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5 REACTOR COOLANT SYSTEMS

5.1 Summary Description

The Reactor Coolant Systems at the NBSR facility include the following systems: Primary Coolant System, Secondary Coolant System, Primary Coolant Purification System, Primary Coolant Makeup, Nitrogen-16 (N-16 or ^{16}N)* Control, and D_2O Experimental Cooling System. The primary purposes of the Reactor Coolant Systems are: to remove the fission and decay heat generated in the core; to dissipate the decay heat to the environment; and to serve as one of the barriers to prevent fission product release to the environment. The primary coolant is heavy water (D_2O) and the secondary coolant is light water (H_2O), both being in their liquid states. Several auxiliary systems, described in Chapter 9, support the Reactor Coolant Systems.

The Reactor Coolant Systems at the NBSR facility are designed to remove sufficient heat to support continuous full-power operation at a power level of 20 MWt and remove the decay heat generated after shutdown from extended full-power operations. While the reactor normally operates under forced primary coolant flow, it can be operated at power levels of up to 10 kWt with reduced or even no flow. Below 10 kWt, heat generation due to fission and decay heat is insufficient to significantly heat the existing large inventory of primary coolant in the Primary Coolant System and the Reactor Vessel.

The Primary Coolant System consists of pumps, heat exchangers, piping, and valves, and is located entirely within the reactor building confinement. While this system is not pressurized, it is closed to the atmosphere. Therefore, it serves as one of the three barriers to fission product release, the other two being the fuel cladding and the reactor building confinement (i.e., Confinement Building). Chapters 4 and 6 of this report discuss these other barriers.

The Primary Coolant System normally operates under conditions of forced flow in which primary coolant enters the bottom of the Reactor Vessel through the inner and outer plenums. The inner plenum feeds primary coolant to the center six fuel assemblies, while the outer plenum feeds the remaining twenty-four fuel assemblies. The coolant flows up through the fuel, removing the heat generated by fission, before exiting from the bottom of the vessel through two outlet pipes. Then, the primary coolant flows through the D_2O Main Circulating Pumps to plate-type Main Heat Exchangers, where the heat from fission in the core is transferred to the secondary coolant. The primary coolant passes through a strainer before returning back to the Reactor Vessel. A shutdown cooling system is provided to remove decay heat.

The Helium Sweep System, described in Chapter 9, maintains a blanket of helium on the heavy water in the Reactor Vessel and the various tanks within the Reactor Coolant Systems. This blanket reduces the loss of heavy water from the system by evaporation and allows for its

* N-16 refers to equipment and system associated with Nitrogen-16 Control, while ^{16}N denotes the isotope of Nitrogen.

recovery as the gas passes through coolers. It also reduces the isotopic degradation of heavy water by light water. The recovered coolant is returned to the D_2O Storage Tank.

The Secondary Coolant System transfers heat from the primary coolant in the Main Heat Exchangers to the atmosphere via a hybrid wet/dry type Cooling Tower. This hybrid design reduces the plume emanating from the cooling tower during operations.

The Primary Coolant Purification System maintains the chemistry of the primary coolant to limit corrosion of the fuel elements and other materials in the Reactor Vessel and the Primary Coolant System. A small portion of the primary coolant in the Primary Coolant System is diverted to the Primary Coolant Purification System via the D_2O Storage Tank. The primary coolant (D_2O) continually passes through filters and ion exchangers to remove suspended particles and to maintain its pH and conductivity.

The capacity of the D_2O Storage Tank, which allows the primary coolant to expand and to contract with variations in coolant temperature, is sufficient to hold the entire coolant inventory used in the Primary Coolant System and its associated systems. As a result, the NBSR does not have a dedicated Primary Coolant Makeup System for adding water to the system. However, heavy water may be added directly from 55-gallon drums on an "as needed" basis.

The ^{16}N control is handled with passive design, shielding of the Primary Coolant System, and access control at the NBSR. Therefore under normal operating conditions, ^{16}N is precluded as a source of radiation exposure to workers without the need for a dedicated active N-16 Control System.

The D_2O Experimental Cooling System uses heavy water from the Primary Coolant Purification System to cool the Cold Neutron Source, Rabbit Tubes, and other experimental facilities.

5.2 Primary Coolant System

5.2.1 Design Bases/Functional Requirements

The Primary Coolant System is designed to transfer 20 MW of heat from the core to the Secondary Coolant System with nominal values of: 9,000 gpm (34,000 lpm) flow, 100 °F (38 °C) reactor inlet temperature, and 114 °F (46 °C) reactor outlet temperature. The system also has several other functions:

a. The coolant in the core region acts as the neutron moderator;
b. The coolant around the core region acts as the reflector;
c. The coolant over the core, together with the coolant in the D_2O Emergency Cooling Tank serves as a reservoir for emergencies;
d. The coolant above the core shields the reactor top (although no credit is taken for this in accident analyses);
e. The coolant would retard the escape of fission products; and,
f. The coolant above the fuel provides an alternate shutdown capability sufficient to shut down the reactor under all conditions.

5.2.2 General System Description

Figure 5.1 shows the flow path for the Primary Coolant System, and Figure 5.2 shows the Primary Coolant System integrated with other heavy water systems. The instrument designators used in these and subsequent drawings are listed in Figure 5.3.

The Primary Coolant System circulates heavy water (D_2O) through the reactor. From the discharge header of the D_2O Main Circulating Pumps, water passes through two Main Heat Exchangers and a reactor inlet strainer. During full-power operation at 20 MWt, approximately 2,300 gpm (8,700 lpm) of heavy water enters the inner plenum to cool the central six fuel elements, and the remaining 6,700 gpm (25,400 lpm) is directed to the outer twenty-four fuel elements via the outer plenum. Approximately 4% of the total flow in each plenum bypasses the fuel elements and cools the various in-core thimbles, poison sleeves, shim safety arms, etc. The heavy water that enters the core passes up through the fuel element and down the outside; it leaves the reactor vessel through two 12-inch (30-cm) pipes, which then join outside the sub-pile area in the Process Room. After passing through a venturi, the heavy water enters the D_2O Main Circulating Pumps suction header. The four D_2O Main Circulating Pumps and two D_2O Shutdown Pumps are arranged in parallel. During normal operation, only three of the four main circulating pumps are normally operated and during shutdown, only one of the two shutdown pumps is normally operated.

A portion of the D_2O in the Primary Coolant System is diverted to the Primary Coolant Purification System by the 3-inch (7.6-cm) normal overflow line in the reactor vessel via the 14,650 gallon (55,500 liters) D_2O Storage Tank. Purified heavy water is then normally returned to the Reactor Coolant Systems via the D_2O Emergency Cooling Tank. The D_2O Storage Tank absorbs the thermal expansion and contraction of the D_2O, and also acts as a reservoir for D_2O released from the vessel and associated components.

5.2.2.1 Heat Source (Reactor Core)

Chapter 4, Reactor Description, gives details of the NBSR Reactor Vessel and fuel. Basically, the vessel is a vertical cylinder with an elliptical cap at the bottom and a flange at the top. One of the two inlet pipes is welded to the inner plenum and the other to the outer plenum in the center of the vessel's bottom, while the two outlet pipes are welded to the bottom of the reactor vessel on either side of the outer plenum. The inner plenum is located within, and is concentric to, the outer plenum. The lower grid plate is bolted to the inner and the outer plenums forming a watertight seal. The upper grid plate is bolted to four mounting brackets welded to the vessel wall. The reactor core contains thirty fuel assemblies. The NBSR is licensed for 20 MW thermal power.

5.2.2.2 Heat Sink (Main Heat Exchangers)

The Main Heat Exchangers, HE-1A, -1B, and -1C, are 35×10^6 BTU/hr (10 MW) each, plate and frame type, single pass, counter-flow heat exchangers, which transfer heat from the primary coolant (D_2O) to the secondary coolant (H_2O). The design pressure of each heat exchanger is 150 psig (1.0 MPa) at a design temperature of 200 °F (93 °C). The heat exchanger has a carbon steel frame and stainless steel plates. The total design pressure-drop on the primary and secondary sides are 5.03 psi (35 kPa) and 5.98 psi (41 kPa), respectively.

Figure 5.4 is an expanded schematic view of one Main Heat Exchanger. Two stainless steel plates are welded together forming a chamber through which D_2O flows. These welded plates or "cassettes" are the heat-transfer medium. Each heat exchanger has a carbon steel plate (or pressure plate), 132 cassettes, and another pressure plate. Each cassette has a gasket on the external sides of its plates. The gaskets are compressed and sealed between the pressure plates with tightening bolts. The gaskets prevent the primary and secondary water from mixing. The failure of one gasket surface will be revealed by water or heavy water leaking to the exterior of the heat exchanger.

Primary coolant (D_2O) flows simultaneously through an inlet on the primary pressure plate to the top of the internal chamber of each cassette. The D_2O then flows through the chamber once, exits through a bottom gasketed port of the cassette, and flows out of the heat exchanger through an outlet on the primary pressure plate. Secondary coolant (H_2O) flows through a bottom inlet port of the secondary pressure plate, up the outside of each cassette simultaneously, exits through a top gasketed port of the cassette, and flows out of the heat exchanger through an outlet on the secondary plate.

The stainless steel plates have the same stamped pattern. Identical gaskets of nitrile are used, except on the plates compressed against the pressure plates. These gaskets are simpler, as they are used only to prevent water from flowing between the pressure plates and the end cassettes.

Two Main Heat Exchangers (HE-1A and HE-1B) are sufficient to transfer all of the heat generated by the reactor to the secondary coolant. Heat exchanger HE-1C acts as a spare and is located in the Process Room in the basement of the Confinement Building, not connected to the primary or the secondary piping. Both the primary- and the secondary-sides of this spare heat exchanger are sealed and a nitrogen blanket is maintained to inhibit corrosion. To place the heat exchanger online, spool pieces are installed between the inlet and outlet flanges on the pressure plate and the primary and secondary piping.

