizer Surge Line | |
| Design pressure, psig | 2,485 |
| Design temperature, °F | 680 |
| Pressurizer Safety Valve Inlet Line | |
| Design pressure, psig | 2,485 |
| Design temperature, °F | 680 |
| Pressurizer (Power-Operated) Relief Valve Inlet Line | |
| Design pressure, psig | 2,485 |
| Design temperature, °F | 680 |

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TABLE 5.4-6 REACTOR COOLANT PIPING
QUALITY ASSURANCE PROGRAM

| | <u>RT*</u> | <u>UT*</u> | <u>PT*</u> |
|--|------------|------------|--------------------------|
| Fittings and Pipe (Castings) | Yes | | Yes |
| Fittings and Pipe (Forgings) | | Yes | Yes |
| Weldments | | | |
| Circumferential | Yes | | Yes |
| Nozzle to runpipe (except no RT for nozzles less than 6 inches) | Yes | | Yes |
| Instrument connections | | | Yes |
| Castings | Yes | | Yes (after finishing) |
| Forgings | | Yes | Yes (after finishing) |

* RT - Radiographic
 UT - Ultrasonic
 PT - Dye Penetrant

TABLE 5.4-7 DESIGN BASES FOR RESIDUAL HEAT REMOVAL SYSTEM OPERATION

| | |
|--|---------------------------------|
| Residual heat removal system startup, hours after reactor shutdown | ~ 4 ³ |
| Reactor coolant system initial pressure, psig | ~ 400 |
| Reactor coolant system initial temperature, °F | ~ 350 |
| Component cooling water design temperature, °F | 105 ¹ |
| Coldown time, hours after initiation of residual heat removal system operation | 14.9 ³ |
| Reactor coolant system temperature at end of cooldown, °F | 140 ³ |
| Decay heat generation at 20 hours after reactor shutdown, Btu/hr | 78.9×10^6 ² |

(1) Maximum temperature at the CCW heat exchanger outlet at 18.9 hours after plant shutdown.

(2) Refer to [Section 5.4.7.2.1](#).

(3) Refer to [Section 5.4.7.2.1](#) and [Figure 5.4-10](#) for single train cooldown which will take the plant to cold shutdown (200°F) within 36 hours after shutdown (actual value is 30.6 hours after shutdown).

**TABLE 5.4-8 RESIDUAL HEAT REMOVAL
SYSTEM COMPONENT DATA**

Residual Heat Removal Pumps

| | |
|--------------------------------|-------|
| Number | 2 |
| Design pressure, psig | 600 |
| Design temperature, °F | 400 |
| Design flow, gpm | 3,800 |
| Design head, ft | 350 |
| NPSH required at 3,800 gpm, ft | 17 |
| Power, hp | 500 |

Residual Heat Exchangers

| | |
|--|--------------------|
| Number | 2 |
| Design heat removal capacity, Btu/hr | 39.1×10^6 |
| Estimated UA, Btu/hr F _{LMTD} | 2.3×10^6 |

| | <u>Tube Side</u> | <u>Shell Side</u> |
|------------------------|----------------------------|-------------------------|
| Design pressure, psig | 600 | 150 |
| Design temperature, F | 400 | 200 |
| Design flow, lb/hr | 1.9×10^6 | 3.8×10^6 |
| Inlet temperature, F* | 140 | 105 |
| Outlet temperature, F* | 120 | 116 |
| Material | Austenitic stainless steel | Carbon steel |
| Fluid | Reactor coolant | Component cooling water |

RHR Isolation Valve Encapsulation Tank (TEJ01A & B)

| | |
|------------------------|----------------------------|
| Manufacturer | Richmond Eng. |
| Quantity | 2 |
| Height ft-in. | 12-6 |
| Diameter ft-in. | 5-6 |
| Design Pressure, psig | 75 |
| Design Temperature, °F | 400 |
| Material | Austenitic stainless steel |
| Codes and Standards | ASME Section III, Class 2 |
| Seismic Category | I |

* Maximum temperatures at 18.9 hours after plant shutdown.

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TABLE 5.4-9 FAILURE MODES AND EFFECTS ANALYSIS - RESIDUAL HEAT REMOVAL SYSTEM ACTIVE COMPONENTS - PLANT COOLDOWN OPERATION

| <u>Component</u> | <u>Failure Mode</u> | <u>Effect on System Operation*</u> | <u>Failure Detection Method**</u> | <u>Remarks</u> |
|--|--|---|---|---|
| 1. Motor-operated gate valve EJ-HV-8701A (EJ-HV-8701B analogous) | Fails to open on demand (open manual mode CB switch selection) | Failure blocks reactor coolant flow from hot leg of RC loop 1 through train "A" of RHR. Fault reduces redundancy of RHR coolant trains provided. No effect on safety for system operation. Plant cooldown requirements will be met by reactor coolant flow from hot leg of RC loop 4 flowing through train "B" of RHR. However, time required to reduce RCS temperature will be extended. | Valve position indication (closed to open position change) at CB; RHR train "A" discharge flow indication (EJ-FI-618) and low flow alarm at CB; and RHR pump discharge pressure indication (EJ-PI-614) at CB. | <p>1. Valve is electrically interlocked with the containment sump isolation valve EJ-HV-8811A and the RWST isolation valve BN-HV-8812A, with RHR to charging pump suction line isolation valve EJ-HV-8804A and with a "prevent-open" pressure interlock (BB-PB-405A) off the seal table. The valve cannot be opened remotely from the CB if one of the indicated isolation valves is open or if RC loop pressure exceeds 360 psig. The valve can be manually opened. See Section 5.4.7.2.7.</p> <p>2. If both trains of RHR are unavailable for plant cooldown due to multiple component failures, the auxiliary feedwater system and SG power-operated relief valves can be used to perform the safety function of removing residual heat.</p> |
| 2. Motor-operated gate valve BB-PV-8702A (BB-PV-8702B analogous) | Same failure modes as those stated for item 1. | Same effect on system operation as that stated for item 1. | Same methods of detection as those stated for item 1. | Same remarks as those stated for item 1, except for pressure interlock (BB-PB-403A) control. |

* See list at end of table for definition of acronyms and abbreviations used.

** As part of plant operation; periodic tests, surveillance inspections, and instrument calibrations are made to monitor equipment and performance. Failures may be detected during such monitoring of equipment, in addition to detection methods noted.

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TABLE 5.4-9 (Sheet 2)

| <u>Component</u> | <u>Failure Mode</u> | <u>Effect on System Operation*</u> | <u>Failure Detection Method**</u> | <u>Remarks</u> |
|--|--|---|---|---|
| 3. RHR pump 1 (RHR pump 2 analogous) | Fails to deliver working fluid. | Failure results in loss of reactor coolant flow from hot leg of RC loop 1 through train "A" of RHRS. Fault reduces redundancy of RHR coolant trains provided. No effect on safety for system operation. Plant cooldown requirements will be met by reactor coolant flow from hot leg of RC loop 4 flowing through train "B" of RHRS. However, time required to reduce RCS temperature will be extended. | Open pump switchgear circuit breaker indication at CB; circuit breaker close position monitor light for group monitoring of components at CB; common breaker trip alarm at CB; RHR train "A" discharge flow indication (EJ-FI-618) and low flow alarm at CB; and pump discharge pressure indication (EJ-PI-614) at CB. | The RHRS shares components with the ECCS. Pumps are tested as part of the ECCS testing program (see Section 6.3.4). Pump failure may also be detected during ECCS testing. |
| 4. Motor-operated gate valve EJ-FCV-610 (EJ-FCV-611 analogous) | a. Fails to open on demand (open manual mode CB switch selection). | Failure blocks miniflow line to suction of RHR pump "A" during cooldown operation or during checking boron concentration level of coolant in train "A" of RHRS via EJ-HV-14. No effect on safety for system operation. Operator may establish miniflow for RHR pump "A" operation by opening of CVCS letdown control valve BG-HCV-128 and manual valve EJ-V001 to allow flow to CVCS. If RHR train "A" is degraded, plant cooldown requirements will be met by redundant RHR train "B". However, time required to reduce RCS temperature will be extended. | Valve position indication (closed to open position change) at CB. | Valve is automatically controlled to open when pump discharge is less than 816 gpm at 300°F (783 gpm at 68°F) and close when the discharge exceeds 1,650 gpm at 300°F (1,582 gpm at 68°F). The valve protects the pump against overheating and loss of discharge flow from the the pump. CB switch set to "Auto" position for automatic control of valve positioning. |
| | b. Fails to close on demand ("Auto" mode CB switch selection). | Failure allows for a portion of RHR heat exchanger "A" discharge flow to be bypassed to suction of RHR pump "A." RHRS train "A" is degraded for the regulation of coolant temperature by RHR heat exchanger "A." No effect on safety for system operation. Cooldown of RCS within established specification cooldown rate may be accomplished through operator action of throttling flow control valve EJ-HCV-606 and controlling cool-down with redundant RHRS train "B." | Valve position indication (open to closed position change) and RHRS train "A" discharge flow indication (EJ-FI-618) at CB. | |

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TABLE 5.4-9 (Sheet 3)

| <u>Component</u> | <u>Failure Mode</u> | <u>Effect on System Operation*</u> | <u>Failure Detection Method**</u> | <u>Remarks</u> |
|---|--|--|--|---|
| 5. Air diaphragm-operated butterfly valve EJ-FCV-618 (EJ-FCV-619 analogous) | a. Fails to open on demand ("Auto" mode CB switch selection) | Failure prevents coolant discharged from RHR pump "A" from bypassing RHR heat exchanger "A" resulting in mixed mean temperature of coolant flow to RCS being low. RHR train "A" is degraded for the regulation of controlling temperature of coolant. No effect on safety for system operation. Cooldown of RCS within established specification rate may be accomplished through operator action of throttling flow control valve EJ-HCV-606 and controlling cooldown with redundant RHR train "B". | RHR pump "A" discharge flow temperature and RHR train "A" discharge to RCS cold leg flow temperature recording (EJ-TR-612) at CB; and RHR train "A" discharge to RCS cold leg flow indication (EJ-FI-618) at CB. | Valve is designed to fail "closed" and is electrically wired so that electrical solenoid of the air diaphragm operator is energized to open the valve. Valve is normally "closed" to align RHR for ECCS operation during plant power operation and load follow. |
| | b. Fails to close on demand ("Auto" mode CB switch selection). | Failure allows coolant discharged from RHR pump "A" to bypass RHR heat exchanger "A", resulting in mixed mean temperature of coolant flow to RCS being high. RHR train "A" is degraded for the regulation of controlling temperature of coolant. No effect on safety for system operation. Cooldown of RCS within established specification rate may be accomplished through operator action of throttling flow control valve EJ-HCV-606 and controlling cooldown with redundant RHR train "B." However, cooldown time will be extended. | Same methods of detection as those stated for item 5.a. | |
| 6. Air diaphragm-operated butterfly valve EJ-HCV-606 (EJ-HCV-607 analogous) | a. Fails to close on demand for flow reduction. | Failure prevents control of coolant discharge flow from RHR heat exchanger "A," resulting in loss of mixed mean temperature coolant flow adjustment to RCS. No effect on safety for system operation. Cooldown of RCS within established specification rate may be accomplished by operator action of controlling cooldown with redundant RHR train "B." | Same methods of detection as those stated for item 5.a. In addition, monitor light and alarm (valve closed) for group monitoring of components at CB. | Valve is designed to fail "open". Valve is normally "open" to align RHR for ECCS operation during plant power operation and load follow. |

