4.0 REACTOR COOLANT SYSTEM

4.1 DESIGN BASES

The Reactor Coolant System circulates coolant at the required flow rate and temperature to meet the heat removal requirements of the core. Heat produced by the nuclear reaction is transferred by the coolant to the steam generators where steam is generated for the turbine plant. The coolant also acts as a neutron moderator and reflector, and as a vehicle for the soluble neutron absorber used in chemical shim control. The Reactor Coolant System also serves safeguard objectives by acting as a barrier against the release of energy and radioactive material into the reactor containment, and by preventing adverse reactivity and thermohydraulic effects resulting from changes in coolant pressure, temperature or soluble absorber concentration.

The system and its auxiliaries are designed to accommodate 10 per cent step changes in plant load and 5 per cent per minute ramp changes over the range from 15 per cent full power up to and including but not exceeding 100 per cent of full power without reactor trip. Based on experience, however, greater capabilities are to be expected as the operating conditions will probably not be as pessimistic as those used for the design basis. The Reactor Coolant System will accept a complete loss of load from full power with reactor trip. In addition, the turbine bypass system will accept an instantaneous 40 per cent loss of rated load without reactor trip by steam dump to the condenser.

In designing Reactor Coolant System components, the code requirements listed in Table 4-1 are considered as minimum design objectives. More severe requirements are often imposed. The design parameters are listed in Table 4-2. Normal operating temperatures and pressures are well below their respective design values, thus providing additional safety margin over the minimum design objectives of the code requirements. In addition, the Reactor Coolant System will be hydrostatically tested prior to initial operation.

Reactor vessel design is based on the transition temperature method of evaluating the possibility of brittle fracture of the vessel material. A design value of 100°F is used as a reasonable estimate of design transition temperature (DTT) for unirradiated material before actual properties are established during fabrication.

TABLE 4-1
REACTOR COOLANT SYSTEM - CODE REQUIREMENTS

Component	Codes
Reactor Vessel	ASME III* Class A
Steam Generator	
Tube Side	ASME III* Class A
Shell Side	ASME III* Class C
Pressurizer	ASME III* Class A
Pressurizer Relief Tank	ASME III, Class C
Pressurizer Safety Valves	ASME III*
Reactor Coolant Piping	ASA B31.1**

*ASME Boiler and Pressure Vessel Code, Section III, Nuclear Vessels

**ASA B31.1, Code for Pressure Piping, American Standards Association, and special nuclear cases where applicable.

A maximum allowable shift in DTT of 275F^{o} is selected as a value which will assure plant operation, heatup and cooldown without undue operating limitations over the plant design lifetime. Experience in calculating the operating limits of reactors previously analyzed(1) indicates that a significant margin exists between this assigned limit and a truly limiting condition for plant operation. In addition, the permissible time-integrated fast neutron flux (energies $>$ 1 mev) obtained from present reference irradiation curves(1) for the 275F^{o} shift leaves an ample margin over the calculated vessel irradiation for the plant design life. The combined margins are such that an increase in vessel irradiation to a value several times higher than the nominal exposure calculated at the core midplane can be tolerated without undue operating restrictions.

(1) U.S. AEC Docket No. 50-206 San Onofre Reactor Vessel Design Report

(1) U.S. AEC Docket No. 50-213 Connecticut-Yankee Reactor Vessel Design Report

TABLE 4-2
PRINCIPAL DESIGN PARAMETERS OF THE REACTOR COOLANT SYSTEM

Reactor Heat Output, MWt	2758
Reactor Heat Output, Btu per hour	9412×10^6
Operating Pressure, psig	2235
Reactor Vessel Inlet Temperature ^oF	543.0
Reactor Vessel Outlet Temperature ^oF	596.0
Number of Loops	4
Design Pressure, psig	2485
Design Temperature, ^oF	650
Hydrostatic Test Pressure (cold), psig	3110
Coolant Volume, including pressurizer, cu. ft.	12,209
Total Reactor Flow, gpm	358,800

4.2 SYSTEM DESIGN AND OPERATION

The Reactor Coolant System consists of four closed loops connected to a reactor vessel. Each loop contains a steam generator, a pump, piping, and instrumentation. A pressurizer is connected to the hot leg of one of the loops. Auxiliary system piping connections into the reactor coolant piping are provided as necessary. A flow diagram of the system is shown in Figure 4-1*.