5.2.2.3 Pumps

5.2.2.3.1 D_2O Main Circulating Pumps (DP-1, -2, -3, and -4)

The four D_2O Main Circulating Pumps are single-stage, shaft-sealed, centrifugal pumps operated in parallel to circulate the primary coolant from the Reactor Vessel to the Main Heat Exchangers. Each pump motor is a single-speed, 480 volt, three-phase, 60 Hz unit having a rating of 125 hp. Pumps DP-1 and DP-3 are powered from Reactor MCC A-3, while pumps DP-2 and DP-4 are powered from Reactor MCC B-4.

The reactor operator remotely controls the pumps from the Main Control Panel located in the Control Room. During normal operation, three pumps are run to maintain the necessary flow, with the fourth serving as an installed spare.

Figure 5.5 shows the flow vs. head characteristics and other information for D_2O Main Circulating Pump.

Figure 5.6 shows the flow vs. head characteristics and other information for different operating conditions of D_2O Main Circulating Pumps.

5.2.2.3.2 D_2O Shutdown Pumps (SDP-1 and -2)

Two centrifugal pumps are installed in parallel with the D_2O Main Circulating Pumps to provide forced cooling to the reactor during shutdown periods, and in the event of a power failure to the D_2O Main Circulating Pumps. Each D_2O Shutdown Pump has a 7½ hp AC motor and a 7½ hp DC motor mounted on a common shaft that turns at 1150 rpm. The AC motor for SDP-1 is powered from Emergency Power MCC A-5, while the AC motor for SDP-2 is powered from Emergency Power MCC B-6. The DC motors for both pumps are powered from MCC DC.

The reactor operator remotely controls the pumps from the Main Control Panel located in the Control Room. Only one of the two D_2O Shutdown Pumps is typically used to remove decay heat from the reactor.

Figure 5.7 shows the flow vs. head characteristics and other information for one operating D_2O Shutdown Pump.

5.2.2.4 Piping

Type 6061-T6 Aluminum is used as the Primary Coolant System's piping material. Leak detectors are installed at major flanges to locate leakage of heavy water (see Section 5.2.11).

5.2.2.5 Valves

5.2.2.5.1 Control Valves

Two types of remotely operated valves are installed in the Primary Coolant System, an air-operated type and a motor-operated type.

As shown in Figure 5.1, the Inlet Isolation Valve, DWV-1, is a 12-inch (30.5-cm) motor-operated, diaphragm valve that controls the flow of primary coolant to the outer plenum. The Inlet Isolation Valve, DWV-2, is an 8-inch (20.3-cm) motor-operated, diaphragm valve that controls the flow of primary coolant to the inner plenum. The reactor operator controls both valves to distribute the flow to the two reactor inlet plenums. Both of these valves are normally fully open.

Both valves are equipped with handwheel operators so they can be positioned manually. Each valve has a leak detector within the valve body, which gives a Control Room indication should a diaphragm leak. DWV-1 is powered from Emergency Power MCC A-5, while DWV-2 is powered from Emergency Power MCC B-6.

Reactor Outlet Isolation Valve, DWV-19, is a motor-operated, fugitive-emission-type, 18-inch (46-cm) butterfly valve located in the primary piping between the vessel's outlet and the D_2O

Main Circulating Pump suction header. Control and indication of the valve are in the Control Room, and the valve can be manually positioned with an attached handwheel. DWV-19 is powered from Emergency Power MCC B-6.

Air-operated diaphragm valves are provided in the vessel normal overflow line, in the fuel transfer overflow line, and in the moderator dump line. There are additional remote-operated valves in the Primary Coolant System with which the operator can redirect water from its normal flow path.

The reactor operator controls the remotely operated valves in the Primary Coolant System from the Main Control Panel located in the Control Room. Except for the three valves mentioned above (i.e., DWV-1, DWV-2 and DWV-19), the electrical power for all valves comes from the Instrument Power Bus in the Main Control Panel.

Chapter 9, Auxiliary Systems, discusses the air needed to operate the pneumatic control valves that is supplied by the Instrument Air System. Control power for the solenoid valves in the Instrument Air System comes from the Instrument Power Bus in the Main Control Panel.

All diaphragm valves, which are 3 inches (7.6 cm) and larger, are equipped with leak detectors to annunciate any failure that could release primary coolant outside of the valve's body.

5.2.2.5.2 Safety Relief Valve

A safety relief valve is installed on the 3-inch (7.6-cm) line branched from the 10-inch (25-cm) suction line of the D_2O Main Circulating Pump, DP-4, and on the reactor's outlet piping. It prevents over-pressurization of the primary system by relieving pressure whenever its set value of 50 psig (0.35 MPa) is exceeded. Any primary coolant released through this relief valve returns to the D_2O Storage Tank. The valve is a 3-inch (7.6-cm), "k"- size orifice relief valve able to pass 202 gpm (760 lpm) of water, while limiting the system's pressure to an increase of no more than 10% above its set value.

5.2.2.5.3 Main Heat Exchanger Isolation Valves

Six isolation valves for the three Main Heat Exchangers are 12-inch (30-cm), fugitive-emission-type, manually operated butterfly valves. Each of the four valves for the two normally in-service heat exchangers is equipped with a leak detector.

5.2.2.6 Instrumentation

Instrumentation is installed to provide remote read-out of the following parameters: reactor inlet flow to each plenum; reactor outlet flow; reactor ΔT; reactor vessel level; reactor overflow; and primary-to-secondary ΔP in the main heat exchangers. Local gauges that do not give Control Room read-out generally measure pressure at various points in the system. Electrical power for the instruments comes from the Instrument Power Bus located in the Main Control Panel.

5.2.2.6.1 Flow

Two channels sense the reactor inlet flows. The Reactor Outer Plenum Flow, Channel FRC-3, measures the flow of primary coolant into the core through the outer plenum, while Reactor Inner Plenum Flow, Channel FRC-4, measures the flow through the inner plenum. Outer plenum flow is measured by a 14-inch (36-cm) venturi, FE-3, installed in the reactor's outer plenum piping. Sensing lines connect the high- and low-pressure ports on the venturi to Flow Transmitter, FT-3 that supplies an electrical signal to Flow Recorder, FR-3, and to Flow Alarm, FA-3. The alarm unit has three on-off control signals: two to the reactor scram circuits, and one to the annunciator system. The range of the channel is 0-8,000 gpm (0-30,300 lpm). Inner plenum flow is measured by a 10-inch (25-cm) venturi, FE-4, installed in the reactor's inlet plenum piping. Sensing lines connect the high- and low-pressure ports on the venturi to Flow Transmitter, FT-4 that supplies an electrical signal to Flow Recorder, FR-4, and to Flow Alarm, FA-4. The alarm unit provides three on-off control signals: two to the reactor scram circuits, and one to the annunciator system. The range of the channel is 0-4,000 gpm (0-15,000 lpm).

Reactor Vessel Outlet Flow Recorder Channel, FR-1, and Reactor Outlet Flow Indicator Alarm Channel, FIA-40, ensure redundant measurement of the outlet flow from the reactor. An 18-inch (46-cm) venturi, FE-1, is common to both channels, and measures the outlet flow. Sensing lines connect the high- and low-pressure ports on the venturi to Flow Transmitters, FT-1 and FT-40. The former supplies an electrical signal to the Thermal Power BTU Recorder (BTUR Recorder). The latter supplies an electrical signal to Flow Indicator, FI-40, and Flow Alarm, FA-40. The alarm unit has three independent on-off outputs feeding two scram circuits and an annunciator. The range of both channels is 0-10,000 gpm (0-37,900 lpm). Section 5.2.2.6.6, Thermal Power, discusses how the flow signal is modified to produce the power signal used by the BTUR Recorder Channel.

The Reactor Vessel Overflow Channel, FIA-2, measures the flow of primary coolant in the overflow line from the top of the reactor vessel, thus assuring that the vessel is filled to normal operating level. Overflow is measured by a 3-inch (7.6-cm) orifice, FE-2, installed in the reactor overflow piping. Sensing lines connect the high- and low-pressure ports on the orifice to Flow Transmitter, FT-2, that, in turn, sends an electrical signal to Flow Indicator, FI-2, and Flow Alarm, FA-2. The alarm unit has two independent on-off outputs that feed the reactor startup interlock relay and the annunciator. The range of the channel is 0-30 gpm (0-115 lpm).

The flow of primary coolant through Main Heat Exchanger HE-1A is measured and recorded by HE-1A Primary Coolant Flow Channel, FR-20. Ultrasonic Flow Element, FE-20, and Flow Transmitter, FT-20, supply a flow signal to Flow Recorder, FR-20. The flow of primary coolant through Main Heat Exchanger HE-1B is measured and recorded by HE-1B Primary Coolant Flow Channel, FR-21. Ultrasonic Flow Element, FE-21, and Flow Transmitter, FT-21, supply a flow signal to Flow Recorder, FR-21. The ultrasonic flow elements are mounted on the primary piping on the outlet side of each heat exchanger. The range of both channels is 0-5,000 gpm (0-19,000 lpm).

5.2.2.6.2 Temperature

Reactor ΔT Recorder Channel, TR-1, measures the differential temperature of the primary coolant across the reactor. Two precision thermohms, TD1-1 and TD1-2, installed in the 18-inch (46-cm) primary piping on the inlet and outlet side of the reactor vessel, continuously monitor and record the ΔT. The differential temperature signal is applied to the Thermal Power Recorder (BTUR). The range of the channel is 0-20 °F (0 to 11°C). The differential temperature signal is used in conjunction with reactor outlet flow, (FR-1) flow signal to calculate the thermal power. Section 5.2.2.6.5 gives more details.

The Reactor ΔT Indicator Channels, TIA-40A and -40B, measure the differential temperature across the reactor's core. Temperature elements TE-40A-I and TE-40A-O are applied to Temperature Transmitter, TT-40A. An output signal proportional to the temperature difference is applied to Temperature Indicator, TI-40A, and to Temperature Alarm, TA-40A. Temperature elements TE-40B-I and TE-40B-O are applied to Temperature Transmitter, TT-40B. An output signal proportional to the temperature difference is applied to Temperature Indicator, TI-40B, and to Temperature Alarm, TA-40B. The alarm units have outputs that supply a signal for reactor scram and annunciator. The range of both channels is 0-30 °F (0 to 17 °C).