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TABLE 5.4-9 (Sheet 4)

| <u>Component</u> | <u>Failure Mode</u> | <u>Effect on System Operation*</u> | <u>Failure Detection Method**</u> | <u>Remarks</u> |
|---|--|---|---|--|
| | b. Fails to open on demand for increased flow. | Same effect on system operation as that stated for item 6.a. | Same methods of detection as those stated for item 6.a. | |
| 7. Manual globe valve EJ-V001 (EJ-V002 analogous) | Fails closed. | Failure blocks flow from train "A" of RHR to CVCS letdown heat exchanger. Fault prevents (during the initial phase of plant cooldown) the adjustment of boron concentration level of coolant in lines of RHR train "A" so that it equals the concentration level in the RCS, using the RHR cleanup line to CVCS. No effect on safety for system operation. Operator can balance boron concentration levels by cracking open flow control valve EJ-HCV-606 to permit flow to cold leg of loop 1 of RCS in order to balance levels using normal CVCS letdown flow. | CVCS letdown flow indication (BG-FI-132) at CB. | Valve is normally "closed" to align RHR for ECCS operation during plant power operation and load follow. |
| 8. Air diaphragm-operated globe valve BG-HCV-128 | Fails to open on demand. | Failure blocks flow from trains "A" and "B" of RHR to CVCS letdown heat exchanger. Fault prevents use of RHR cleanup line to CVCS for balancing boron concentration levels of RHR trains "A" and "B" with RCS during initial cooldown operation and later in plant cooldown for letdown flow. No effect on safety for system operation. Operator can balance boron concentration levels with similar actions, using pertinent flow control valve EJ-HCV-606 (EJ-HCV-607), as stated for item 7. Normal CVCS letdown flow can be used for purification if RHR cleanup line is not available. | Valve position indication (degree of openings) at CB and CVCS letdown flow indication | <ul style="list-style-type: none"> 1. Same remark as that stated above for item 7. (BG-FI-132) at CB. 2. Valve is a component of the CVCS that performs an RHR function during plant cooldown operation. |

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TABLE 5.4-9 (Sheet 5)

| <u>Component</u> | <u>Failure Mode</u> | <u>Effect on System Operation*</u> | <u>Failure Detection Method**</u> | <u>Remarks</u> |
|--|---------------------------|---|--|---|
| 9. Motor-operated gate valve BN-HV-8812A (BN-HV-8812B analogous) | Fails to close on demand. | Failure reduces the redundancy of isolation valves provided to isolate RHRS train "A" from RWST. No effect on safety for system operation. Check valve EJ-8958A in series with motor-operated valve provides the primary isolation against the bypass of RCS coolant flow from the suction of RHR pump "A" to RWST. | Valve position indication (open to closed position change) at CB and valve (closed) monitor light and alarm at CB. | Valve is a component of the ECCS that performs an RHR function during plant cooldown. Valve is normally "open" to align RHRS for ECCS operation during plant power operation and load follow. |

List of acronyms and abbreviations

Auto - Automatic
 CB - Control board
 CVCS - Chemical and volume control system
 ECCS - Emergency core cooling system
 RC - Reactor coolant
 RCS - Reactor coolant system
 RHR - Residual heat removal
 RHRS - Residual heat removal system
 RWST - Refueling water storage tank
 SG - Steam generator

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TABLE 5.4-10 PRESSURIZER DESIGN DATA

| | |
|---|-------|
| Design pressure, psig | 2,485 |
| Design temperature, °F | 680 |
| Surge line nozzle diameter, in. | 14 |
| Heatup rate of pressurizer using heaters only, °F/hr | 55 |
| Internal volume, ft ³ | 1,800 |
| Normal conditions at 100% rated load | |
| Steam volume, ft ³ | 720 |
| Water volume, ft ³ | 1,080 |

TABLE 5.4-11 REACTOR COOLANT SYSTEM
DESIGN PRESSURE SETTINGS

| | <u>Psig</u> |
|--|-------------|
| Hydrostatic test pressure | 3,107 |
| Design pressure | 2,485 |
| Safety valves (begin to open) | 2,460 |
| High pressure reactor trip | 2,385 |
| High pressure alarm | 2,310 |
| Power-operated relief valves | 2,335* |
| Pressurizer spray valves (full open) | 2,310 |
| Pressurizer spray valves (begin to open) | 2,260 |
| Proportional heaters (begin to operate) | 2,250 |
| Operating pressure | 2,235 |
| Proportional heater (full operation) | 2,220 |
| Backup heaters on | 2,210 |
| Low pressure alarm | 2,210 |
| | |
| Low pressure reactor trip | 1,885 |

* At 2,335 psig, a pressure signal initiates actuation (opening) of these valves. Remote manual control is also provided.

**TABLE 5.4-12 PRESSURIZER QUALITY
ASSURANCE PROGRAM**

| | <u>RT</u> ^(a) | <u>UT</u> ^(a) | <u>PT</u> ^(a) | <u>MT</u> ^(a) |
|--|--------------------------|--------------------------|--------------------------|--------------------------|
| Heads | | | | |
| Plates | | Yes | | |
| Cladding | | | | Yes |
| Shell | | | | |
| Plates | | Yes | | |
| Cladding | | | | Yes |
| Heaters | | | | |
| Tubing ^(b) | | Yes | Yes | |
| Centering of element | Yes | | | |
| Nozzle (Forgings) | | Yes | Yes ^(c) | Yes ^(c) |
| Weldments | | | | |
| Shell, longitudinal | Yes | | | Yes |
| Shell, circumferential | Yes | | | Yes |
| Cladding | | | Yes | |
| Nozzle safe end | Yes | | Yes | |
| Instrument connection | | | Yes | |
| Support skirt, longitudinal seam | Yes | | | Yes |
| Support skirt to lower head | | Yes | | Yes |
| Temporary attachments (after removal) | | | | Yes |
| All external pressure boundary welds after shop hydrostatic test | | | | Yes |

(a) RT - Radiographic
 UT - Ultrasonic
 PT - Dye Penetrant
 MT - Magnetic Particle

(b) Or a UT and ET

(c) MT or PT

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TABLE 5.4-13 PRESSURIZER RELIEF TANK
DESIGN DATA

| | |
|--|-----------------------|
| Design pressure, psig | 100 |
| Normal operating pressure, psig | 3 |
| Final operating pressure, psig | 50 |
| Rupture disc release pressure, psig | |
| Nominal | 91 |
| Range | 86 to 100 |
| Normal water volume, ft ³ | 1,350 |
| Normal gas volume, ft ³ | 450 |
| Design temperature, °F | 340 |
| Initial operating water temperature, °F | 120 |
| Final operating water temperature, °F | 200 |
| Total rupture disc relief capacity at 100 psig, lb/hr | 1.6 x 10 ⁶ |
| Cooling time required following maximum discharge approximately, hr | |
| Spray feed and bleed | 1 |
| Utilizing RCDT heat exchanger | 8 |

TABLE 5.4-14 RELIEF VALVE DISCHARGE
TO THE PRESSURIZER RELIEF TANK

Reactor Coolant System

- | | |
|--|---------------------------------------|
| 3 Pressurizer safety valves | Figure 5.1-1, Sheet 2 |
| 2 Pressurizer power-operated relief valves | Figure 5.1-1, Sheet 2 |

Residual Heat Removal System

- | | |
|---|------------------------------|
| 2 Residual heat removal pump suction line from the reactor coolant system hot legs | Figure 5.5-7 |
|---|------------------------------|

Chemical and Volume Control System

- | | |
|--------------------------|---------------------------------------|
| 1 Seal water return line | Figure 9.3-8, Sheet 1 |
| 1 Letdown line | Figure 9.3-8, Sheet 1 |

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TABLE 5.4-15 REACTOR COOLANT
SYSTEM VALVE DESIGN PARAMETERS

| | |
|--|-------------|
| Design/normal operating pressure, psig | 2,485/2,235 |
| Preoperational plant hydrotest, psig | 3,107 |
| Design temperature, °F | 650 |

TABLE 5.4-16 REACTOR COOLANT SYSTEM VALVES
NONDESTRUCTIVE EXAMINATION PROGRAM

| | | <u>RT</u> ^(a) | <u>UT</u> ^(a) | <u>PT</u> ^(a) |
|------------------------------|--|--------------------------|--------------------------|--------------------------|
| Boundary Valves, Pressurizer | | | | |
| Relief and Safety Valves | | | | |
| Castings | (larger than 4 inches) | Yes | | Yes |
| | (2 inches to 4 inches) | Yes ^(b) | | Yes |
| Forgings | (larger than 4 inches) | (c) | (c) | Yes |
| | (2 inches to 4 inches) | | | Yes |
| (a) | RT - Radiographic UT - Ultrasonic PT - Dye Penetrant | | | |
| (b) | Weld ends only | | | |
| (c) | Either RT or UT | | | |

**TABLE 5.4-17 PRESSURIZER VALVES
DESIGN PARAMETERS**

Pressurizer Safety Valves

| | |
|---|-------------------------|
| Number | 3 |
| Minimum relieving capacity at 2,485 psig, ASME rated flow, lb/hr | 420,000 |
| Set pressure, psig | 2,460 |
| Design temperature, °F | 650 |
| Fluid | Saturated steam |
| Transient condition, °F | (Superheated steam) 680 |
| Backpressure | |
| Normal, psig | 3 to 5 |
| Expected during discharge, psig | 500 |
| Environmental conditions | |
| Ambient temperature (°F) | 50 to 120 |
| Relative humidity (%) | 0 to 100 |

Pressurizer Power-Operated Relief Valves

| | |
|---|-------------------------|
| Number | 2 |
| Design pressure, psig | 2,485 |
| Design temperature, °F | 650 |
| Relieving capacity at 2,335 psig, per valve, lb/hr | 210,000 |
| Fluid | Saturated steam |
| Transient condition, °F | (Superheated steam) 680 |

APPENDIX 5.4A SAFE SHUTDOWN

5.4A.1 INTRODUCTION

The SNUPPS powerblock has been designed to enable the plant to be placed in a safe shutdown (hot standby or cold shutdown) condition, using only safety-related systems. The intent of Regulatory Guide 1.139 and BTP RSB 5-1 for achieving cold shutdown are met. Clarifications and specific exceptions to these guides are discussed in [Tables 5.4A-1](#) and [5.4A-2](#), respectively.