Pressure in the system is controlled by the pressurizer, where water and steam are maintained in equilibrium to minimize pressure variations due to contraction and expansion of the coolant. Steam can either be formed by electrical heaters, or condensed by a controlled water spray. Spring-loaded steam safety valves and power-operated relief valves are connected to the pressurizer and discharge to the pressurizer relief tank, where the steam is condensed and cooled by mixing with water.

All materials are corrosion resistant in the coolant operating environment. The Chemical and Volume Control System maintains reactor coolant chemistry in accordance with the composition of Table 4-3. Frequent analyses will be made to check the coolant composition.

* The containment boundary shown on the process flow diagram indicates those major components which are to be located inside the reactor containment. The intersection of a process line with this boundary indicates a functional penetration; however, the actual number of piping penetrations required will be determined in the final designs.

TABLE 4-3
REACTOR COOLANT WATER CHEMICAL COMPOSITION

Oxygen, ppm, max.	0.1
Chloride, ppm, max.	0.15
Fluoride, ppm, max.	0.1
Hydrogen, cc (STP) per kg H_2O	25-35
Total suspended solids, ppm max.	1.0
pH control agent	0.3×10^{-4} to 3.2×10^{-4} molal strong base alkali and/or ammonia up to 20 ppm NH_3 maximum
Boric Acid	0 to 23,000 ppm

4.3 COMPONENTS

4.3.1 REACTOR VESSEL

The reactor vessel is a vertical cylinder with a hemispherical bottom and a flanged and gasketed upper head. Figure 4-2 is a schematic of the vessel, which is constructed of SA 302 Grade B, low alloy steel. All internal surfaces are clad (using the weld deposit method) with Type 304 austenitic stainless steel.

As previously described in Section 3.2.2.2, coolant enters through four nozzles in the side of the reactor vessel and flows downward through the annular space between the vessel wall and the core barrel into a plenum at the bottom of the vessel where it reverses direction. After passing upward through the reactor core the coolant flows out of the vessel through four exit nozzles located on the same level as the inlet nozzles.

A one piece thermal shield, concentric with the reactor core, is located between the core barrel and the reactor vessel. The shield, which is cooled by the coolant on its downward pass, protects the vessel by attenuating much of the gamma radiation and some of the fast neutrons that escape from the core. This shield minimizes thermal stresses in the vessel resulting from heat generated by gamma energy. The weight of the thermal shield is supported by lugs at the bottom of the core barrel. The thermal shield is stabilized at the top by guide lugs mounted on the core barrel.

Specimens of vessel plate material, placed near the inside of the vessel wall and periodically sampled during vessel life, will be used to substantiate the allowance for design transition temperature (DTT) shift. To ensure against excessive cold stress of the reactor vessel, startup and shutdown procedures will be specified to limit pressure and thermal stresses to a safe range when the vessel temperature is below the design transition temperature (DTT). When the vessel temperature is above DTT, the material is sufficiently ductile to permit safe loading to stresses well above those incurred in reactor operation.

The vessel and its internals are constructed so as to permit removal of all internals, including the thermal shield and material specimens, at any time during plant life.

The closure head is bolted to the vessel and is removed for refueling and maintenance. A double gasketed seal with a monitored leakoff is provided for sealing the head.

Principal design parameters of the reactor vessel are given in Table 4-4.