The Reactor Outlet Temperature Recorder Channel, TRA-2, measures the temperature of the primary coolant leaving the reactor. A resistance temperature detector (RTD), TE-2, is mounted in the reactor's 18 inch (46 cm) outlet piping. An R-to-I converter, TT-2, transforms the resistance measurement to an electrical signal that is applied to Temperature Recorder, TR-2, and to Temperature Alarm, TA-2. The alarm unit has outputs that supply a signal for a rundown and annunciator. The range of the channel is 50-200 °F (28-111 °C).

The Reactor Inlet Temperature Recorder Controller Channel, TRCA-3, measures the temperature of the primary coolant entering the reactor. A resistance temperature detector (RTD), TE-3, is mounted in the 18 inch (46 cm) inlet piping of the reactor. An R-to-I converter, TT-3, transforms the resistance measurement to an electrical signal that is applied to Temperature Controller, TC-3, to Temperature Recorder, TR-3, and to Temperature Alarm, TA-3. The temperature controller regulates the secondary coolant bypass flow around the cooling tower by controlling the position of Secondary Coolant Bypass Valves, SCV-1, -2 and -3, to maintain a constant primary coolant inlet temperature. The alarm unit has outputs that supply a signal to annunciate an abnormal temperature. The range of the channel is 50-130 °F (28-72 °C).

D_2O Heat Exchanger HE-1A Outlet Temperature Channel, TR-4, measures and records the primary outlet temperature from Main Heat Exchanger HE-1A. Thermocouple, TE-4, is mounted in the heat exchanger's 12 inch (30 cm) outlet piping. Temperature Transmitter, TT-4, applies a signal to Temperature Recorder TR-4. D_2O Heat Exchanger HE-1B Outlet Temperature Channel, TR-5, measures and records the primary outlet temperature from Main Heat Exchanger HE-1B. Thermocouple, TE-5, is mounted in the 12 inch (30 cm) outlet piping from the heat exchanger. Temperature Transmitter, TT-5, applies a signal to Temperature Recorder TR-5. The range of both channels is 50-150 °F (28-83 °C).

5.2.2.6.3 Level

The Reactor Vessel Level Recorder Channel, LRC-1, measures and records the level of the primary coolant in the reactor vessel. Level Transmitter, LT-1, applies a signal to Level Recorder, LR-1, and Level Alarms, LA-1 and LA-2 that is proportional to the level of D_2O in the vessel. The alarm units have six sets of contacts: two for low level reactor scram, one to allow the operator to open emergency cooling valve DWV-35, one for an alarm at the NIST emergency console (activated only when the DAY/NIGHT switch is in the NIGHT position, which is used when the building is locked-up with no one present), one to secure the operation of the Main D_2O Circulation Pumps, and one for annunciation. The range of the channel is 0-200 inches (0-510 cm).

The Reactor Vessel Level Indicator Channel, LIA-40, measures and displays the level of the primary coolant in the reactor vessel. Level Transmitter, LT-40, applies a signal to Level Indicator, LI-40, and Level Alarms, LA-40A/B and -40C/D that is proportional to the level of D_2O in the reactor vessel. The alarm units have outputs that supply a signal for a high-level alarm, a low-level alarm, a low-level rundown, and a low-level scram. They also supply a signal for opening Emergency Cooling Valve DWV-34 and another for securing the operation of the D_2O Main Circulating Pumps. The range of the channel is 60-200 inches (150-510 cm).

On a scram signal from both channels, LRC-1 and LIA-40, the D_2O Main Circulating Pumps are automatically tripped.

5.2.2.6.4 Pressure

All pressure measurements are made with local Bourdon-tube type pressure gauges. The suction and discharge pressures of all pumps are sensed, as well as the inlet pressures of the heat exchangers.

HE-1A Primary/Secondary Differential Pressure Indicator, PIA-30, measures the differential pressure between the primary and secondary sides of Heat Exchanger HE-1A. Pressure Transmitter, PT-30, supplies a signal to Pressure Indicator, PI-30, and to Pressure Alarm, PA-30 that alerts the operator to a low ΔP condition across the heat exchanger. The range of the channel is 0-50 psid (0-345 kPa).

HE-1B Primary/Secondary Differential Pressure Indicator, PIA-40, measures the differential pressure between the primary and secondary sides of Heat Exchanger HE-1B. Pressure Transmitter, PT-40, supplies a signal to Pressure Indicator, PI-40, and Pressure Alarm, PA-40. An alarm alerts the operator to a low ΔP condition across the heat exchanger. The range of the channel is 0-50 psid (0-345 kPa).

5.2.2.6.5 Thermal Power

Thermal power output from the reactor is calculated and recorded by the Thermal Power Recorder Channel, BTUR. Reactor Vessel Outlet Flow Recorder Channel, FR-1, applies a signal to the BTUR Recorder that is proportional to the flow of primary coolant through the reactor. Reactor ΔT Recorder Channel, TR-1, applies a signal to the BTUR Recorder that is proportional to the differential temperature across the reactor. The BTUR Recorder combines these two inputs to derive the reactor's power level for display and recording. The range of the channel is 0-30 MW.

5.2.2.7 Other Related Subsystems

5.2.2.7.1 Strainer

There is one 18-inch (46-cm) aluminum strainer on the reactor's inlet. The strainer has a removable bolted cover so that an interior stainless-steel wire #3 (approximately 1/4 inch (0.7 cm) slot) mesh basket can be removed for maintenance.

5.2.3 Design and Operating Parameters and Specifications

Table 5.1 lists the design and operating parameters for the Primary Coolant System.

5.2.4 System Operation

5.2.4.1 Removal of Heat from the Fuel

The main goal of the Primary Coolant System is to remove the fission energy from the reactor's fuel assemblies without any boiling during normal reactor operation. A detailed description of the definition and derivation of the thermal hydraulic limits is presented in Chapter 4. To achieve this goal, the following are imposed on the heat removal system:

a. The flow distribution in the core region should adequately cool all coolant channels;
b. The temperature of the primary coolant at the core outlet should remain lower than the rundown set point, and the differential temperature across the core should remain lower than the scram set point; and,
c. The coolant's height should be maintained at or above the level specified in the thermal-hydraulic limits calculations.

The Primary Coolant System also is designed to remove the decay heat generated in the fuel assemblies following reactor shutdown after extended operation.

Analysis showed that the reactor can be operated at power levels of up to 10 kWt with reduced or no flow, since the heat generated by the core is insufficient to significantly heat the coolant inventory in the Primary Coolant System and the Reactor Vessel.

5.2.4.2 Transfer of Heat from Primary Coolant System to Secondary Coolant System

The Primary Coolant System removes heat from the core generated by the fission of ^{235}U. Coolant enters through a plenum at the bottom of the fuel, passes up through it and into the reactor vessel, and then out through two outlet pipes in the bottom of the vessel. The inner six fuel positions and the G4 thimble are fed by one plenum, while the remaining fuel and thimbles are fed by a second concentric plenum. The core support structure is designed to reduce bypass flow through the clearance. All in-core positions are filled with a fuel element or an experimental thimble to prevent excessive bypass flow. The primary coolant passes out of the reactor and flows through the D_2O Main Circulating Pumps and the Main Heat Exchangers before returning to the reactor vessel in a closed loop.

The Main Heat Exchangers transfer heat to the secondary coolant. Two plate-type single-pass counter flow heat exchangers are designed to transfer in excess of 20 MWt. Their performance is determined by their design, size, primary and secondary flow rates, and fouling. Fouling on the primary side of the heat exchangers is not a problem because of the stringent specification on primary water chemistry. The fouling of the secondary coolant is avoided due to the secondary water chemistry control and the presence of automatic strainers in the system. The heat exchangers do not impose any limits on reactor operation.

Two D_2O Shutdown Pumps are installed in the primary piping in parallel with the four D_2O Main Circulating Pumps. Forced cooling is maintained by one of the two pumps after shutdown until the decay heat generated within the fuel elements has decayed to acceptable levels.

5.2.4.3 Reactor Shutdown

Reactor shutdowns are performed with full primary coolant flow. The need for shutdown cooling is a function of the amount of decay heat resulting from the reactor's power operations.

Upon loss of offsite electric power, all of the running D_2O Main Circulating Pumps trip off-line and a reactor scram occur due to the low flow of primary coolant (FRC-3, FRC-4, or FIA-40). Non-emergency loads are shed automatically by the tripping scheme on the electrical distribution system. The power feed to Uninterruptible Power Supply (UPS) automatically shifts from the offsite utility to the station battery. Diesel generators automatically start up and pick up the feeds for MCC A-5 and B-6. One of the D_2O Shutdown Pumps automatically starts up to provide primary coolant flow through the reactor to remove the decay heat generated in the fuel after shutdown. A detailed description of consequences of a loss of primary coolant flow from multiple events is included in Section 13.1.4.

5.2.4.4 Locations, Designs, and Functions of Essential Components

The Reactor Vessel contains the reactor core and core support structure, the heavy water coolant /moderator/reflector and its helium blanket, control devices, Inner Reserve Tank, the emergency cooling distribution pan, and D_2O Holdup Pan. The Reactor Vessel flange rests on top of the Thermal Shield Shim Ring. The Reactor Vessel and thermal shield are located in the middle of room C-100 in the Confinement Building.

The Process Room contains the piping, strainers, D_2O Main Circulating Pumps, D_2O Shutdown Pumps, Main Heat Exchangers, control valves, and instrumentation associated with the Primary Coolant System. A curb captures any primary coolant that may leak from the system and collects it in a sump. Vent and drain lines are equipped with manual valves and flanges with quick-disconnect fittings to provide two barriers between the primary coolant and the atmosphere.