Appendix 3B and [Section 9.5.1](#) provide the results of integrated hazards analyses which demonstrate that the SNUPPS units have been designed to withstand postulated events. Items considered include tornados, floods, missiles, pipe breaks, fires, and seismic events. The single failure criteria utilized in the design are discussed in [Section 3.1](#).

The safe shutdown functions described in this Appendix are controlled and monitored from the control room. For a discussion of safe shutdown using controls and indications entirely outside of the control room, see [Section 7.4.3](#).

5.4A.2 SYSTEMS REQUIRED TO GO FROM HOT STANDBY TO COLD SHUTDOWN

In order to safely shutdown the plant, the following functions must be performed:

- a. Circulation of the reactor coolant
- b. Heat removal (short term and long term)
- c. Boration
- d. Depressurization

[Table 3.11\(B\)-3](#) provides a detailed listing of every component that is required to achieve and maintain a safe shutdown. The systems have redundancy/diversity, and no single failure will compromise safety functions. All power supplies and control functions for required portions of these systems are Class 1E, as described in [Chapters 7.0 and 8.0](#), except as described for the boric acid transfer system ([Section 9.3.4](#)). As discussed in [Section 3.2](#), all components meet the requirements of Regulatory Guides 1.26 and 1.29. The following are the major systems that are employed to achieve and maintain a safe shutdown:

- a. Reactor Coolant System (See [Chapter 5.0](#))
- b. Main Steam System (See [Section 10.3](#))
- c. Auxiliary Feedwater System (See [Section 10.4.9](#))

- d. Chemical and Volume Control System (See [Section 9.3.4](#))
- e. Borated Refueling Water System (See [Section 6.3](#))
- f. Residual Heat Removal System (See [Section 5.4.7](#))
- g. Component Cooling Water System (See [Section 9.2.2](#))
- h. Essential Service Water System (See [Section 9.2.1.2](#))
- i. Supportive HVAC Systems (See [Section 9.4](#))
- j. Emergency Diesel Generators (See [Sections 9.5.4 through 9.5.8](#))
- k. Spent Fuel Pool Cooling System (See [Section 9.1.3](#))
- l. Supportive Portions of Instrument Air System (See [Section 9.3.1](#))

Each of the system descriptions identifies the integral role that the system plays in achieving and maintaining a safe shutdown. Instrumentation applications for safe shutdown are described in this section and in [Chapter 7.0](#).

5.4A.3 SAFE SHUTDOWN SCENARIO

The plant is designed with a number of systems which will be used, if available under normal or emergency conditions, to safely shut down the plant. The following shutdown scenario demonstrates that the plant can be taken to a cold shutdown condition, using only safety-related equipment. Although the use of certain nonsafety-related items would be preferable in most situations, this scenario does not take credit for nonsafety-related items because of the assumptions stated in [Section 3.1](#) for the single failure criteria.

The safe shutdown licensing basis is hot standby and the safe shutdown design basis is cold shutdown. Should an event occur which would place the plant under a Limiting Condition of Operation, or if recovery from the event will cause the plant to be shut down for an extended period of time, the plant may be taken from a hot standby condition to a cold shutdown condition. The RHR system has a lower design pressure than the RCS. Therefore, cooldown from hot standby to cold shutdown requires a two-step process. During the first step, transfer of decay heat and the stored thermal energy of the reactor coolant system after reactor shutdown, will be via the steam generators. During the second step, the RHR system will be utilized as a means of heat transfer.

5.4A.3.1 Maintain a Hot Standby Condition

In the physical layout of the reactor coolant system, the reactor core is at a lower elevation with respect to the steam generators; consequently, the higher temperature

heat source is below the heat sink. This configuration ensures heat will be transported from the reactor core to the steam generators via the free convection flow phenomena.

Imbalance of forces is needed to initiate a convective flow. A thin layer of fluid near the heat transfer surfaces in the reactor core is heated, generating a gradient in temperature and density. When a particle of heated fluid is displaced from near the heat transfer surface, it enters a region of greater average density and is, therefore, subject to a buoyant force. The buoyancy force is opposed by viscous drag and by heat diffusion. Convection begins when buoyancy overcomes the dissipative effect of viscous drag and heat diffusion. As the temperature of the fluid in the reactor core is increased relative to the temperature of the fluid in the steam generators, a convective flow will be maintained throughout the reactor coolant system.

The auxiliary feedwater system, in conjunction with the safety-related portion of the main steam system, is initially relied upon to transfer residual core heat from the RCS, via the steam generators, to the atmosphere. This is accomplished by releasing steam from the secondary side of the steam generators, while maintaining steam generator pressure. Steam is released via the power-operated atmospheric steam dump (ASD) valves.

The auxiliary feedwater system is used to maintain a level in the steam generators during this period of time.

Water is provided to the auxiliary feedwater pumps (AFP) from the nonsafety-related condensate storage tank (CST); however, this tank is not seismic Category I and, in the case of an SSE or tornado hazard, the unprotected CST may be unavailable and is not credited for accident mitigation. In this case, redundant pressure transmitters in the suction lines of the auxiliary feedwater pumps (AFP) will detect loss of AFP suction pressure and isolate the AFP suction header from the CST. Concurrently, with CST isolation, the essential service water (ESW) pumps are started, and the valves in the ESW headers are opened to admit ESW to the AFPs.

The CST isolation valves are in series with check valves to further preclude the short-circuiting of ESW flow to the nonsafety-related CST. The ESW auxiliary feedwater supply valves are segregated by train relationships to the motor-driven AFPs with the turbine-driven AFP being fed by both train A and B ESW headers. Therefore, even with a single failure, ESW will be aligned to a minimum of one motor-driven AFP and the turbine-driven AFP.

The motor-operated AFP discharge valves are segregated by train relationship to the motor-driven AFPs, each pump feeding two steam generators. The turbine-driven AFP has two air-operated discharge valves of one train and two of the other, so as to have redundant and opposite train segregation to the motor-operated valves associated with the motor-driven AFPs. A safety-related gas supply is provided for these valves. In all cases, adequate auxiliary feedwater is supplied to the steam generators for residual heat removal.

The steam generator ASDs are air-operated valves segregated by train relationship with the steam generators, such that adequate relief capability exists at all times to accomplish residual heat removal. The ASDs are remotely controlled valves, which can either automatically maintain a preset pressure in the main steam piping or can be manually controlled from either the main control board, the auxiliary shutdown panel, or locally for AB-PV-2 and 3. A safety-related gas supply is provided for these valves.

In order to maintain an extended hot standby (greater than 24 hours), additional negative reactivity must be added to the RCS. This is accomplished by borating the RCS while relying on natural circulation in the RCS to ensure adequate mixing of the injected boric acid within the reactor coolant.

The design boration condition is based on adding sufficient boric acid to bring the reactor to a xenon-free cold shutdown condition from the hot full-power peak xenon condition. The addition of approximately 2700 gallons of minimum 7000 ppm boric acid is required within 25 hours after reactor shutdown from hot full power equilibrium xenon to maintain the reactor in a hot standby condition. This is equivalent to approximately 8,500 gallons of water from the refueling water storage tank (RWST) (at 2350 ppm boron). In terms of boron concentration in the RCS, this corresponds to approximately 300 ppm boron, assuming zero boron concentration in the RCS initially. A total of 13,450 gallons of makeup is required to maintain the RCS in a hot standby condition.

Boration may be accomplished by using the boric acid transfer pumps (BATPs) and boric acid tanks or by using the RWST and the ECCS centrifugal charging pumps. At least one BATP will be available under most plant conditions. Each pump is powered from a redundant separation group of the onsite emergency power distribution system. The supply circuit breakers are shunt tripped only upon the occurrence of an SIS. However, operation of the BATPs cannot be assured following a seismic event or upon occurrence of an SIS. When this is the case, the RWST will be used as the source of borated makeup to the RCS. The BAT system is available for all events following which the RWST is assumed to be unavailable. Redundant level indication for the BATs and RWST is provided on the MCB.

These level indications are used to determine that sufficient boron concentration has been attained for safe shutdown.

If the normal charging path is unavailable, boron will be added through one of two diverse flow paths in the charging system (reactor coolant pump seals or the boron injection path). Each path is capable of delivering a controlled flow of borated water, using jog control switches, from the RWST or BAT system which can be matched to the letdown rate in order to maintain pressurizer level. The emergency safety-related letdown path diverts cooled letdown (after the excess letdown heat exchanger) to the PRT. In addition, letdown from the RCS may also be accomplished, utilizing the pressurizer PORVs. These valves are powered by redundant power trains.

The PRT has a total volume capacity of 13,500 gallons. Prior to initiating letdown through the excess letdown heat exchanger, the 10,000 gallons of relatively clean water in the PRT can be discharged to the containment normal sump at a controlled rate. This will make the PRT available to contain the cooled letdown from the excess letdown heat exchanger and, thereby, minimize release of airborne radioactivity to the containment.

During the hot standby condition, the reactor coolant pump seals require cooling by either seal injection or component cooling water. Normally, the operator will ensure that a continuous source of component cooling water is provided. Subsequent seal injection via the ECCS charging pump should only be allowed based on RCS boration/inventory consideration. RCS leakage past the seal, with no seal injection, will go to the PRT via the seal return line relief valve, and the loss is considered in the RCS inventory.

5.4A.3.2 Achieve and Maintain Cold Shutdown

With the RCS in a hot standby condition, cold shutdown procedures may be initiated.