TABLE 4-4
PRINCIPAL DESIGN PARAMETERS OF THE REACTOR VESSEL

Material	SA-302 Grade B, low alloy steel, internally clad with Type 304 austenitic stainless steel
Design pressure, psig	2485
Design temperature, ^{o}F	650
Operating pressure, psig	2235
Inside diameter of shell, in.	173
Outside diameter across nozzles, in.	245
Overall height of vessel and enclosure head, ft.-in.	42-4
Minimum clad thickness, in.	0.156
Hydrostatic test pressure (cold), psig	3110

4.3.2 STEAM GENERATORS

Each loop contains a vertical shell and U-tube steam generator. A typical steam generator of this type is shown in Figure 4-3. Principal design parameters are listed in Table 4-5. The reactor coolant enters the inlet channel head at the bottom of the steam generator through a nozzle, flows through the U-tubes to an outlet channel and leaves the generator through another bottom nozzle. The inlet and outlet channels are separated by a partition. Manways are provided to permit access to both the inlet and outlet of the primary side of the tube plate.

Feedwater to the steam generator enters just above the top of the U-tubes through a feedwater ring. The water flows downward through an annulus between the tube wrapper and the shell and then upward through the tube bundle where part of it is converted to steam.

The steam-water mixture from the tube bundle passes through a steam swirl vane assembly. The vanes impart a radial acceleration to the mixture and separate the water particles from the steam. The water spills over the edge of the swirl vane housing and combines with the feedwater for another passage through the steam generator.

The steam rises through additional separators to limit the moisture content of the steam to one fourth of one per cent or less under all steady load conditions. A manway is provided for access to the moisture separating equipment.

The steam generator is constructed primarily of carbon steel. The heat transfer tubes are Inconel. The interior surfaces of the reactor coolant channel heads and nozzles are clad (using the weld deposit method) with austenitic stainless steel, and the side of the tube sheet in contact with the reactor coolant is clad with Inconel.

TABLE 4-5
PRINCIPAL DESIGN PARAMETERS OF THE STEAM GENERATORS

Number of Units	4
Type	Vertical U-tube with integral-moisture separator
Tube Material	Inconel
Shell Material	Carbon Steel
Tube Side Design Pressure, psig	2485
Tube Side Design Temperature, ^{o}F	650
Tube Side Design Flow, lb/hr	34.05×10^{6}
Shell Side Design Pressure, psig	1085
Shell Side Design Temperature, ^{o}F	600
Operating Pressure, Tube Side, Nominal, psig	2235
Operating Pressure, Shell Side, Maximum psig	1005

TABLE 4-5 (Continued)

Maximum Moisture at Outlet at Full Load, %	1/4
Hydrostatic Test Pressure, Tube Side (cold), psig	3110

4.3.3 REACTOR COOLANT PUMPS

Each loop contains a vertical single stage centrifugal pump of the controlled leakage type. A view of a controlled leakage pump is shown in Figure 4-4 and principal design parameters for the pumps are listed in Table 4-6.

Reactor coolant is pumped by the impeller attached to the bottom of the rotor shaft. The coolant is drawn up through the bottom of the impeller, discharged through spiral passages in the guide vanes and out through an exit in the side of the casing. The motor-impeller can be removed from the casing for maintenance or inspection without removing the casing from the piping. All parts of the pump in contact with the reactor coolant are constructed of corrosion resistant materials.

The pump employs a controlled leakage seal assembly to restrict leakage along the pump shaft, as well as a secondary seal which directs the controlled leakage out of the pump and a vapor seal which minimizes the leakage of vapor from the pump into the containment atmosphere.

High pressure water is injected into the reactor coolant pump between the impeller and the controlled leakage seal. Part of the flow enters the Reactor Coolant System through a labyrinth seal in the lower pump shaft to serve as a buffer to keep reactor coolant from entering the upper portion of the pump. The remainder of the injection water flows along the drive shaft, through the controlled leakage seal, leaves the pump and returns to the seal water injection circuit. A very small amount which leaks through the secondary seal is also collected and piped to the Waste Disposal System.

Component cooling water is supplied by the Auxiliary Coolant System to the motor bearing cooler and the thermal barrier cooling coil.