5.2.5 Control and Safety Instrumentation

Section 5.2.2.6 discusses the instrumentation associated with the Primary Coolant System. While the sensors for pressure, temperature, level, and other monitored parameters are located appropriately throughout the system, the readout devices and controllers are sited in the Main Control Panel in the Control Room. This arrangement gives the reactor operator a single convenient location from which to control and operate the reactor. Table 5.2 lists the Limiting Safety System Settings, while Table 5.3 lists the Primary Coolant System Safety Instrumentation.

The reactor operator can remotely control pumps and valves from the Main Control Panel. Five annunciator panels mounted in this panel alert the operator to changing conditions. The alarm channels receive their inputs from the various instrument channels throughout the plant and from auxiliary contacts in monitored equipment. The Instrument Power Bus within the Main Control Panel supplies electrical power for all of the instrumentation and control equipment.

Section 5.3 of the Technical Specifications covers the Surveillance Standards applicable to the Reactor Control and Safety System. This standard requires that the reactor safety system channels be tested for operability before each reactor startup following a shutdown longer than 24 hours, or at least quarterly. This test includes verifying the proper trip settings of safety system channels. In addition, each safety channel must be calibrated annually. Because redundancy is incorporated into all important safety channels, random failures should not jeopardize their ability to perform their required functions. However, to ensure that failures do not go undetected, frequent surveillance is performed.

A second requirement of the technical specifications is a weekly comparison of power range indication with flow-ΔT product when the reactor is operating above 5 MWt. Because various experiments require precise operating conditions, the NBSR was designed to ensure that power level channels can be easily, accurately, and frequently recalibrated. Calibration involves comparing nuclear channels with the thermal power measurement channel (flow-ΔT product). Because of the small ΔT in the NBSR (about 14 ^{o}F (8 °C) at 20 MWt) these calibrations need not be performed at a power less than 10 MWt to support 20 MWt operations. However, to ensure that there are no gross discrepancies between nuclear instruments and flow-ΔT indicators, comparisons (but not necessarily calibrations) are made above 5 MWt.

Technical specifications also require that following maintenance on any part of the reactor control and reactor safety systems, the repaired portion be satisfactorily tested before the system is considered operable.

5.2.6 Special Features of Primary Coolant System

The NBSR is a D_2O moderated, reflected, and cooled tank-type reactor design. The core is immersed in heavy water to thermalize fast neutrons, to remove heat created by the reaction, and to serve as the first stage of shielding. The side reflector is 20 inches (50 cm) thick and the top reflector's thickness is normally maintained at about 118 inches (300 cm). While the thickness of the side reflector is fixed by the design and construction of the reactor core and tank, the operator controls the thickness of the top reflector. During normal operation, the level of the heavy water in the reactor tank is maintained at about 118 inches (300 cm), the height of the inlet to the 3-inch (7.6-cm) overflow pipe. In the unlikely event that the shim safety arms cannot be inserted, the operator can initiate a Moderator Dump to drop the water level to approximately 1 inch (2.5 cm) above the core for an emergency shutdown of the reactor. This ensures a capability sufficient for reactor shutdown under all conditions. The operability of the moderator dump system is considered necessary to safely operate the reactor. Accordingly, the Technical Specifications for the Reactor Control and Safety Systems require that the moderator dump system is operable for the reactor to be operated.

5.2.7 Special Features that Affect or Limit Personnel Radiation Exposures

Handling and storage of reactor fuel elements are described in Chapter 9. The discussions include new fuel storage, irradiated (or spent) fuel storage, handling of fuel elements, and safety considerations associated with handling and storage of reactor fuel elements.

5.2.8 Primary Coolant System Radiation Monitors

There are no specific radiation monitors for the primary coolant system. Regular sampling, as described in Chapter 11, Radiation Protection and Waste Management, monitors radionuclide concentrations in the primary coolant.

5.2.9 Auxiliary Systems using Primary Coolant

Several auxiliary systems that use primary coolant are connected to the Primary Coolant System.

The Primary Coolant Purification System maintains the chemistry and the purity of the primary coolant. This system is essential for properly controlling the water chemistry of the primary coolant and for maintaining it free of suspended impurities. Properly controlling chemistry ensures that the components in contact with the primary coolant are not degraded over the life of the plant. The primary coolant must be pure to minimize the contaminants. By minimizing these contaminants personnel exposures will also be lowered. The Primary Coolant Purification System supplies heavy water to the D_2O Emergency Cooling Tank, the D_2O Injection System, and the D_2O Experimental Cooling System. Section 5.4 discusses this system in detail.

Fresh heavy water is added to the D_2O Storage Tank from a 55-gallon (210 liter) drum either through valve DWV-222 or valve DWV-230. While this arrangement has no direct effect on the design and operation of the Primary Coolant System, it is needed to replenish primary coolant lost over time through evaporation or in other ways. Section 5.5 discusses this system in detail.

The D_2O Experimental Cooling System provides heavy water for cooling the Cold Neutron Source, the rabbits, and other experimental stations. While this system has no direct effect on the design and operation of the Primary Coolant System, it is necessary to cool selected experiments. Section 5.7 gives details of these systems.

While these auxiliary systems interface with the Primary Coolant System and utilize primary coolant, the failure in any of them will not prevent the Primary Coolant System from cooling the reactor core, either during normal power operation or during shutdown.

5.2.10 Radiation Shielding Provided for the Primary Coolant

Twenty inches (51 cm) of heavy water surrounding the reactor core serves as the side reflector and the top reflector thickness of heavy water is determined by a 3 inch (7.6 cm) overflow pipe, which maintains a heavy water level at 118 inches (300 cm) above the top of the core. The thermal shield surrounds the reactor vessel and consists of 2-inch (5 cm) thick lead followed by 8 inch (20 cm) steel for a height of 8 feet 4 inches (2.5 meters) starting 4 feet 6 inches (1.4 meters) below the central plane of the core. The upper section of the thermal shield has 2-inch (5 cm) thick lead and 6-inch (15 cm) thick steel. The lead thickness was chosen to minimize the gamma ray flux at the vessel wall. The thermal shield removes most of the gamma ray energy and protects the concrete shield from excess heating, which would cause cracking due to the temperature differentials within the concrete.

The biological or bulk shield consisting of heavy concrete surrounding the thermal shield, the upper and lower shielding doughnuts, and the center shield plug provide shielding for personnel. The bulk shield is designed to reduce the radiation to levels that will yield normally insignificant level of radiation. The bulk shielding completely surrounds the reactor, becoming an integral part of the first and second floors.

Access to the reactor is from the second floor of the Confinement Building. Two doughnut-shaped plugs, one above the other, and a stepped cylindrical plug, which fits into the doughnut, are mounted on the top of the Reactor Vessel. The center plug is 5 feet (1.5 meters) thick, which is thinner than the doughnut combination leaving a 2 feet (0.6 m) deep well in the center of the floor over the reactor. This well is covered with a removable steel floor plate, 6 inches (15 cm) thick.

The bulk reactor shield is made of magnetite concrete with a minimum dry density of 240 lbs/ft^3 (3,850 kg/m^3). The minimum thickness of the reactor shield in the high-flux central plane region of the reactor is 74 inches (190 cm). The concrete was formed directly against the thermal shield on the inside and the ½ inch (1.3 cm) thick steel faceplates on the outside. The top plugs are made of stainless steel and filled with 3 inches (7.6 cm) of lead on the bottom, followed by magnetite concrete.

The core can be refueled without removing the center shielding plug or either of the shielding doughnuts. The level of the coolant in the reactor vessel is lowered to just below the opening to the fuel-transfer chute. Fuel removed from the reactor is transferred to the storage pool through the fuel-transfer chute. New fuel is loaded through an opening in the center shielding plug. A fuel pickup tool and fuel transfer arms remotely handle all of the fuel in the reactor vessel.

Because of the design and construction of the shields, no credit is taken in the accident analyses for the shielding provided by the primary coolant above the core.

5.2.11 Leak Detection System

During normal operation of the Primary Coolant System, the highest D_2O temperature is approximately 114°F (46°C) at the reactor outlet and its highest pressure is approximately 65 psig (450 kPa) at the discharge of the main coolant pumps. These relatively low temperatures and pressures reduce wear on the system's components, which, in turn, minimizes the potential for developing a measurable leak.

Precautions are taken to prevent the heavy water in the primary system from mixing with the light water in the secondary. Production of ^{16}N in the primary coolant is associated with reactor power operations. Tritium is present at all times in the primary coolant. Any leak is quickly discovered by detectors located in the secondary system, which sense the ^{16}N activity in any heavy water that might enter. If a detector alarms, the secondary water is sampled for tritium, and D_2O tank levels in the primary system are checked. If these checks confirm that a leak has developed, the reactor is shut down and the heat exchanger is isolated. Should a N-16 monitor indicate a level much higher than the alarm's set point, the reactor is shut down immediately without waiting for additional confirmation.

The aluminum plate-type fuel elements used at the NBSR are designed to retain any non-gaseous fission products. The NBSR does not normally operate with faulty fuel elements, i.e., fuel elements that release some fission products. Consequently, there are no significant amounts of fission products in the primary water during normal operations. If an element were to develop a leak, it would be quickly detected and action taken. Other than the very short-lived ^{16}N activity, the only significant radioactivity in the primary system is tritium. In addition to the ^{16}N monitors, a leak into the secondary system can be detected by a change in the level of the D_2O storage tank and by periodic sampling of the secondary water for tritium. These methods are sensitive enough to detect a leak of above 36 gallons (135 liters) in one day or 50 gallons (190 liters) in one week.

Assuming that the tritium concentration at 20 MWt has reached a level of 5 Ci/L, the 36 gallon (135 liter) release in one day would result in a maximum release concentration of 0.1 μCi/mL to the sanitary sewer at the site boundary. Exposure to an individual from this one-day release would be far less than 5 mrem. Based on a 100% release into the atmosphere, the maximum concentration at the site boundary would be approximately 6×10^{-7} μCi/mL or again, an exposure much less than 5 mrem for that day.