The essential functions which must be continued or initiated to achieve cold shutdown are:

- a. Continued residual heat removal via the steam generators, utilizing auxiliary feedwater and the atmospheric steam dump valves.
- b. Letdown and boration to cold shutdown boric acid concentrations.
- c. Continued circulation of the coolant in the RCS.
- d. RCS depressurization.
- e. Initiation of the residual heat removal (RHR) system when the RCS temperature and pressure are reduced below approximately 350°F and 400 psig.

Following boration to the cold shutdown concentration, cooldown is accomplished by increasing the steam dump from the steam generator ASDs to attain a primary side cooling of approximately 50°F/hr. In conjunction with this portion of the cooldown, the ECCS charging pumps are used to deliver refueling water to makeup for primary contraction due to cooling.

Letdown and boration to achieve cold shutdown boric acid concentrations are identical to procedures described above for the hot standby condition. The completion of this step requires that the RCS boron concentration be increased to approximately 1400 ppm boron at the beginning of an operating fuel cycle and to approximately 1000 ppm boron at the end of the cycle. These concentrations range from approximately 200 to 700 ppm higher than the boron concentrations at hot full power equilibrium xenon and about 500 to 1000 ppm higher than concentrations at hot full power peak xenon. The specific

required cold shutdown concentration for any time during any fuel cycle and for the actual xenon condition may be calculated by the plant operator using a written procedure.

Boration of the RCS to the cold shutdown concentration is required by procedure to be accomplished prior to any significant cooldown of the RCS. In order to maintain pressurizer level within the defined operating band, boration is a combined charging and letdown process. Typical volumes of water to be charged and letdown range from 33,500 to 40,000 gallons when the RWST is the source of borated water, depending on the fuel cycle burnup.

The RCS cold shutdown concentration is ensured by process control, i.e., knowledge of initial RCS boron concentrations and knowledge of amounts and concentrations of injected fluid (either RWST or BAT fluids) ensures that the cold shutdown concentration is obtained.

Continued circulation of RCS is accomplished by natural circulation resulting from heat removal via the steam generators.

Depressurization of the RCS is achieved through the use of the power-operated pressurizer relief valves. As previously stated, each valve has an independent safety-related power actuation train.

Prior to reducing RCS pressure below 1000 psig, it is necessary to ensure that all accumulator tank isolation valves are in the closed position to avoid their discharge to the RCS. For two of the four valves (those powered by the assumed operational diesel generator), this is accomplished from the associated MCC. If power is not available for the remaining two valves, the operator can vent cover gas from the affected accumulator.

When the RCS has been cooled and depressurized below approximately 350°F and 400 psig, the residual heat removal (RHR) system is put in service. This is done by establishing component cooling water flow through the RHR heat exchanger by opening the associated motor-operated valve and by closing the motor-operated isolation valves to the RCS cold legs and to the RHR pump suction from the RWST.

The next operation requires that the RCS/RHR isolation valves be opened. With a loss of offsite power in conjunction with the failure of one diesel generator, one of the two isolation valves in each RHR suction line cannot be opened from the main control board. In order to initiate system operation, the motor control center (MCC) of the failed diesel generator train must be energized by providing a temporary cable intertie from the MCC located in the opposite electrical penetration room powered by the operational diesel generator.

After opening the RCS/RHR isolation valves, the RHR pump is manually started to circulate flow through the miniflow line. Either of the miniflow bypass valves will

automatically open to maintain minimum flow based on the signal received from the flow indicating switch in the outlet piping of the pump.

At this point, it is possible to obtain a manual sample of the RHR loop fluid to ensure that the boron concentration is greater than or equal to the required cold shutdown RCS concentration. This sample can be obtained at any of several drain and vent connections, the local sample connection, or via the direct connection to the nuclear sampling system, if available. During this period of time, the operator has determined the status of the RHR system controls and is prepared to put the RHR system into operation. The next step is to establish flow from the RCS hot leg to the RCS cold legs via the RHR pump and heat exchanger. To do this, the RHR pump is stopped while the RHR/RCS cold leg return valve is opened.

The RHR pump is restarted to initiate the final cooldown phase. At this point, since the air-operated flow control valves may not be functional, administrative control is required to avoid excessive heat loads (and resulting excessive duty) on the component cooling water system. Two methods of achieving this control are: 1) only one RHR pump may be operated or two RHR pumps can be started/stopped, over an extended period of time, to limit the total heat load on the RHR heat exchangers, or 2) throttling of the CCW flow to the RHR heat exchanger can be accomplished. This will result in less flow, though at a higher temperature, back to the CCW heat exchangers.

Continued operation in this mode will decrease the RCS temperature to cold shutdown conditions.

The capability of the RHRSM to accommodate a single component failure and still perform a safety grade cooldown is demonstrated in the failure mode and effects analysis of the RHRS for safety-related cold shutdown operations provided as **Table 5.4A-3**.

TABLE 5.4A-1 DESIGN COMPARISON TO REGULATORY POSITIONS OF REGULATORY GUIDE 1.139 REV 1,
DRAFT 2 DATED FEBRUARY 25, 1980 TITLED "GUIDANCE FOR RESIDUAL HEAT REMOVAL TO ACHIEVE AND
MAINTAIN COLD SHUTDOWN:

A complete discussion of the SNUPPS plant cold shutdown capability is provided in [Appendix 5.4A](#).

| <u>REGULATORY POSITION</u> | <u>UNION ELECTRIC</u> |
|--|--|
| <p>1. FUNCTIONAL</p> <p>The <u>method utilized</u> to take the reactor from normal operating conditions to cold shutdown should satisfy the functional guidance presented below.</p> <ul style="list-style-type: none"> a. The design should be such that the reactor can be taken from normal operating conditions to cold shutdown using only <u>safety-related</u> systems that satisfy General Design Criteria 1 through 5. b. These <u>safety-related</u> systems should have suitable redundancy in components and features and suitable interconnection, leak detection and containment, and isolation capabilities to ensure that, for onsite electric power system operation (assuming offsite power is not available) and for offsite electric power system operation (assuming onsite power is not available), the system safety function can be accomplished assuming a single failure. <p>In demonstrating that the <u>method can be utilized</u> to perform its function assuming a single failure, limited operator action outside the control room would be acceptable if suitably justified. <u>Necessary operator actions to maintain hot shutdown or proceed from that plant condition to cold shutdown should be planned no sooner than one hour from the time when shutdown is commenced.</u> This limited operator action should not result in an exposure beyond the allowed limits assuming high radio-activity in the reactor coolant or containment building environment.</p> <ul style="list-style-type: none"> c. The <u>method</u> should be capable of bringing the reactor to a <u>hot</u> shutdown condition, <u>where RHR cooling may be initiated</u>, within <u>approximately</u> 36 hours following shutdown with only offsite power or onsite power available, assuming the most limiting single failure. d. <u>Instrumentation and controls including protective measures and interlocks associated with the safety-related systems required to achieve or maintain cold shutdown should meet the requirements of IEEE Standards 279-1971, 323, 384, and 344 and the guidance provided in Regulatory Guides 1.89, 1.75, and 1.100.</u> e. <u>The safety-related systems should be classified as Seismic Category I and meet the guidance provided in Regulatory Guide 1.29.</u> | <p>1a. The reactor coolant system, in conjunction with several supporting systems, can be brought to a cold shutdown condition following any given hazard (GDCs 2, 3, and 4) using safety-related systems (design in compliance with GDC 1).</p> <p>1b. Complies. Section 3.1.2 provides the single failure criteria that is used, including the bases for operator action outside the control room. Table 5.4A-3 provides a safety related cold shutdown (CSD) FMEA.</p> <p>1c. Complies. See Section 5.4.7.2.1.</p> <p>1d. Except for the boric acid transfer system controls and the pressurizer heaters, the instrumentation and controls are designed in accordance with applicable Regulatory Guides and IEEE standards. The highly reliable design of the pressurizer heaters and the BAT system (both of which are capable of being manually loaded on the diesels) are described in Sections 5.4, 7.4, 8.3, and 9.3.4.</p> <p>1e. Except as discussed in 1d, all components and systems comply.</p> |

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TABLE 5.4A-1 (Sheet 2)

| <u>REGULATORY POSITION</u> | <u>UNION ELECTRIC</u> |
|--|--|
| 2. REACTIVITY CONTROL | 2. Complies. |
| A safety-related system should meet GDC 1-5, 26, and 27 and be capable of controlling and monitoring boron concentration in order to ensure reactor subcriticality from operating conditions through cold shutdown. | |
| 3. HEAT REMOVAL TO REDUCE THE RCS FROM PLANT OPERATING CONDITIONS TO RHR SYSTEM OPERATING CONDITIONS | |
| a. PWR Plants | |
| (1) <u>Auxiliary Feedwater System</u> | 3.a.(1) The auxiliary feedwater system complies with these requirements, as discussed in 10.4.9. The essential service water system (Section 9.2.1.2) which provides the ultimate water supply has adequate inventory to supply short-term and long-term requirements. |
| A safety-related auxiliary feedwater system should be designed and constructed to provide a reliable source of cooling water at PWR plants in accordance with GDC 1-5, 44, 45, and 46. The safety-related water supply for the auxiliary feedwater system for a PWR should have sufficient inventory to permit operation at hot-standby conditions for at least 4 hours followed by cooldown to the conditions permitting operation of the RHR system. The inventory needed for cooldown should be based on the longest cooldown time needed with either only onsite or only offsite power available with an assumed single failure. The capability should exist for providing cooling water from the ultimate heat sink prior to exhaustion of the safety-related water supply. Automatic initiation should be provided for the auxiliary feedwater system. The automatic initiation signals and circuits should be safety-related and be designed so that a single failure will not result in the loss of AFWS function. Testability of the initiating signals and circuits should be a feature of the design. Manual initiation capability from the control room should be safety-related and be designed so that a single failure will not result in the loss of system function. The a-c motor-driven pumps and valves in the AFWS should be included in the automatic actuation (simultaneous and/or sequential) of the loads to the emergency buses. The automatic initiating signals and circuits should be designed so that their failure will not result in the loss of manual capability to initiate the AFWS from the control room. A safety-related redundant system should be provided for indication in the control room of auxiliary feedwater flow to each steam generator. | Safety-related (Class 1E) indication of the AFW flow to each generator is provided in the control room. Safety-related steam generator level indication provides a backup means of determining the AFW flow. |
| (1) <u>Steam Relief</u> | 3.a.(2) Complies, as discussed in Section 10.3 . |
| A safety-related redundant atmospheric secondary side steam relief system should be designed to provide for reduction of the RCS temperature to RHR system operating conditions. | |
| (2) <u>Steam Generator Inventory</u> | 3.a.(3) Complies, as discussed in Section 10.4.7 . |
| Each steam generator should be equipped with a safety-related redundant water level indication and alarm system. | |