The squirrel cage induction motor driving the pump is air cooled and has oil lubricated thrust and radial bearings. A water lubricated radial bearing provides support for the pump shaft.

TABLE 4-6
PRINCIPAL DESIGN PARAMETERS OF THE REACTOR COOLANT PUMPS

Number of units	4
Type	Vertical, single stage radial flow with bottom suction and horizontal discharge
Design Pressure, psig	2485
Design Temperature, ^{o}F	650
Operating Pressure, nominal, psig	2235
Suction Temperature, ^{o}F	543.0
Design capacity, gpm	89,700
Design head, ft.	272
Hydrostatic test pressure, (cold), psig	3110
Motor type	A-C Induction, single speed
Motor rating	6000 Hp

4.3.4 PRESSURIZER

The pressurizer maintains the required reactor coolant pressure during steady-state operation, limits the pressure changes caused by coolant thermal expansion and contraction during normal load transients, and prevents the pressure in the Reactor Coolant System from exceeding the design pressure.

Under normal full power operating conditions about one-half of the pressurizer volume is occupied by water and the other half by steam. The pressurizer contains replaceable direct immersion heaters and is equipped with multiple safety and relief valves, a spray nozzle, interconnecting piping, valves and instrumentation. The electric heaters, located in the lower section of the vessel, are capable of raising the temperature of the pressurizer and its contents at the desired rate during startup of the reactor plant.

The pressurizer is designed to accommodate positive and negative surges caused by load transients. During a positive surge (caused by a decrease in plant load), power operated spray valves admit water from the cold leg of a coolant loop to condense steam in the vessel so that the pressure will not increase to a value that would actuate power operated relief valves. In addition, the spray valves can be operated manually by a switch in the central control room. A small continuous spray flow prevents excessive cooling of the spray piping. The resultant recirculation of reactor coolant through the pressurizer also reduces the difference between reactor coolant loop and pressurizer boron concentrations.

Power-operated relief valves and code safety valves attached to the top of the pressurizer protect against pressure surges which are beyond the pressure limiting capacity of the pressurizer spray.

During a negative surge (caused by an increase in plant load), flashing of water to steam and generation of steam by automatic actuation of the heaters keep the pressure above the minimum allowable limit. Heaters are also energized on high water level during positive surges to heat the subcooled surge water entering the pressurizer from the reactor coolant loop.

The pressurizer is constructed of carbon steel and internal surfaces are clad (using the weld deposit method) with austenitic stainless steel. The heaters are sheathed in austenitic stainless steel. Principal design parameters of the pressurizer are given in Table 4-7.

4.3.5 PRESSURIZER RELIEF TANK

Steam and water discharged from the pressurizer relief and safety valves pass to the pressurizer relief tank which is partially filled with water at or near ambient containment conditions. The cool water condenses the discharged steam and the condensate is drained to the Waste Disposal System. The tank normally contains water covered by a predominantly nitrogen atmosphere. Steam is discharged under the water level to condense and cool by mixing with the water. The tank is equipped with a spray and a drain which are operated to re-establish normal conditions in the tank following a discharge. The tank is protected against a steam discharge that would exceed the design pressure by a rupture disc which discharges into the reactor containment. The tank is carbon steel with a corrosion resistant coating on the internal surface.

TABLE 4-7
PRINCIPAL DESIGN PARAMETERS FOR THE PRESSURIZER AND PRESSURIZER RELIEF TANK

<u>Pressurizer</u>	
Design pressure, psig	2485
Design temperature, ^{o}F	680
Operating pressure, nominal, psig	2235
Materials of construction	Carbon steel, internally clad with stainless steel

TABLE 4-7 (Continued)

Approximate internal volume, cu. ft.	1600
Type of Heaters	Direct immersion
Hydrostatic test pressure (cold) psig	3110
Pressurizer Relief Tank	
Design pressure, psig	100
Design Temperature, ^{o}F	340
Normal water temperature, ^{o}F	120
Total volume, cu. ft.	1400
Material of construction	Carbon steel

4.3.6 PIPING

The austenitic stainless steel reactor coolant piping and fittings which make up the loops are 29 in. I.D. in the hot legs, 27-1/2 in. I.D. in the cold legs and 31 in. I.D. between the steam generator and the reactor coolant pump inlet. The design pressure is 2485 psig and design temperature is 650^{o}F. The pressurizer relief line which connects the pressurizer safety and relief valves to the discharge nozzle flange on the pressurizer relief tank is carbon steel.