The 50 gallon (190 liter) leak in one week would give lower daily concentrations than those above and an individual exposure nearly as small.

These hypothetical leaks are of a magnitude that can be easily detected. Conceivably, a leak might be so small that it could not be located; the rate would have to be less than 0.5 gal/day (1.9 liter/day). Such a leak could still be detected through the tritium sampling of the secondary water, but it might not be possible to locate it to repair it. It is very unlikely that any such leak would remain small for a long time. If, however, it was not located and repaired for a whole year, 180 gallons (680 liters) of D_2O would be released to the secondary system during the year.

This would give an average concentration at the site boundary of no more than 1.7×10^{-9} µCi/mL, or an exposure of less than 1 mrem per year.

These calculations are based on a conservatively high tritium level of 5 Ci/L in the primary system. The only direct releases from the primary system to the environment result from the unusual occurrence of a leak in the heat exchanger, and, even then they would be only a very small fraction of the allowable effluent concentrations. The design of the heat exchangers effectively allows only a plate failure as a source of leakage to the secondary system.

Other possible sources of leakage would be at flanged connections, pump shaft seals, and shim-blade shaft seals. Most valves are of the diaphragm type, thus eliminating stem-packing leakage. Fugitive-emissions-type butterfly valves are employed where appropriate, e.g., to isolate the main heat exchangers. Their stems are sealed using a special packing design, basically eliminating any water leakage. The major components of the Primary Coolant System are equipped with leak-detection sensors.

Leak detectors are installed at major flanges, primary pumps, and at other locations throughout the Primary Coolant System to alert the reactor operator of any leakage from the system. All valves that are 3 inches (7.6 cm) or larger are equipped with leak detectors to detect any failure, which could introduce system water to the exterior of the valve body.

5.2.12 Normal Radionuclide Concentration Limits for the Primary Coolant

Impurities in the D_2O are kept at low concentrations by filters and ion exchanger columns in the purification system. The isotopic purity of D_2O as received will be approximately 99.5%. System pressures are adjusted so that any failure of heat exchanger plates will result in leakage of D_2O to the exterior of the heat exchanger or into the light-water system to prevent degradation of the heavy water.

Tritium is the isotope of interest for the NBSR. As of January 2003, the tritium concentration in the D_2O was approximately 1.47 Ci/L. For a detailed discussion concerning tritium, see Chapter 11.

Small quantities of fission products from fuel surface contamination and cladding transmission may also be found in the primary coolant. Even after years of operation, the inventory of fission product in the coolant is very low.

Small concentrations of Cobalt-60 and other radioactive contaminants are generated from sources such as the main coolant pumps and the aluminum piping.

Significant changes to the concentration of radioactive contaminants in the primary water would be detected. Previous experience verified the sensitivity of the detection system and the performance of the purification system.

5.2.13 Allowable Hydrogen Limits

Deuterium gas (D_2) will collect in the helium-cover gas system because of the radiolytic disassociation of D_2O. The primary system could be damaged if this gas were to reach an explosive concentration (about 7.8% by volume at 25 ^oC in helium) and mix with air. The Helium Sweep Gas System, discussed in Chapter 9, provides an inert helium atmosphere over all vessels and tanks that normally contain heavy water. The system also maintains the proper oxygen concentration in the sweep gas, and recombines any disassociated D_2O that might be present. A 4% limit on D_2 gas is imposed to ensure a substantial margin below the lowest potentially explosive value.

5.2.14 Technical Specification Requirements

Five Technical Specifications apply to the Primary Coolant System.

5.2.14.1 Technical Specification 2.1, Safety Limit

This Technical Specification applies to the reactor power and primary coolant flow and temperature. Its objective is to maintain the integrity of the fuel cladding and prevent the release of significant amounts of fission products. Reactor power, primary coolant flow, and reactor inlet temperature are not allowed to exceed the limits established in the specification. Maintaining the integrity of the fuel cladding requires that it should remain below its melting temperature. For all operating conditions that avoid a departure from nucleate boiling (DNB), cladding temperatures remain substantially below the blistering temperature. Conservative calculations (Chapter 4, Reactor Description) showed that limiting the combinations of reactor power, and the primary coolant temperature and flow to values more conservative than the safety limits will prevent failure of the cladding.

5.2.14.2 Technical Specification 2.2, Limiting Safety System Setting (LSSS)

This Technical Specification applies to limiting settings for instruments monitoring the safety limit parameters. Its objective is to ensure protective action occurs if any of the principal process variables should approach the LSSS. Limiting safety-system settings are established for reactor power, reactor outlet temperature, and primary coolant flow. At the values selected, the safety-system settings provide a significant margin from the safety limits. Even in the extremely unlikely event that all three parameters simultaneously reach their safety-system settings, the burnout ratio is at least 1.3. For all other conditions, the ratio is considerably higher (Chapter 13, Accident Analyses). This ensures that any reactor transient caused by equipment malfunction or operator error will be terminated well before the safety limits are reached. Overall uncertainties in process instrumentation have been incorporated into limiting safety-system setting values.

5.2.14.3 Technical Specification 3.2, Reactor Coolant System

This Technical Specification applies to the capability of the primary coolant emergency cooling and heat exchanger isolation. Its objectives are to ensure adequate cooling capability for the reactor, and to provide the means of containing D_2O-to-H_2O heat exchanger leakage. The reactor is prohibited from operating unless at least one shutdown cooling pump is operable, unless the heat exchanger's isolation valves are operable, unless either a secondary cooling water activity monitor or a D_2O storage tank level monitor sensitive to a loss of 300 gallons (1150 liters) of D_2O is operable, with a vessel coolant level more than 25 inches (64 cm) below the overflow standpipe level, or with a D_2 concentration in the Helium Sweep System greater than 4% by volume.

Loss of flow accidents were analyzed for the NBSR, assuming a single shutdown cooling pump is operable. Under this condition, the hot spot of the hottest plate remains below 160 ^oF (70 ^oC) (Chapter 13, Accident Analyses). Further, analyzing the case of a no-shutdown cooling flow (Chapter 13, Accident Analyses), the maximum temperature of the fuel plate would be less than 500^{o}F (260^{o}C), well below the temperature that would cause any damage. To ensure that fuel-plate temperatures following loss of flow will be near or below normal operating temperatures, a shutdown pump is required.

The effect of leakage through the heat exchangers from the primary to the secondary systems was analyzed. Calculations show that tritium releases offsite are below the concentrations allowed by 10 CFR 20 (Chapter 11, Radiation Protection and Waste Management). To minimize the amount of any such leakage, the heat-exchanger D_2O isolation valves are required to be operational and there must be a means for detecting the leakage.

The limiting value for the level of the reactor vessel coolant is somewhat arbitrary because the core is in no danger so long as it is covered with water. However, a drop in level indicates a malfunction of the coolant system and possible approach to uncovering the core. Thus, a measurable value well above the minimum level is chosen to give a generous margin (i.e., about 7 feet (2 meter)) above the fuel elements. To allow periodic surveillance of the effectiveness of the moderator dump, the reactor must be operated without restrictions on the reactor vessel level. This is permissible under conditions when forced primary cooling is not required, such as is set out in Section 2.1 of the Technical Specifications.

5.2.14.4 Technical Specification 4.2, Reactor Coolant System

This Technical Specification applies to the Primary Coolant System, its objective being to ensure the system's continued integrity. It requires the primary coolant system's relief valve to be lifted annually. Major additions, modifications, or repairs of the reactor coolant system or its connected auxiliaries are required to be tested before use.

The most probable failure mechanisms for the primary coolant system are overpressure and corrosion. The only area where significant corrosion is possible is the secondary side of the main heat exchanger. To protect against overpressure, a relief valve is installed on the primary system. To be effective, the condition of each of these protective devices must be verified periodically. The frequency for lifting the relief valve is consistent with industry practices for such valves under clear water service conditions.

Major additions, modifications or repairs of the primary system shall be either pressure tested or checked by X-ray, ultrasonic, gas-leak test, dye-penetrant, or similar methods.

5.2.14.5 Technical Specification 5.2, Reactor Coolant System

This Technical Specification applies to the design features of the Primary Coolant System, stating that it consists of a reactor vessel, a single cooling loop, containing heat exchangers, and appropriate pumps and valves. All materials, including those of the reactor vessel, in contact with primary coolant (D_2O) are aluminum alloys or stainless steel, except gaskets and valve diaphragms. The reactor vessel is designed in accordance with Section III of Major Section 8.0 of the American Society of Mechanical Engineers (ASME) Code for Unfired Pressure Vessels. It is designed for 50 psig (0.35 MPa) and 250 ^{o}F (120 ^{o}C). Heat exchangers are designed for 100 psig (0.7 MPa) and a temperature of 150 ^{o}F (66 ^{o}C). The connecting piping is designed for 125 psig (0.9 MPa) and a temperature of 150 ^{o}F (66 ^{o}C).

The Primary Coolant System has been described and analyzed as a single-loop system containing heat exchangers. The materials of construction, being primarily aluminum alloys and stainless steel, are chemically compatible with the D_2O coolant. The stainless-steel pumps are heavy-walled and are sited in areas of low stress, so they should not be susceptible to chemical attack or stress corrosion failures. The failure of the gaskets and valve bellows, although undesirable, would not cause catastrophic failure of the primary system; hence, strict material limitations are not required for technical specifications. The design temperature and pressure of the reactor vessel and other primary system components provide adequate margins over operating temperatures and pressures. It is believed prudent to retain these margins to further reduce the probability of a primary-system failure. The reactor vessel was designed to meet Section VIII, 1959 Edition, of the ASME Code for Unfired Pressure Vessels. Subsequent changes should be made in accordance with the most recent edition of this code.

Because the safety analysis is based on the Reactor Coolant Systems as presently designed and with the present margins, it is considered necessary to retain this design and these margins, or to redo the analysis.