TABLE 5.4A-1 (Sheet 3)

| <u>REGULATORY POSITION</u> | <u>UNION ELECTRIC</u> |
|--|---|
| b. BWR Plants | 3.b. Not applicable to SNUPPS. |
| (1) Steam Relief | A safety-related redundant steam relief system should be designed to allow for controlled reactor coolant system depressurization by steam relief to the pressure suppression pool. |
| (2) Reactor Vessel Inventory | The reactor vessel should be equipped with a safety-related redundant water level indication and alarm system. |
| 4. RESIDUAL HEAT REMOVAL | 4. The RHR system meets the applicable GDCs, as described in Section 5.4.7 . |
| The RHR system should meet GDC 1-5 and 34 with at least two redundant trains of pumps and heat exchangers. Beginning 4 hours after reactor shutdown, each train should have sufficient heat removal capability (a) for maintaining the RCS at hot shutdown (RHR system initial operating conditions) at that time in core life when the greatest amount of decay and residual heat is present, and (b) to provide for cooldown of the RCS from hot shutdown to cold shutdown conditions. | |
| a. RHR System Isolation | |
| (1) Isolation of the suction side of <u>each RHR system train from direct RCS pressure</u> should be provided by at least two power-operated valves in series, with valve position indicated in the control room. Alarms in the control room should be provided to alert the operator if either valve is open when the RCS pressure exceeds the RHR system design pressure. The <u>isolation valve system</u> should <u>have two or more</u> independent interlocks to prevent the valves from being opened unless the RCS pressure is below the RHR system design pressure. <u>Upon loss of actuating power, isolation valves should not change position unless movement is to a position that provides greater safety.</u> The <u>isolation valve system</u> should <u>have two or more</u> independent protective measures to close any open valve in the event of an increase in the RCS pressure above the RHR system design pressure. All isolation valves on the <u>discharge and suction sides of the RHR system</u> should be classified ASME OM Code Subsection ISTC, Category A, and be leak tested at each refueling outage. | 4.a.1 Complies, except that automatic closure in the event of an increase in RCS pressure is not provided. Instead, a control room alarm will alert the operator if a valve is open when RCS pressure exceeds RHR system design pressure. Operating procedures will verify that isolation valves are closed prior to increasing RCS pressure above RHR system design pressures. See Section 5.4.7 . |
| (2) One of the following should be provided on the discharge side of the RHR system to isolate it from the RCS: | 4.a.2 Complies. Meets Paragraph C. |
| (a) The valves, position indicators, alarms, and interlocks described in item (1). | |

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TABLE 5.4A-1 (Sheet 4)

| <u>REGULATORY POSITION</u> | <u>UNION ELECTRIC</u> |
|---|--|
| (b) One or more check valves in series with a normally closed power-operated valve. <u>The position of the power-operated valve should be indicated in the control room.</u> If the RHR system discharge line is used for an ECCS function, the power-operated valve should be opened upon receipt of a safety-injection signal once the reactor coolant pressure has decreased below the ECCS design pressure. | |
| (c) Two check valves in series. | |
| b. RHR System Pressure Relief | 4.b. Complies, as described in Sections 5.2.2.10 and 5.4.7.2.5 . |
| To protect the RHR system against accidental overpressurization when it is in operation (not isolated from the RCS), pressure relief in the RHR system should be provided with relieving capacity in accordance with the ASME Boiler and Pressure Vessel Code. The most limiting pressure transient during the plant operating condition when the RHR system is not isolated from the RCS should be considered when selecting the pressure relieving capacity of the RHR system. For example, during shutdown cooling in a PWR with no steam bubble in the pressurizer, inadvertent operation of an additional charging pump in the normal charging mode or a high head ECCS pump (for those plants at which the high head pumps serve a dual function) should be considered in selecting the design bases. | |
| Fluid discharge through the RHR system pressure relief valves should be collected and contained so that a relief valve that is stuck in the open position will not: | |
| (1) Result in flooding of any safety-related equipment. | |
| (2) Reduce the capability of the ECCS below that needed to mitigate the consequences of a postulated LOCA. | |
| (3) Result in a non-isolatable situation in which the water provided to the RCS to maintain the core in a safe condition is discharged outside the containment. | |
| If interlocks are provided to automatically close the isolation valves when the RCS pressure exceeds the RHR design pressure, relief capacity should be provided during the time that the valves are closing <u>such as to prevent the RHR design pressure from being exceeded.</u> | |
| c. RHR System Pump Protection | 4.c. Complies. See Section 5.4.7 . |
| The design and operating procedures of the RHR system and plant operating procedures should be such that no single failure or single operator error can result in loss of the RHR function <u>due to damage of the RHR system pumps including overheating, cavitation, or loss of adequate pump suction head.</u> | |

TABLE 5.4A-1 (Sheet 5)

| <u>REGULATORY POSITION</u> | <u>UNION ELECTRIC</u> |
|--|--|
| d. RHR System Testing | 4.d. Complies. See Chapters 7.0 and 8.0 for IEEE testing. See the responses to Regulatory Guides 1.22 and 1.68 for testing. |
| For the RHR system, the isolation valve operability and interlock circuits should be designed to permit on-line testing when operating in the RHR mode. System testing should meet the requirements of IEEE Standard 338 and the <u>guidance</u> of Regulatory Guide <u>1.118</u> . | |
| The preoperational and initial startup test program should be in conformance with Regulatory Guide 1.68. <u>In addition</u> , the programs for pressurized water reactors should include tests with supporting analysis to confirm (a) that adequate mixing of borated water added to <u>the reactor coolant system</u> prior to or during cooldown can be achieved under natural circulation conditions and permit estimation of the times required to achieve such mixing and (b) that the cooldown under natural circulation conditions can be achieved within the <u>guidelines</u> specified in the emergency operating procedures. | |
| <u>The RHR system should be designed to permit on-line pressure and functional testing to assure</u> | |
| (1) <u>the structural and leaktight integrity of its components.</u> | |
| (2) <u>the operability and performance of the active components of the system, and</u> | |
| (3) <u>the operability of the system as a whole and, under conditions as close to design as practical, the transfer between normal and emergency power sources, and the operation of the associated cooling water system.</u> | |
| e. RHR System Operational Indication | 4.e. Complies. |
| <u>Indication of isolation valve position, system pressure and flow, and pump operating status should be available in the control room.</u> | |
| f. RHR System Integrity | 4.f. Complies. |
| <u>The RHR system should be designed and constructed to have the capability to remove heat from the reactor coolant during normal and following accident conditions. Since the reactor coolant may be highly radioactive following accident conditions, the RHR system integrity should be such that radioactivity is not released to the environment beyond accepted limits. The design should include features to prevent unacceptable degradation of long-term heat removal capability and leakage resulting from a degraded core condition or the containment post-accident environment. In addition, the system should be designed so that the operator can assess the status, isolate, maintain and repair the RHR system, as needed. Specifically, the RHR system integrity should meet the following criteria:</u> | |

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TABLE 5.4A-1 (Sheet 6)

| <u>REGULATORY POSITION</u> | <u>UNION ELECTRIC</u> |
|--|--|
| (1) <u>Leakage from the system such as from valves and pump seals should be monitored and controlled. The leakage limits at which an RHR train is to be declared inoperable and isolated should be stated in the Plant Technical Specifications. Indication of the amount of leakage, such as sump level indication, radiation levels and system isolation should be available locally and in the control room. Valve lineup and isolation capability should be such as to preclude the possibility that highly radioactive sump water can be automatically transferred to the radwaste processing system.</u> | 4.f.1 Complies, leakage detection is discussed in Section 9.3.3 . |
| (2) <u>Shielding should be provided to maintain personnel exposure as low as is reasonably achievable (ALARA). Shielding protection should also be provided for instruments, components, or other items which might be adversely affected by high radiation fields. Provisions should be made for access to, and minor repair of, equipment outside containment which may fail during a post-incident recovery period.</u> <u>Provisions should be made for tie-in of additional equipment or systems in the event that major repair is necessary. Area temperature monitoring and control should be provided for the RHR system environment with indication and control in the control room.</u> | 4.f.2 Complies, except that area temperature monitoring is not provided for the SNUPPS project. High temperature alarm is provided in the MCR for the RHR pump rooms. Compliance with ALARA requirements are discussed in Section 12.3.1 . |
| (3) <u>The RHR system including the leakage collection sump should be located in a closed area which is equipped with an engineered safety feature filtration system (as given in Regulatory Guide 1.52) and radiation monitors. These areas should be maintained at a sufficient negative pressure (typically, at least - 1/8 inch. water gauge) with respect to the ambient atmosphere to prevent exfiltration of activity which could bypass the ESF filter system.</u> | 4.f.3 The emergency exhaust filtration system which serves this function following an LOCA is discussed in Sections 9.4.2 and 9.4.3 . |
| g. <u>RHR Cooling Water Supply System</u> <u>The safety-related system should be designed and constructed with at least two independent subsystems or trains such that each has the capacity to adequately remove heat from the reactor coolant in accordance with GDC 1, 2, 3, 4, 5, 44, 45 and 46. Cooling water radioactivity should be monitored at the output of the RHR heat exchangers with indication and an alarm in the control room.</u> | 4.g Complies, except that the radiation monitors are not located on the outlet of the RHR heat exchanger. Instead, each train of component cooling water is provided with radiation monitors within the system. See Section 9.2.2 . |

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TABLE 5.4A-1 (Sheet 7)

REGULATORY POSITION

5. NATURAL CIRCULATION COOLING FOR PWR PLANTS

To ensure the capability to achieve and maintain natural circulation within the primary system, redundant emergency power, which meets General Design Criteria 17 and 18, should be provided to each of the following:

- a. The minimum number of pressurizer heaters required to maintain natural circulation conditions.
- b. The control and motive power systems for the power-operated relief valves and associated block valves, and
- c. The pressurizer level indication instrument channels.