Smaller piping, including the pressurizer surge and spray lines, drains, and connections to other systems, is austenitic stainless steel. All joints and connections are welded except for stainless steel flange connections to the carbon steel pressurizer relief line.

Thermal sleeves are installed at the following locations where high thermal stresses could otherwise develop due to rapid changes in fluid temperature during normal operational transients:

a) Return line from the residual heat removal loop of the Auxiliary Coolant System

b) Both ends of the pressurizer surge line

c) Pressurizer spray line connection to the pressurizer

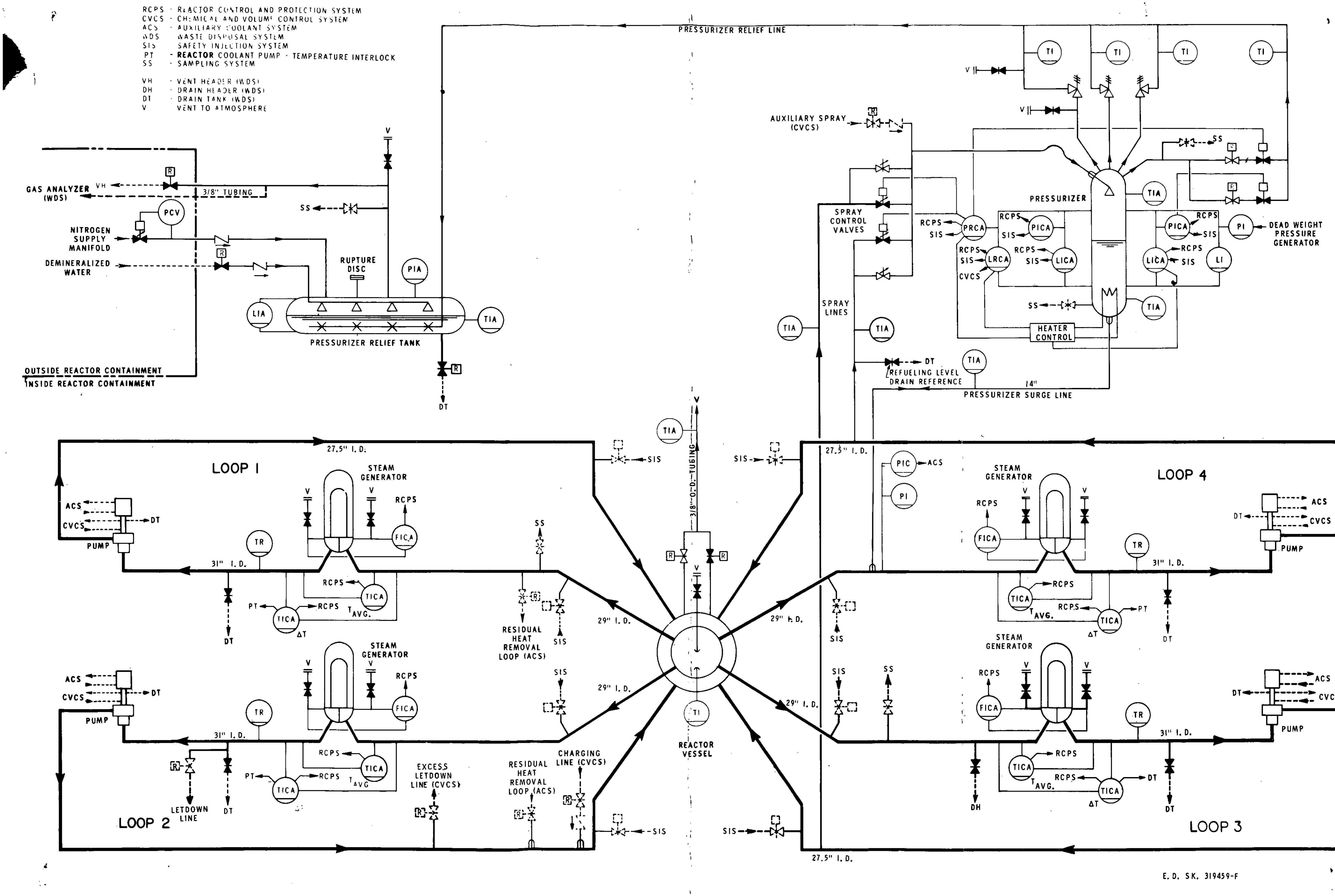
d) Charging line

4.3.7 VALVES

All valve surfaces in contact with reactor coolant are austenitic stainless steel or a material of equivalent corrosion resistance. Connections to stainless steel piping are welded.