5.3 Secondary Coolant System

5.3.1 Design Bases/Functional Requirements

The Secondary Coolant System is designed to transfer heat from the Reactor Coolant Systems and various other auxiliary systems to the atmosphere.

5.3.2 System Description

Figure 5.8 shows the flow path for the Secondary Coolant System. The system removes heat from the following heat exchangers associated with the Reactor Coolant Systems and auxiliary support systems: Main Heat Exchangers (HE-1A, 1B, 1C), D_2O Purification Heat Exchanger

(HE-2), Thermal Shield Heat Exchanger (HE-6), Thermal Column Heat Exchanger, Experimental Demineralizer Heat Exchanger (HE-7), and the Helium Compressor Secondary Cooling Heat Exchanger. The heat load in the secondary coolant from these heat exchangers is transferred to the atmosphere via a hybrid wet/dry, plume abatement Cooling Tower.

Primarily, the Secondary Coolant System circulates light water (H_2O) through the Main Heat Exchangers, HE-1A and HE-1B (if necessary HE-1C), to remove heat from the primary coolant that is generated by fission in the core. There are six parallel Main Secondary Coolant Pumps, arranged in two sets of three parallel pumps. These pumps circulate the secondary coolant through the secondary side of the Main Heat Exchangers (8,000 – 10,000 gpm). Water from each set of pumps passes through a discharge strainer to filter out particulates and minimize fouling of the heat exchangers. The strainers are cleaned automatically by a backwash system, which consists of a Backwash Assist Pump and Bag Filter. The Bag Filter is changed manually as required. When the reactor is shutdown, a single smaller pump (Pump SD of 750 gpm) provides secondary flow in lieu of the Main Secondary Coolant Pumps.

Two Secondary Auxiliary Booster Pumps (Aux 1 and Aux 2) supply water from the discharge header of the Main Secondary Coolant Pumps to the D_2O Purification Heat Exchanger (HE-2), the Thermal Shield Heat Exchanger (HE-6), and the Thermal Column Heat Exchanger. Normally, one of these pumps is operating while the other remains in standby. Demineralized water from the Experimental Deminerizer Heat Exchanger (HE-7) can be piped into the secondary system if it becomes necessary to cool the experiments using the Experimental Demineralized Water Cooling System.

The Helium Compressor Secondary Cooling Pumps (Pumps 1 and 2) supply water from the suction header of the Main Secondary Coolant Pumps to the Helium Compressor Secondary Cooling Heat Exchanger. This removes the heat generated in the Cold Source Refrigerator. Normally, one of these pumps is operating, drawing its water from the inlet line from the Main Secondary Pumps, while the other remains in standby.

Upon leaving the Main Heat Exchangers, a portion of the water passes through a radiation detector and a test-coupon station. The radiation detectors monitor the secondary water for the presence of ^{16}N, an indicator of a primary-to-secondary leak. The test coupons monitor for any long-term effects that the secondary coolant might be having on the secondary piping.

Secondary system flow is measured by an installed flow element. The flow is then directed to the Cooling Tower or partially bypassed through valves SCV-1, SCV-2, and SCV-3, depending on cooling requirements as established by Reactor Inlet Temperature Recorder Controller Channel, TRCA-3. This channel is discussed in Section 5.2.2.6.2.

The Cooling Tower is a hybrid wet/dry, plume abatement design that cools the water by evaporation. As the water cascades down the cooling tower, fans draw air through the tower. The position of the roll-up doors on the wet section of the tower minimizes the plume emanating from the structure during reactor operations. The cooled water collects in the basin and provides the net positive suction head for the main secondary coolant pumps. The Cooling Tower is constructed of wood, fiberglass, and galvanized metal and is discussed in Section 5.3.2.2.

Secondary coolant losses, due to evaporation, leakage, and blow down, are automatically made up from the domestic water system by valve SCV-4. The cooling tower's sump level controls SCV-4, so that an adequate head of water is maintained for the main secondary coolant pumps.

There is a chemical addition system located in the chemical addition shack at the Cooling Tower to regulate corrosion and biological growth in the secondary system. Water is continuously blown down to the sewer system to remove concentrated solids and to maintain a low concentration of dissolved solids.

The number of Main Secondary Coolant Pumps during normal operation depends on the requirements of the plant for heat removal and the ambient conditions at the Cooling Tower. During shutdown, one Shutdown Cooling Pump may be operated to remove decay heat from the reactor.

5.3.2.1 Heat Source (Heat Exchangers)

The Secondary Cooling System supplies cooling water to several systems to remove heat generated within them. The heat-removal capacity of the system exceeds the total heat generated in all of these individual systems.

5.3.2.1.1 Main Heat Exchangers (HE-1A, -1B and -1C)

The Main Heat Exchangers, HE-1A, -1B, and -1C, are 35×10^6 BTU/hr (10 MW) each, plate-and-frame type, single-pass, counter flow heat exchangers which transfer heat from the Primary Coolant System to the Secondary Coolant System. The design pressure of each heat exchanger is 150 psig (1 MPa) at a design temperature of 200 °F (93 °C). The heat exchanger has a carbon steel frame and stainless steel plates. The total design pressure drop on the secondary side is 5.98 psi (41 kPa).

Section 5.2.2.2 discusses the design and operation of these heat exchangers.

5.3.2.1.2 D_2O Purification Heat Exchanger (HE-2)

The D_2O Purification Heat Exchanger, HE-2, is a 1.2×10^6 BTU/hr (0.35 MW), plate-and-frame type, single-pass, counter flow heat exchanger, which transfers heat from the Primary Coolant Purification System to the Secondary Coolant System. The purpose is to cool the primary coolant to prevent degradation to the ion exchangers and filters used in the Primary Coolant Purification System. The design pressure of this heat exchanger is 150 psig (1 MPa) at a design temperature of 200 °F (93 °C). At flows of 65 gpm (250 lpm) on the primary side and 170 gpm (645 lpm) on the secondary, D_2O is cooled from l00 °F to 90 °F (38 °C to 32 °C), depending on secondary water temperature. The heat exchanger has a carbon steel frame and stainless steel plates.

5.3.2.1.3 Thermal Shield Heat Exchanger (HE-6)

Thermal Shield Heat Exchanger, HE-6, is a 2.8×10^6 BTU/hr (0.8 MW) plate-and-frame type, single-pass, counter flow heat exchanger, which transfers heat from the Thermal Shield cooling water to the secondary cooling water. The design pressure of this heat exchanger is 100 psig (0.7 MPa) at a design temperature of 200 °F (93 °C). Thermal Shield cooling water enters the heat exchanger at 95 °F (35 °C) and leaves at 90 °F (32 °C). The heat exchanger has a carbon steel frame and stainless steel plates.

5.3.2.1.4 Experimental Demineralized Water Heat Exchanger (HE-7)

Experimental Demineralized Water Heat Exchanger, HE-7, is a 1.1×10^6 BTU/hr (0.3 MW), plate-and-frame type, single-pass, counter flow heat exchanger, which transfers heat from the Experimental Demineralized Water cooling water to the secondary cooling water. The design pressure of this heat exchanger is 150 psig (1 MPa) at a design temperature of 225°F (110 °C). The heat exchanger has a carbon steel frame and stainless steel plates.

At present, the system is only operated to supply water pressure for the refueling cannon. Since the refueling system generates no heat, the secondary cooling water supply is not connected to the HE-7 heat exchanger; instead, the secondary water piping bypasses it.

5.3.2.1.5 Thermal Column Heat Exchanger

The Thermal Column Heat Exchanger is a 1.0×10^5 BTU/hr (0.03 MW), plate-and-frame type, single-pass, counter flow heat exchanger which transfers heat from the Thermal Column cooling water to the secondary cooling water. The design pressure of this heat exchanger is 150 psig (1 MPa) at a design temperature of 200 °F (93 °C). The heat exchanger has a carbon steel frame and stainless steel plates.

5.3.2.1.6 Helium Compressor Secondary Cooling Heat Exchanger

The Helium Compressor Secondary Cooling Heat Exchanger is a 1.2×10^6 BTU/hr (0.35 MW), plate-and-frame type, multi-pass, counter flow heat exchanger, which transfers heat from the Helium Compressor cooling water to the secondary cooling water. The design pressure of this heat exchanger is 150 psig (1 MPa) at a design temperature of 200 °F (93 °C). The heat exchanger has a carbon steel frame and stainless steel plates.

5.3.2.2 Heat Sink (Cooling Tower)

Heat is transferred from the secondary coolant to the atmosphere by a hybrid wet/dry, plume abatement Cooling Tower, as shown in Figure 5.9. The tower is designed to transfer 75×10^6 BTU/hr (22 MW) to the atmosphere under adverse (high humidity and temperature) weather. As the water cascades down the cooling tower, fans draw air through the tower, cooling the secondary water by evaporation. The cooled water collects in the concrete catch basin below the tower and provides the net positive suction head for the Main Secondary Coolant Pumps. The cooling tower is constructed of wood, fiberglass, and galvanized metal. The materials of construction are compatible with the water chemistry of the secondary cooling system.

The Cooling Tower is divided into three sections, or "cells". Each cell has a single seven-blade fan driven by a 75 hp, 480 volts, three-phase motor. The motors are powered from Motor Control Center MCC A-7 and B-8. Each cell is further subdivided into a "wet" and a "dry" section. Both have a pair of roll-up doors that the operator can position to minimize the plume emanating from the structure during power operations. The operator controls the fans and roll-up doors from the control room.

5.3.2.3 Pumps

5.3.2.3.1 Main Secondary Cooling Pumps (1-6)

The six Main Secondary Cooling Pumps are single-stage, centrifugal units operated in parallel to circulate the secondary coolant from the Cooling Tower to the heat exchangers. Each pump has a 1780 rpm, 480 volt, 60 hp, three-phase, 60 Hz motor. Each pump is rated at 2,850 gpm (10,800 lpm) flow with a head of 70 feet (21 meter). Pumps 1, 3, 4, and 5 are powered from Pump Room MCC A-7 while pumps 2 and 6 are powered from Pump Room MCC B-8. Figure 5.10 shows the flow vs. head characteristics of these pumps.