6. REACTOR COOLANT SYSTEM INVENTORY

a. PWR Plants

A safety-related system should be designed and constructed to meet GDC 1-5 and 33 and capable of providing reactor coolant makeup and letdown control with a sufficient water supply to account for cooldown shrinkage, required letdown for boration, and technical specification allowed leakage from operating conditions to cold shutdown.

b. BWR Plants

A safety-related system (or systems) should meet GDC 1-5 and 33 and be designed and constructed to provide a reliable source of makeup water to the reactor coolant inventory. A safety-related water supply should have sufficient inventory to permit maintenance of plant operating conditions for at least 4 hours followed by cooldown to RHR system operating conditions.

UNION ELECTRIC

5. Complies. See response to Regulatory Guides 1.22 and 1.68. The natural circulation test was performed at Diablo Canyon and verified by a partial test at Callaway.

The unit is provided with two groups of backup pressurizer heaters. The heater groups and their associated controls are powered from a diesel-backed bus through qualified isolation devices that shed their load only upon an SIS or emergency bus undervoltage signal. If desired, these devices can be manually reclosed from the control room, following reset of the initiating trip signals. The emergency diesel generators are sized in excess of that required to carry all connected pressurizer heaters concurrent with the loads required for a LOCA. They are provided with a full complement of status indication in the control room.

The pressurizer is provided with two Class 1E power-operated relief valves (PORV) and two Class 1E power-operated relief valve isolation valves (PORVIV). These valves are powered from the onsite emergency power supply, with redundant Class 1E power supplying the two valves associated with each flow path.

Three loops of the pressurizer level instrumentation are powered from Class 1E power supplies. In addition, a fourth nonsafety grade instrumentation loop is provided.

- 6.a Complies. The chemical and volume control system is described in **Section 9.3.4.**

- 6.b Not applicable to SNUPPS.

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TABLE 5.4A-1 (Sheet 8)

| <u>REGULATORY POSITION</u> | <u>UNION ELECTRIC</u> |
|--|-----------------------|
| <p><u>7. OPERATIONAL PROCEDURES</u></p> <p>The operational procedures for bringing the plant from normal operating power to cold shutdown should be in conformance with Regulatory Guide 1.33. For pressurized water reactors, the operational procedures should include specific procedures and information required for cooldown under natural circulation conditions. <u>In addition, plant procedures for all activities should provide instruction in such a manner that will not lead to a loss of the RHR system.</u></p> <p><u>Emergency procedures should address cooldown during or after an accident, including natural circulation cooldown in the case of PWR plants. These emergency procedures should include guidance on safe shutdown to cold conditions in the event of failure of non-safety-related equipment and single failures of safety-related equipment. Other cases which the emergency procedures should address are RHR heat exchanger tube leak, high radioactivity in the reactor coolant, and high airborne radioactivity in the RHR system room.</u></p> <p><u>Emergency procedures should be prepared to address the transfer of the pressurizer heaters to the emergency power source in the event that this action is necessary. The method and time required to accomplish the transfer of the preselected pressurizer heaters to the emergency buses should be described in written approved procedures and be consistent with the timely initiation and maintenance of natural circulation.</u></p> | <p>7. Complies.</p> |

**TABLE 5.4A-2 DESIGN COMPARISON OF TABLE 1 OF BTP RSB 5-1 FOR
POSSIBLE SOLUTIONS FOR FULL COMPLIANCE**

| <u>Design Requirements of BTP RSB 5-1</u> | <u>Process and (System or Component)</u> | <u>Possible Solution for Full Compliance</u> | <u>Union Electric</u> |
|---|--|---|--|
| I. Functional Requirement for Taking to Cold Shutdown <ul style="list-style-type: none"> a. Capability using only safety grade systems b. Capability with either only onsite or only offsite power and with single failure (limited action outside CR to meet SF) c. Reasonable time for cooldown, assuming most limiting SF and only offsite or only onsite power | Long-term cooling (RHR drop line) | Provide double drop line (or valves in parallel) to prevent single valve failure from stopping RHR cooling function. (Note: This requirement in conjunction with meeting effects of single failure for long-term cooling and isolation requirements involve increased number of independent power supplies and possibly more than four valves.) | Series power-operated valves are provided in both RHR/RCS shutdown lines. Design can withstand a single failure, as discussed in Section 5.4.7. |

TABLE 5.4A-2 (Sheet 2)

| <u>Design Requirements of BTP RSB 5-1</u> | <u>Process and (System or Component)</u> | <u>Possible Solution for Full Compliance</u> | <u>Union Electric</u> |
|---|---|--|--|
| | Heat removal and RCS circulation during cooldown to cold shutdown. (Note: Need SG cooling to maintain RCS circulation even after RHRs in operation when under natural circulation) (steam dump valves.) | Provide safety-grade dump valves, operators, and power supply, etc. so that manual action should not be required after SSE, except to meet single failure. | Complies. |
| | Depressurization (Pressurizer auxiliary spray or power-operated relief valves) | Provide upgrading and additional valves to ensure operation of auxiliary pressurizer spray, using only safety-grade subsystem meeting single failure. Possible alternative may involve using pressurizer power-operated relief valves which have been upgraded. Meet SSE and single failure without manual operation inside containment. | Complies. Fully qualified Class 1E pressurizer power-operated relief valves are provided |

TABLE 5.4A-2 (Sheet 3)

| <u>Design Requirements of BTP RSB 5-1</u> | <u>Process and (System or Component)</u> | <u>Possible Solution for Full Compliance</u> | <u>Union Electric</u> |
|---|--|--|--|
| | Boration for cold shutdown (CVCS and boron sampling) | Provide procedure and upgrading where necessary, such that boration to cold shutdown concentration meets the requirements of I. Solution could range from (1) upgrading and adding valves to have both letdown and charging paths safety grade and meet single failure to (2) use of backup procedures involving less cost. For example, boration without letdown may be acceptable and eliminate need for upgrading letdown path. Use of ECCS for injection of borated water may also be acceptable. Need surveillance of boron concentration (boronometer and/or sampling). Limited operator action inside or outside of containment if justified. | The excore detector will alert the operator of any criticality potential. Charging to and letdown from the RCS are controlled quantities. No boron sampling is required. |
| II. RHR Isolation | RHR System | Comply with one of allowable arrangements given. | II. Complies. See Section 5.4.7. |
| III. RHR Pressure Relief | | | |

TABLE 5.4A-2 (Sheet 4)

| <u>Design Requirements of BTP RSB 5-1</u> | <u>Process and (System or Component)</u> | <u>Possible Solution for Full Compliance</u> | <u>Union Electric</u> |
|--|--|---|---|
| b. Collect and contain relief discharge | RHR System | Determine piping, etc., needed to meet requirement and provide in design. | III. Complies. See Section 5.4.7. |
| V. Test Requirement | | | |
| b. Meet R.G. 1.68. For PWRs, test plus analysis for cooldown under natural circulation to confirm adequate mixing and cooldown within limits specified in EOP. | | Run tests and confirming analysis to meet requirement. | V. Complies. See R.G. 1.68 response. The natural circulation test was performed at Diablo Canyon and verified by a partial test at Callaway. |
| VI. Operational Procedure | | | |
| a. Meet R.G. 1.33. For PWRs, include specific procedures and information for cooldown under natural circulation. | | Develop procedures and information from test and analysis. | VI. Complies. |
| VII. Auxiliary Feedwater Supply | Emergency Feedwater Supply | | |

TABLE 5.4A-2 (Sheet 5)

| <u>Design Requirements of BTP RSB 5-1</u> | <u>Process and (System or Component)</u> | <u>Possible Solution for Full Compliance</u> | <u>Union Electric</u> |
|--|--|--|---|
| a. Seismic Category I supply for auxiliary FW for at least 4 hours at hot shutdown plus cooldown to RHR cut-in based on longest time for only onsite or only offsite power and assumed single failure. | | From tests and analysis obtain conservative estimate of auxiliary FW supply to meet requirement and provide seismic Category I supply. | VII. Preoperational and startup test will establish the amount of makeup water required. Essential service water is the seismic Category I supply. Hot shutdown is within the RHR cut-in temperature; therefore, there is no ensuing cooldown required. |

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TABLE 5.4A-3 RESIDUAL HEAT REMOVAL - SAFETY RELATED COLD SHUTDOWN OPERATIONS - FAILURE MODES AND EFFECTS ANALYSIS (FMEA)

| <u>Component</u> | <u>Failure Mode</u> | <u>Function</u> | <u>Effect on System Operation*</u> | <u>Failure Detection Method**</u> | <u>Remarks</u> |
|--|--|---|---|---|--|
| 1. Motor-operated gate valve EJ-HV-8701A (EJ-HV-8701B analogous) | Fails to open on demand. | Provides isolation of fluid flow from the RCS to RHR pump 1 (pump 2). | Failure blocks RC flow from hot leg of RC loop 1 through train "A" of RHR. Fault reduces redundancy of RHR coolant trains provided. No effect on safety for system operation. Plant cooldown requirements will be met by RC flow from hot leg of RC loop 4 flowing through train "B" of RHR. However, time required to reduce RCS temperature will be extended. | Valve position indication (closed to open position change) at CB; RHR train "A" discharge flow indication (EJ-FI-618) and low flow alarm at CB; and RHR pump discharge pressure indication (EJ-PI-614) at CB. | <p>1. Valve is electrically interlocked with the containment sump isolation valve EJ-HV-8811A and the RWST isolation valve BN-HV-8812A, with RHR to charging pump suction line isolation valve EJ-HV-8804A and with a "prevent-open" pressure interlock (BB-PB-405A) off the seal table. The valve cannot be opened remotely from the CB if one of the indicated isolation valves is open or if RC loop pressure exceeds 360 psig. The valve can be manually opened. See Section 5.4.7.2.7.</p> <p>2. If both trains of RHRs are unavailable for plant cooldown due to multiple component failures, the auxiliary feedwater system and SG power-operated relief valves can be used to perform the safety function of removing residual heat.</p> |
| 2. Motor-operated gate valve BB-PV-8702A (BB-PV-8702B analogous) | Same failure modes as those stated for item 1. | Same function as that stated for item 1. | Same effect on system operation as that stated for item 1. | Same methods of detection as those stated for item 1. | Same remarks as those stated for item 1., except for pressure interlock (BB-PB-403A) control. |

* See list at end of table for definition of acronyms and abbreviations used.

** As part of plant operation, periodic tests, surveillance inspections, and instrument calibrations are made to monitor equipment and performance. Failures may be detected during such monitoring of equipment, in addition to detection methods noted.