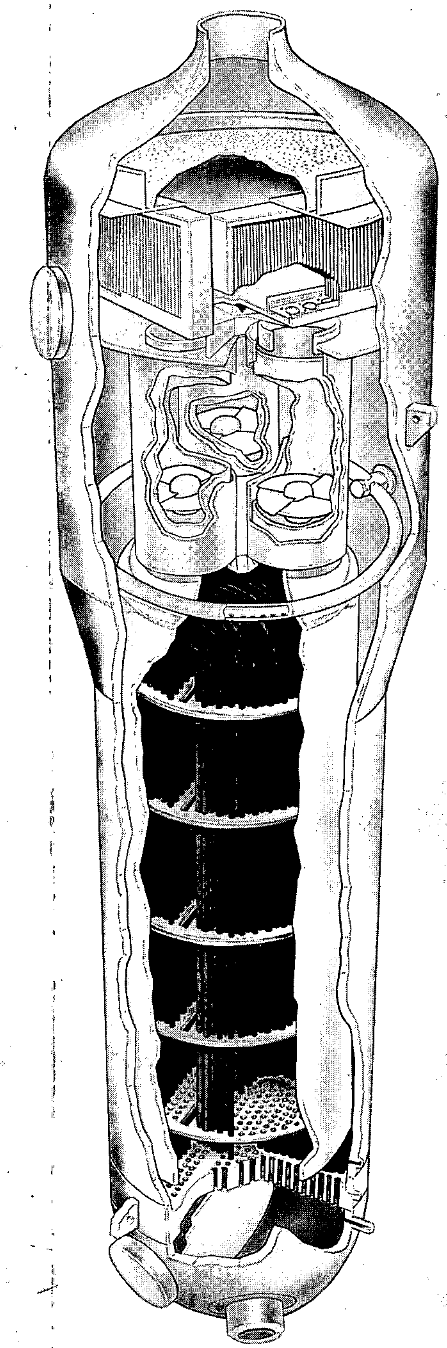
Valves that perform a modulating function are equipped with two sets of packing and an intermediate leakoff connection that discharges to the Waste Disposal System. All other valves have stem leakage control such as backseats. Leakoff connections will be provided if required by valve size and fluid conditions.

The power operated relief valves and spring loaded safety valves are connected to the steam phase of the pressurizer. A remotely operated stop valve permits isolation of the power operated relief valves if excessive leakage develops. A locally-adjusted throttling valve in parallel with the surge spray valves permits a small continuous circulation spray flow through the spray line and the pressurizer.