The reactor operator remotely controls the pumps from the Main Control Panel in the Control Room. The number of Main Secondary Coolant Pumps in operation at any time depends on the plant's heat removal requirements and the ambient conditions (temperature and humidity) at the Cooling Tower.

5.3.2.3.2 Secondary Shutdown Pump (SD)

The Secondary Shutdown Pump is a single-stage, centrifugal unit used, as needed, to circulate secondary water during periods when the reactor is shutdown. The pump has a single-speed, 480 volt, 25 hp, three-phase, 60 Hz motor powered from Emergency Motor Control Center A-5. The pump is rated at 750 gpm (2,800 lpm) with a discharge head of 90 feet (27 meter).

5.3.2.3.3 Secondary Auxiliary Booster Pumps (AUX 1 and AUX 2)

The two Secondary Auxiliary Booster Pumps are single-stage, centrifugal units used to supply cooling to the auxiliary heat exchangers. Each pump has a 1,765 rpm, 480 volt, 25 hp, three-phase, 60 HZ motor. Pump number 1 is powered from Pump Room Motor Control Center MCC A-7, while pump number 2 is powered from MCC B-8. Each pump is rated at 750 gpm (2,800 lpm) with a head of 90 feet (27 meter). The units are normally operated with one running and the other in standby.

5.3.2.3.4 Helium Compressor Secondary Cooling Pumps (1 and 2)

The two Helium Compressor Secondary Cooling Pumps are single-stage, centrifugal units used to supply cooling to the helium compressor heat exchanger. Each pump has a 1,755 rpm, 480 volt, 30 hp, three-phase, 60 Hz motor. Pump number 1 is powered from Pump Room Motor Control Center MCC A-7, while pump number 2 is powered from MCC B-8. Each pump is rated at 400 gpm (1,500 lpm) with a head of 175 feet (53 meter). The units are operated with one running and the other in standby.

5.3.2.3.5 Backwash Assist Pump

The Backwash Assist Pump is a single-stage, centrifugal unit used to assist in cleaning the two Automatic Strainers installed in the secondary system piping. The pump has a 1, 760 rpm, 480 volt, 15 hp, three-phase, 60 Hz motor. The pump is rated at 250 gpm (950 lpm) with a head of 100 feet (30 meter). The two Automatic Strainer Control Units control the pump automatically.

5.3.2.4 Piping

Piping throughout the system is carbon steel, except in the radiation detector/secondary sample loop and the chemical addition system, where it is PVC. The diameter of the main piping is 20 to 24 inches (50 to 60 cm). The piping to the auxiliary heat exchangers is 4 to 6 inches (10 to 15 cm) in diameter.

5.3.2.5 Valves

Several remotely controlled valves in the secondary piping system allow the reactor operator to control the flow of cooling water from the Main Control Panel in the Control Room. Most of these valves have pneumatic positioners, while the remaining ones are motor operated. The 150 psi (1 MPa) air to operate the pneumatic control valves is supplied by the Instrument Air System, which is discussed in Chapter 9, Auxiliary Systems. Control power to operate the solenoid valves in the Instrument Air System comes from the Instrument Power Bus in the Main Control Panel.

Secondary Coolant Bypass Valves, SCV-1 and SCV-2, are 6-inch (15-cm), pneumatically positioned valves used to cross-connect the common suction header for Main Secondary Coolant Pumps 4, 5, and 6 with the common outlet header from Main Heat Exchangers HE-1A and -1B. Secondary Coolant Bypass Valve, SCV-3, is a 10-inch (25-cm), pneumatically positioned valve used to cross-connect the common suction header for Main Secondary Coolant Pumps 1, 2 and 3 with the common outlet header from Main Heat Exchangers HE-1A and -1B. The Reactor Inlet Temperature Recorder Controller Channel, TRCA-3, maintains a constant primary coolant inlet temperature by controlling the positions of SCV-1, -2 and -3 to regulate the secondary coolant bypass flow around the cooling tower. Section 5.2.2.6.2 discusses this temperature channel in more detail.

The Secondary Coolant Makeup Valve, SCV-4, is a 3-inch (7.6-cm), pneumatically positioned valve used to replenish lost secondary water from the domestic water supply for maintaining the level of water in the cooling tower's basin. Cooling Tower Level Channel, LIC-9, automatically controls this valve to make up for losses due to evaporation and leakage.

The Secondary Auxiliary Heat Exchanger Control Valve, SCV-5, is a 6-inch (15-cm), pneumatically positioned valve used to control the flow of secondary coolant to the Secondary Auxiliary Heat Exchangers. The reactor operator remotely controls the position of this valve from the Main Control Panel in the Control Room.

The Secondary Coolant Automatic Strainer Control Valves, SCV-10 and SCV-11, are 3-inch (7.6-cm), motor-operated valves used to control the flow of backwash water from the two Automatic Strainers. These valves are automatically controlled by the Strainer Controllers.

The D_2O Purification Heat Exchanger Secondary Cooling Water Control Valve, SCV-12, is a 4-inch (10-cm), pneumatically positioned valve used to control the flow of secondary coolant to the Purification Heat Exchanger, HE-2. This valve is located in the inlet piping to the heat exchanger. The operator remotely controls the position of this valve from the Main Control Panel in the Control Room. This valve is interlocked with the operation of the D_2O Storage Tank Pumps, DP-7 and DP-8. To ensure a greater pressure on the primary side of the heat exchanger than on its secondary side, one of these pumps must be running before SCV-12 will open.

Experimental Demineralizer Heat Exchanger Secondary Cooling Water Control Valve, SCV-13, is a 4-inch (10-cm), pneumatically positioned valve used to control the flow of secondary coolant to the Experimental Demineralizer Heat Exchanger, HE-7. At present, the secondary coolant piping is not connected to the HE-7 heat exchanger, but instead, bypasses it. Section 5.3.2.1.4 discusses HE-7 in more detail.

The Thermal Shield Secondary Cooling Water Control Valve, SCV-14, is a 4-inch (10-cm), pneumatically positioned valve used to control the flow to secondary coolant to the Thermal Shield Heat Exchanger, HE-6. This valve is located in the inlet piping to the heat exchanger. The Thermal Shield Heat Exchanger Secondary Inlet Valve Controller maintains a constant Thermal Shield Cooling Water outlet temperature by throttling the flow of secondary cooling water supplied to the heat exchanger.

The Secondary Header Isolation Valve, SCV-50, is a 20-inch (51-cm), motor-operated valve used to control the flow of secondary coolant to the Main Heat Exchangers, HE-1A, -1B and -1C. This valve is located in the secondary header before the heat exchanger. The operator controls this valve from the Main Control Panel in the Control Room. This valve is interlocked with the Secondary Shutdown Pump when the control switch is in the AUTO position, so that the valve automatically closes when the Secondary Shutdown Pump starts, and opens when it stops.

5.3.2.6 Instrumentation

Necessary instrumentation is installed to remotely readout the secondary cooling water flow, its temperature and pressure at various locations in the loop, the radiation level of the water, and the level of the cooling tower basin. Other measurements generally are taken by local gauges, which do not give Control Room read-out. Local temperature indicators also are placed at various points in the system. Electrical power for the instruments comes from the Instrument Power Bus located in the Main Control Panel.

5.3.2.6.1 Flow

The flow of secondary coolant through Main Heat Exchanger HE-1A is measured by HE-1A Secondary Cooling Water Flow Channel, FI-22. Ultrasonic Flow Element, FE-22, and Flow Transmitter, FT-22, supply a flow signal to Flow Indicator, FI-22. The flow of secondary coolant through Main Heat Exchanger HE-1B is measured by HE-1B Secondary Cooling Water Flow Channel, FI-23. Ultrasonic Flow Element, FE-23, and Flow Transmitter, FT-23, supply a flow signal to Flow Indicator, FI-23. The ultrasonic-flow elements are mounted on the secondary piping on the inlet side of each heat exchanger. The range of both channels is 0-6,000 gpm (0-22,700 lpm).

The Secondary Header Flow Indicator Channel, FI-12, measures the flow of secondary coolant through the common discharge header on the outlet side of Main Heat Exchangers HE-1A, -1B, and -1C. Flow is measured by a 20-inch venturi, FE-12, located in the secondary piping between the heat exchangers and the cooling tower. Sensing lines connect the high- and low-pressure ports on the venturi to Flow Transmitter, FT-12 that supplies an electrical signal to Flow Indicator, FI-12, and Flow Alarm, FA-12. The alarm unit alerts the operator to a low-flow condition. The range of the channel is 0-12,000 gpm (0-45,400 lpm).

The Secondary Auxiliary Cooling Flow Channel, FIA-17, measures the combined flow of secondary coolant to the D_2O Purification Heat Exchanger (HE-2), Thermal Shield Heat Exchanger (HE-6), Experimental Demineralized Water Heat Exchanger (HE-7), and Thermal Column Heat Exchanger. Flow is measured by a 5-inch (12.7-cm) venturi, FE-17, located in the common header piping on the outlet from the Secondary Auxiliary Pumps. Sensing lines connect the high- and low-pressure ports on the venturi to Flow Transmitter, FT-17 that supplies an electrical signal to Flow Indicator, FI-17. The range of the channel is 0-1,000 gpm (0-3,800 lpm).

The flow of secondary coolant through D_2O Purification Heat Exchanger, HE-2, is measured by HE-2 Secondary Cooling Water Flow Channel, FI-26. Ultrasonic Flow Element, FE-26, and Flow Transmitter, FT-26, supply a flow signal to Flow Indicator, FI-26. The ultrasonic-flow element is mounted on the secondary piping on the heat exchanger's inlet side. The channel range is 0-300 gpm (0-1,135 lpm).