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TABLE 5.4A-3 (Sheet 2)

| <u>Component</u> | <u>Failure Mode</u> | <u>Function</u> | <u>Effect on System Operation*</u> | <u>Failure Detection Method**</u> | <u>Remarks</u> |
|--|---------------------------------|---|---|--|--|
| 3. RHR pump 1 (RHR pump 2 analogous) | Fails to deliver working fluid. | Provides fluid flow of RC through RHR heat exchanger 1 (heat exchanger 2) to reduce RCS temperature during cooldown operation. | Failure results in loss of RC flow from hot leg of RC loop 1 through train "A" of RHRS. Fault reduces redundancy of RHR coolant trains provided. No effect on safety for system operation. Plant cooldown requirements will be met by RC flow from hot leg of RC loop 4 flowing through train "B" or RHRS. However, time required to reduce RCS temperature will be extended. | Open pump switchgear circuit breaker indication at CB; circuit breaker close position monitor light for group monitoring of components at CB; common breaker trip alarm at CB; RHR train "A" discharge flow indication (EJ-FI-618) and low flow alarm at CB; and pump discharge pressure indication (EJ-PI-614) at CB. | The RHRS shares components with the ECCS. Pumps are tested as part of the ECCS testing program (see Section 6.3.4). Pump failure may also be detected during ECCS testing. |
| 4. Motor-operated gate valve EJ-FCV-610 (EJ-FCV-611 analogous) | a. Fails to open on demand. | Provides regulation of fluid flow through miniflow bypass line to suction of RHR pump 1 (pump 2) to protect against overheating of the pump and loss of discharge flow from the pump. | Failure blocks miniflow line to suction of RHR pump "A". RHR train "A" is degraded for the protection of RHR pump A. No effect on safety for system operation. Plant cooldown requirements will be met by operator action of controlling cooldown with redundant RHR train "B". However, time required to reduce RCS temperature will be extended. | Valve position indication (closed to open position change) at CB. | Valve is automatically controlled to open when pump discharge is less than 816 gpm at 300°F (783 gpm at 68°F) and close when the discharge exceeds 1,650 gpm at 300°F (1582 gpm at 68°F). CB switch set to "Auto" position for automatic control of valve positioning. |

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TABLE 5.4A-3 (Sheet 3)

| <u>Component</u> | <u>Failure Mode</u> | <u>Function</u> | <u>Effect on System Operation*</u> | <u>Failure Detection Method**</u> | <u>Remarks</u> |
|---|------------------------------|--|--|--|--|
| | b. Fails to close on demand. | Same function as that stated for item 4.a. | Failure allows for a portion of RHR heat exchanger "A" discharge flow to be bypassed to suction of RHR pump "A". RHRS train "A" is degraded for the regulation of coolant temperature by RHR heat exchanger "A." No effect on safety for system operation. cooldown of RCS within established specification cooldown rate may be accomplished through operator action of throttling flow control valve EJ-HCV-606 and controlling cooldown with redundant RHRS train "B." | Valve position indication (open to closed position change) and RHRS train "A" discharge flow indication (EJ-FI-618) at CB. | |
| 5. Air diaphragm-operated butterfly valve EJ-FCV-618 (EJ-FCV-619 analogous) | a. Fails to open on demand. | Controls rate of fluid flow bypassed around RHR heat exchanger 1 (heat exchanger 2) during cooldown operation. | Failure prevents coolant discharged from RHR pump "A" from bypassing RHR heat exchanger "A" resulting in mixed mean temperature of coolant flow to RCS being low. RHRS train "A" is degraded for the regulation of controlling temperature of coolant. No effect on safety for system operation. cooldown of RCS within established specification rate may be accomplished through operator action of throttling flow control valve EJ-HCV-606 and controlling cooldown with redundant RHRS train "B." | RHR pump "A" discharge flow temperature and RHRS train "A" discharge to RCS cold leg flow temperature recording (EJ-TR-612) at CB; and RHRS train "A" discharge to RCS cold leg flow indication (EJ-FI-618) at CB. | <ul style="list-style-type: none"> 1. Valve is designed to fail "closed" and is electrically wired so that electrical solenoid of the air diaphragm operator is energized to open the valve. Valve is normally "closed" to align RHRS for ECCS operation during plant power operation and load follow. 2. Valve operation is not required for safety grade cold shutdown operations. |

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TABLE 5.4A-3 (Sheet 4)

| <u>Component</u> | <u>Failure Mode</u> | <u>Function</u> | <u>Effect on System Operation*</u> | <u>Failure Detection Method**</u> | <u>Remarks</u> |
|---|---|--|--|---|---|
| | b. Fails to close on demand. | Same function as that stated for item 5.a. | Failure allows coolant discharged from RHR pump "A" to bypass RHR heat exchanger "A", resulting in mixed mean temperature of coolant flow to RCS being high. RHRS train "A" is degraded for the regulation of controlling temperature of coolant. No effect on safety for system operation. Cooldown of RCS within established specification rate may be accomplished through operator action of throttling flow control valve EJ-HCV-606 and controlling cooldown with redundant RHRS train "B." However, cooldown time will be extended. | Same methods of detection as those stated for item 5.a. | |
| 6. Air diaphragm-operated butterfly valve EJ-HCV-606 (EJ-HCV-607 analogous) | a. Fails to close on demand for flow reduction. | Controls rate of fluid flow through RHR heat exchanger 1 (heat exchanger 2) during cooldown operation. | Failure prevents control of coolant discharge flow from RHR heat exchanger "A", resulting in loss of mixed mean temperature coolant flow adjustment to RCS. No effect on safety for system operation. Cooldown of RCS within established specification rate may be accomplished by operator action of controlling cooldown with redundant RHRS train "B." | Same methods of detection as those stated for item 5.a. In addition, monitor light and alarm (valve closed) for group monitoring of components at CB. | <ul style="list-style-type: none"> 1. Valve is designed to fail "open". Valve is normally "open" to align RHRS for ECCS operation during plant power operation and load follow. 2. Valve operation is not required for safety grade cold shutdown operations. |
| | b. Fails to open on demand for increased flow. | Same function as that stated for item 6.a. | Same effect on system operation as that stated for item 6.a. | Same methods of detection as those stated for item 6.a. | |
| 7. No entry | | | | | |

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TABLE 5.4A-3 (Sheet 5)

| <u>Component</u> | <u>Failure Mode</u> | <u>Function</u> | <u>Effect on System Operation*</u> | <u>Failure Detection Method**</u> | <u>Remarks</u> |
|---|------------------------------|---|--|---|---|
| 8. No entry | | | | | |
| 9. Motor-operated gate valve BN-HV-8812A (BN-HV-8812B analogous) | Fails to close on demand. | RWST to RHR suction isolation | Failure prevents isolation of RWST from RHR pump 1 (pump 2). Negligible effect on safety for system operation. Alternate RHR train is available by isolating RWST to RHR pump 2 (pump 1) via isolation valve BN-HV-8812B (BN-HV-8812A). Only effect is an increase in time required to reduce RCS temperature. | Valve position indication (open to closed position change) at CB. Valve closed position monitor light and alarm for group monitoring of components. | <p>1. Valve is normally open during plant operation (for alignment of ECCS). Valve interlocked so it must be closed before valves EJ-HV-8701A and BB-PV-8702A (EJ-HV-8701B and BB-PV-8702B) can be opened.</p> <p>2. See item 3 "Effect on System Operation".</p> |
| 10. Solenoid-operated globe valve BG-HV-8154A (BG-HV-8154B analogous) | a. Fails to open on demand. | Provides isolation of fluid flow from the RCS to the PRT via the excess letdown heat exchanger. | Failure reduces redundancy of providing flow from the RCS to the PRT. Negligible effect on safety for system operation. Letdown flow provided by parallel letdown path through alternate isolation valve BG-HV-8154B (BG-HV-8154A). | Valve open/close position indication at CB; and letdown high temperature indication and alarm at CB. | The letdown path to the PRT provides fluid flow out of the RCS to accommodate boration makeup flow into the RCS. |
| | b. Fails to close on demand. | Same function as that stated for item 10.a. | Failure reduces redundancy of isolating flow from the RCS to the PRT. Negligible effect on safety for system operation. RCS letdown flow isolation provided by alternate series isolation valve BG-HV-8153A (BG-HV-8153B). | Same methods of detection as those stated for item 10.a. | |
| 11. Solenoid-operated globe valve BG-HV-8153A (BG-HV-8153B analogous) | a. Fails to open on demand. | Same function as that stated for item 10.a. | Same effect on system operation as that stated for item 10.a, except for alternate isolation valve BG-HV-8153B (BG-HV-8153A). | Same methods of detection as those stated for item 10.a. | Same remarks as those stated for item 10.a. |

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TABLE 5.4A-3 (Sheet 6)

| <u>Component</u> | <u>Failure Mode</u> | <u>Function</u> | <u>Effect on System Operation*</u> | <u>Failure Detection Method**</u> | <u>Remarks</u> |
|---|------------------------------|---|--|---|--|
| | b. Fails to close on demand. | Same function as that stated for item 10.a. | Same effect on system operation as that stated for item 10.b, except for alternate series isolation valve BG-HV-8154A (BG-HV-8154B). | Same methods of detection as those stated for item 10.a. | |
| 12. Solenoid-operated globe valve BB-HV-8157A (BB-HV-8157B analogous) | Fails to open on demand. | Same function as that stated for item 10.a. | Same effect on system operation as that stated for item 10.a, except for alternate parallel isolation valve BB-HV-8157B (BB-HV-8157A). | Same methods of detection as those stated for item 10.a. | Same remarks as those stated for item 10.a. |
| 13. Solenoid-operated power-operated relief valve BB-PCV-456A (BB-PCV-455A analogous) | a. Fails to open on demand. | Provides relief to and isolation of fluid flow from pressurizer to PRT. | Failure reduces redundancy of providing flow from pressurizer to PRT. Negligible effect on safety for system operation. Pressurizer vent flow provided by a parallel pressurizer vent path through alternate relief valve BB-PCV-455A. | Valve open/closed position indication at CB; pressurizer power-operated relief valve outlet temperature indication at CB. | Pressurizer vent path to the PRT provides fluid flow out of the RCS to permit RCS depressurization to RHR initiation conditions. |
| | b. Fails to close on demand. | Same function as that stated for item 13.a. | Failure reduces redundancy of isolating flow from the pressurizer to the PRT. Negligible effect on safety for system operation. Pressurizer vent flow isolation provided by series isolation valve BB-HV-8000B (BB-HV-8000A). | Same methods of detection as those stated for item 13.a. | |
| 14. Motor-operated gate valve BB-HV-8000A (BB-HV-8000B analogous) | Fails to close on demand. | Provides isolation of fluid flow from pressurizer to PRT. | Same effect on system operation as that stated for item 13.b, except pressurizer vent flow isolation provided by series relief valve BB-PCV-455A (BB-PCV-456A) if the RCS pressure is below the PORV setpoint. | Same methods of detection as those stated for item 13.a. | Same remarks as those stated for item 13.a. |