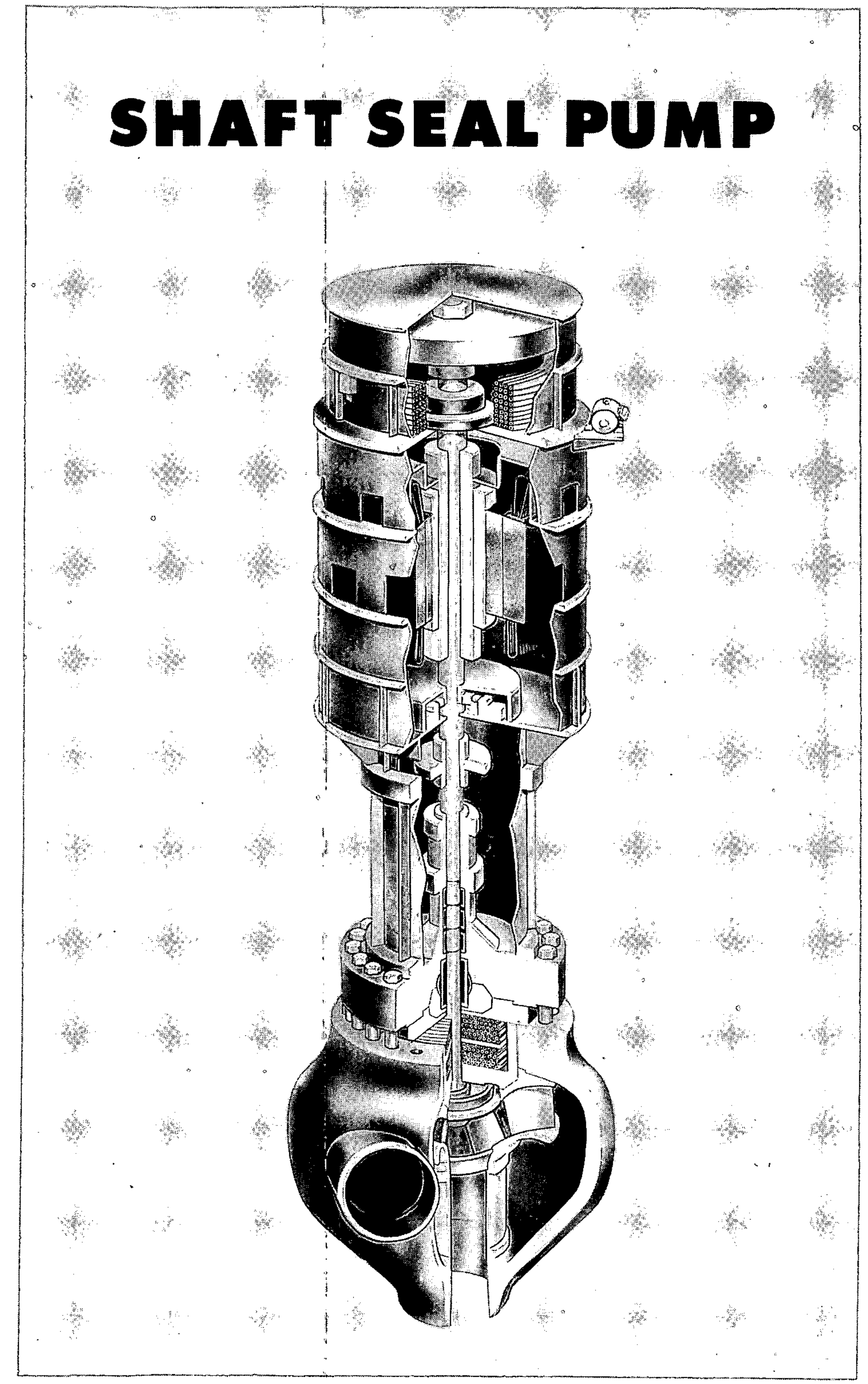


REACTOR COOLANT SYSTEM
FIG. 4-1

STEAM GENERATOR



CUTAWAY OF STEAM GENERATOR
FIG. 4-3



CUTAWAY OF REACTOR COOLANT PUMP
FIG. 4-4