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TABLE 5.4A-3 (Sheet 7)

| <u>Component</u> | <u>Failure Mode</u> | <u>Function</u> | <u>Effect on System Operation*</u> | <u>Failure Detection Method**</u> | <u>Remarks</u> |
|--|---------------------------|---|---|---|--|
| 15. Motor-operated gate valve EP-HV-8808A (EP-HV-8808B, EP-HV-8808C EP-HV-8808D analogous) | Fails to close on demand. | Provides isolation of fluid flow from accumulator 1 (accumulator 2, accumulator 3, accumulator 4) to the RCS. | Failure prevents isolation of accumulator 1 (accumulator 2, accumulator 3, accumulator 4) from the RCS. Negligible effect on safety for system operation. Accumulator 1 (accumulator 2, accumulator 3, accumulator 4) is depressurized by opening vent isolation valve EP-HV-8950A (EP-HV-8950B or C, EP-HV-8950D or E, EP-HV-8950F). | Valve open/closed position indication at CB; valve (closed) monitor light and alarm at CB; and accumulator pressure indication and low alarm at CB. | Accumulators are isolated or vented during plant cooldown to not affect RCS depressurization to RHR initiation conditions. |
| 16. Solenoid-operated globe valve EP-HV-8950A (EP-HV-8950F analogous) | Fails to open on demand. | Provides venting of nitrogen gas from accumulator 1 (accumulator 4) to containment. | Failure prevents venting of accumulator 1 (accumulator 4) to containment. Negligible effect on safety for system operation. Accumulator 1 (accumulator 4) is isolated from RCS by closing isolation valve EP-HV-8808A (EP-HV-8808D). | Valve open/closed position indication at CB and accumulator pressure indication and low alarm at CB. | Same remarks as those stated for item 15. |
| 17. Solenoid-operated globe valve EP-HV-8950B/8950D (EP-HV-8950C/8950E analogous) | Fails to open on demand. | Provides venting of nitrogen gas from accumulator 2/ accumulator 3. | Failure reduces redundancy in venting accumulator 2/ accumulator 3. Negligible effect on safety for system operation. Accumulator 2/ accumulator 3 venting capability provided by valves EP-HV-8950C/8950E if accumulator isolation valves EP-HV-8808B/8808C cannot be closed. | Same methods of detection as those stated for item 16. | Same remarks as those stated for item 15. |

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TABLE 5.4A-3 (Sheet 8)

| <u>Component</u> | <u>Failure Mode</u> | <u>Function</u> | <u>Effect on System Operation*</u> | <u>Failure Detection Method**</u> | <u>Remarks</u> |
|--|---------------------------------|---|--|--|--|
| 18. Centrifugal charging pump PBG05A (PBG05B analogous) | Fails to deliver working fluid. | Provides fluid flow of borated water from the RWST to the RCS and RCP seal injection. | Failure reduces redundancy of providing borated water to the RCS at high RCS pressures. Fluid flow from charging pump PBG05A (PBG05B) will be lost. Minimum flow requirements for boration, makeup, and seal injection will be met by PBG05B (PBG05A). | Charging pump discharge header pressure and flow indication at CB. Open/closed pump switchgear circuit breaker indication on CB. Circuit breaker closed position monitor light for group monitoring of component at CB. Common breaker trip alarm at CB. | The ECCS charging pumps provide boration, seal injection, and makeup flow to the RCS during safety grade cold shutdown operations. |
| 19. Motor-operated gate valve BG-LCV-112C (BG-LCV-112B analogous) | Fails to close on demand. | Provides isolation of fluid discharge from the VCT to the suction of charging pumps. | Failure reduces redundancy of providing VCT discharge isolation. Negligible effect on safety for system operation. Alternate isolation valve BG-LCV-112B (BG-LCV-112C) provides back-up tank discharge isolation. | Valve open/closed position indication at CB and valve (closed) monitor light and alarm at CB. | The ECCS charging pumps' suction is isolated from the VCT and aligned to the RWST (for boration/makeup) during safety grade cold shutdown operations. |
| 20. Motor-operated gate valve BG-HV-8105 (BG-HV-8106 analogous) | Fails to close on demand. | Provides isolation of fluid flow from the charging pump discharge header to the CVCS normal charging line to the RCS. | Failure reduces redundancy of providing isolation of charging pump discharge to normal charging line of CVCS. Negligible effect on safety for system operation. Alternate isolation valve BG-HV-8106 (BG-HV-8105) provides backup normal CVCS charging line isolation. | Valve position indication (open to closed position change) at CB. Valve closed position monitor light and alarm for group monitoring of components at CB. | Normal charging line is isolated during safety grade cold shutdown operations. Boration and makeup flow provided to RCS through redundant ECCS headers to the RCS cold legs. |
| 21. Motor-operated gate valve BN-LCV-112E (BN-LCV-112D analogous) | Fails to open on demand. | Provides isolation of fluid discharge from the RWST to the suction of charging pumps. | Failure reduces redundancy of providing fluid flow from RWST to suction of PBG05B. Negligible effect on safety for system operation. Alternate isolation valve BN-LCV-112D (BN-LCV-112E) opens to provide backup flow path to suction of PBG05A. | Valve open/closed position indication at CB and valve (open) monitor light and alarm at CB. | The ECCS charging pumps' suction is aligned to the RWST for makeup/boration to the RCS during safety grade cold shutdown operations. |

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TABLE 5.4A-3 (Sheet 9)

| <u>Component</u> | <u>Failure Mode</u> | <u>Function</u> | <u>Effect on System Operation*</u> | <u>Failure Detection Method**</u> | <u>Remarks</u> |
|--|---------------------------|---|---|---|---|
| 22. Motor-operated globe valve BG-HV-8110 (BG-HV-8111 analogous) | Fails to open on demand. | Provides isolation of ECCS charging pump mini-flow line. | Failure reduces redundancy of providing boration/makeup flow from the RWST to the RCS under low flow throttled conditions where ECCS charging pump minimum flow requirements cannot be met without mini-flow. Negligible effect on safety for system operation. PBG05B (PBG05A) minimum flow requirements will be met utilizing mini-flow isolation valve BG-HV-8111 (BG-HV-8110). Boration/makeup flow requirements are satisfied by the redundant alternate train. | Valve position indication (open to closed position change) at CB. Valve closed position monitor light and alarm for group monitoring of components at CB. | 1. Valve aligned to close upon receipt of an SIS coincident with ECCS charging pump flow ≥ 258.9 gpm. 2. Normally open valve. |
| 23. Motor-operated globe valve BG-HV-8357A (BG-HV-8357B analogous) | Fails to open on demand. | Provides safety grade seal injection flow path. | Failure reduces redundancy of providing seal injection flow to the RCP seals. Negligible effect on safety for system operation. Alternate valve BG-HV-8357B (BG-HV-8357A) opens to provide a seal injection flow path to the RCPs. Seal injection flow requirements are satisfied by the redundant alternate path. | Valve open/closed position indication at CB. | |
| 24. Motor-operated gate valve EJ-HV-8716A (EJ-HV-8716B analogous) | Fails to close on demand. | Provides separation between the two RHR trains during cooldown operation. | Failure reduces redundancy for isolating RHR trains during cooldown. Negligible effect on system operation. Isolation valve EJ-HV-8716B (EJ-HV-8716A) provides backup isolation between the two RHR trains. | Valve open/closed position indication at CB and valve (closed) monitor light and alarm at CB. | |

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TABLE 5.4A-3 (Sheet 10)

| <u>Component</u> | <u>Failure Mode</u> | <u>Function</u> | <u>Effect on System Operation*</u> | <u>Failure Detection Method**</u> | <u>Remarks</u> |
|--|--------------------------|--|--|---|---|
| 25. Motor-operated globe valve EM-HV-8803A (EM-HV-8803B analogous) | Fails to open on demand. | Provides flow control from PBG05A (PBG05B) to RCS for boration/makeup. | Failure reduces redundancy of providing boration/makeup flow to RCS from PBG05A (PBG05B). Negligible effect on safety for system operation. Alternate control valve EM-HV-8803B (EM-HV-8803A) controls flow from PBG05B (PBG05A). | Valve open/closed position indication at CB. Valve open position monitor light and alarm for group monitoring of components. | Path utilized for boration/makeup flow to RCS for safety grade cold shutdown operation. (Also ECCS injection/recirculation) |
| 26. Motor-operated gate valve BB-HV-8037A (BB-HV-8037B analogous) | Fails to open on demand. | PRT to containment sump isolation. Boron injection discharge to RCS. | Failure reduces redundancy of providing flow from the PRT to containment sump. Negligible effect on safety for system operation. Letdown flow provided by parallel path through alternate isolation valve BB-HV-8037B (BB-HV-8037A). | Valve position indication (closed to open position change) at CB. Valve open position monitor light and alarm for group monitoring of components. | Letdown path to containment sump provides flow out of PRT to accommodate flow out of RCS during shutdown operations. |
| 27. Motor-operated gate valve EM-HV-8801A (EM-HV-8801B analogous) | Fails to open on demand. | Boron injection discharge to RCS. | Failure reduces redundancy of providing flow via the boron injection header to RCS. Negligible effect on safety for system operation. Flow path provided by parallel isolation valve EM-HV-8801B (EM-HV-8801A). | Valve position indication (closed to open position change) at CB. Valve open position monitor light and alarm for group monitoring of components. | Path utilized for boration/makeup flow to RCS for safety grade cold shutdown operation. (Also ECCS injection/recirculation) |

List of acronyms and abbreviations

CB - Control board
 CVCS - Chemical and volume control system
 ECCS - Emergency core cooling system
 RC - Reactor coolant
 RCS - Reactor coolant system
 RHR - Residual heat removal
 RHRS - Residual heat removal system
 RWST - Refueling water storage tank
 SG - Steam generator
 RCP - Reactor coolant pump

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TABLE 5.4A-3 (Sheet 11)

VCT - Volume control tank
PRT - Pressurizer relief tank