The flow of secondary coolant through Thermal Shield Heat Exchanger, HE-6, is measured by HE-6 Secondary Cooling Water Flow Channel, FI-27. Ultrasonic Flow Element, FE-27, and Flow Transmitter, FT-27, supply a flow signal to Flow Indicator, FI-27. The ultrasonic flow elements are mounted on the secondary piping on the outlet side of each heat exchanger. The range of the channel is 0-750 gpm (0-2,840 lpm).

The flow of secondary coolant through Helium Compressor Secondary Cooling Heat Exchanger is measured by the Helium Compressor Secondary Flow Channel, FI-30 that has a 4-inch (10.2-cm) orifice, FE-30, located in the common header piping on the outlet from the Helium Compressor Secondary Cooling Pumps. Sensing lines connect the high- and low-pressure ports on the orifice to Flow Transmitter, FT-30. This flow transmitter supplies an electrical signal to Flow Indicator, FI-30, for local indication only on the first floor of the Pump House. The channel's range is 0-500 gpm (1,900 lpm).

5.3.2.6.2 Temperature

The Cooling Tower Temperature, TIA-12, measures the temperature of the water in the cooling tower's basin. Thermocouple, TE-12, is mounted in this basin. Temperature Transmitter, TT-12, provides an electrical signal that is applied to Temperature Indicator, TI-12, and Temperature Alarm, TA-12. The alarm unit has outputs that send a signal to annunciate a low temperature condition. The range of the channel is 30-130 ^{o}F (17 to 72 ^{o}C).

The HE-1A Secondary Outlet Temperature Channel, TI-13, measures the secondary cooling water's outlet temperature from the Main Heat Exchanger HE-1A. Thermocouple, TE-13, is mounted in the 12-inch (30.5-cm) outlet piping from the heat exchanger. Temperature Transmitter, TT-13, applies a signal to Temperature Indicator, TI-13. HE-1B Secondary Outlet Temperature Channel, TI-33, measures the secondary cooling water outlet temperature from Main Heat Exchanger HE-1B. Thermocouple, TE-33, is mounted in the 12-inch outlet piping from the heat exchanger. Temperature Transmitter, TT-33, applies a signal to Temperature Indicator, TI-33. The range of both channels is 50-150 ^{o}F (28-83 ^{o}C).

The Secondary Header Inlet Temperature Channel, TI-14, measures the inlet temperatures of the secondary cooling water for the Main Heat Exchangers HE-1A and -1B. Thermocouple, TE-14, is mounted in the 20-inch (50.8-cm) secondary header piping. Temperature Transmitter, TT-14, applies a signal to Temperature Indicator, TI-14. The range of the channel is 50-150 ^{o}F (28-83 ^{o}C).

The Thermal Shield Heat Exchanger Secondary Outlet Temperature Channel, TIA-17, measures the temperature of the secondary cooling water outlet from the Thermal Shield Heat Exchanger. Thermocouple, TE-17, is mounted in the 4-inch outlet piping from the heat exchanger. Temperature Transmitter, TT-17, applies a signal to Temperature Indicator, TI-17, and Temperature Alarm, TA-17. The alarm unit has outputs that supply a signal to annunciate a high-temperature condition. The range of the channel is 50-125 ^{o}F (28-70 ^{o}C).

The HE-2 Secondary Outlet Temperature Channel, TI-36, measures the outlet temperature of the secondary cooling water from the D_2O Purification Heat Exchanger, HE-2. Thermocouple, TE-36, is mounted in the 4-inch (10.2-cm) outlet piping from the heat exchanger. Temperature Transmitter, TT-36, applies a signal to Temperature Indicator, TI-36. The channel's range is 50-125 ^{o}F (28-70 ^{o}C).

5.3.2.6.3 Pressure

All pressure measurements are made with local Bourdon-tube-type pressure gauges. Suction and discharge pressures of all pumps are sensed, as well as the inlet and outlet pressures of the three auxiliary heat exchangers and the helium compressor secondary cooling heat exchanger.

The HE-1A Primary/Secondary Differential Pressure Indicator, PIA-30, measures the differential pressure between the primary and secondary sides across the Main Heat Exchanger, HE-1A. Pressure Transmitter, PT-30, supplies a signal to Pressure Indicator, PI-30, and Pressure Alarm, PA-30. An alarm alerts the operator to a low ΔP condition across the heat exchanger. The range of the channel is 0-50 psid (0.35 MPa).

The HE-1B Primary/Secondary Differential Pressure Indicator, PIA-40, measures the differential pressure between the primary and secondary sides across the Main Heat Exchanger HE-1B. Pressure Transmitter, PT-40, supplies a signal to Pressure Indicator, PI-40, and Pressure Alarm, PA-40. An alarm alerts the operator to a low ΔP condition across the heat exchanger. The range of the channel is 0-50 psid (0.35 MPa).

The HE-2 Primary/Secondary Differential Pressure Indicator, PIA-31, measures the differential pressure between the primary and secondary sides of D_2O Purification Heat Exchanger HE-2. Pressure Transmitter, PT-31, supplies a signal to Pressure Indicator, PI-31, and Pressure Alarm, PA-31. An alarm alerts the operator to a low ΔP condition across the heat exchanger. The range of the channel is 0-50 psid (0.35 MPa).

5.3.2.6.4 Radiation Monitors

The presence of ^{16}N in the secondary coolant is indicative of a primary-to-secondary coolant leak. Secondary Cooling N-16 Radiation Monitors RM3-1 and RM3-3 provide redundant monitoring for ^{16}N in the secondary coolant. A sample line taps off the common secondary discharge header after Main Heat Exchangers HE-1A and HE-1B, continuously diverting a small amount of secondary water for monitoring. Two GM Detectors, RD3-1 and RD3-3, are mounted in the piping of the N-16 monitoring station located in the Pump House. They feed two pre-amplifiers and two rate meters. The latter give both local indication at the monitoring station and remote indication on the Main Control Panel. Alarm contacts sound an alarm when there is high activity in the secondary coolant. The range of both channels is $10\text{-}10^6$ CPM.

5.3.2.6.5 Level

The Cooling Tower Level Controller Channel, LIC-9, measures and controls the level of the cooling tower's water. Level Transmitter, LT-9, applies a signal to Level Controller, LC-9, Level Indicator, LI-9, and Level Alarm, LA-9. The controller maintains an adequate head of water for the Main Secondary Coolant Pumps by controlling the Secondary Coolant Makeup Valve, SCV-4. The alarm unit has outputs that supply a signal to annunciate high-level and low-level conditions. The channel's range is 0-50 inches (0-127 cm).

5.2.3.7 Secondary Strainer System

Even though the basin of the Cooling Tower is covered, debris and foreign matter may still enter the Secondary Coolant System. Two Automatic Strainers and their associated control valves and instrumentation and a common Backwash Assist Pump and bag filter are installed in the secondary piping to continuously remove any debris from the secondary water. Debris is periodically taken out of each strainer by a motorized internal cleaning arm, aided by the Backwash Assist Pump. Backwashing occurs after a pre-set time interval or whenever the pressure differential across a filter exceeds 5 psid (34 kPa). The control panels for each strainer are interlocked to prevent both units from backwashing simultaneously. Debris removed from each strainer is trapped in the common bag filter. Contacts in a pressure switch on the inlet to the bag filter annunciate an alarm in the Control Room, alerting the reactor operator when the bag filter is full.

The Backwash Assist Pump is discussed in Section 5.3.2.3.5, and the Secondary Coolant Automatic Control Valves SCV-10 and SCV-11 is discussed in Section 5.3.2.5.

5.3.2.8 Make-Up Water

The local utility supplies the water used as make-up to the secondary cooling system via the domestic water system of the National Institute of Standards and Technology.

Evaporation in the cooling tower tends to concentrate solids in the secondary water. These solids are entrained in a water stream and then removed via a blow down system. The blow down water is directed to the sanitary sewer through a solenoid valve, a flow meter, and a manual throttle valve. The solenoid is energized from the chemistry control panel on room D100.

5.3.2.9 Corrosion Control

A chemical addition system, consisting of a chemical control system, a corrosion inhibitor injection pump, and a reservoir of inhibitor, is provided so that substances can be added to control corrosion and biological growths.

In automatic status, the pump continuously injects inhibitor. The operator manually adds the biocide. Because these are closed systems, the operator does not routinely handle chemicals.

5.3.3 Design and Operating Parameters and Specifications

Table 5.4 lists the design and operating parameters for the Secondary Coolant System.

5.3.4 System Operation

5.3.4.1 Primary-To-Secondary Differential Pressure

Section 5.2.11, Leak Detection System, discusses primary coolant leakage from the Primary Coolant System and its components. Analysis of the expected concentrations and rates of exposure at the site boundary demonstrate that the releases would be only a very small fraction of the allowable effluent concentrations. Leak detectors on the components of the Primary Coolant System and ^{16}N detectors in the Secondary Coolant System alert the reactor operator to any primary-to-secondary coolant leak.

Of greater concern is the dilution of the heavy water (D_2O) primary coolant by the introduction of light water (H_2O) secondary coolant, which degrades the nuclear characteristics of the moderator and the introduces negative reactivity into the core. The designs of the Primary Coolant System and the Secondary Coolant System maintain the pressure on the primary coolant sides of Main Heat Exchanger HE-1A and -1B and Purification Heat Exchanger HE-2 greater than that of the secondary sides during normal operations, when flow is established in both systems, and during normal shutdown periods. An alarm alerts the reactor operator to a low ΔP condition across the heat exchangers. Section 5.3.2.6.3 discusses the differential pressure channels.

On rare instances when maintenance work is underway the secondary sides of these heat exchangers attain a higher pressure; then, the primary sides are pressurized with helium to ensure that no secondary coolant leak into the primary coolant side of the heat exchangers.

5.3.4.2 Removal of Heat from the Secondary Coolant System

The design goal of the Secondary Coolant System design is the transfer of heat from the Primary Coolant System and the various other auxiliary systems to the atmosphere. The hybrid wet/dry Cooling Tower is designed to reject $75x10^6$ BTU/hr (22 MW) to the atmosphere under the most adverse weather conditions. To ensure the integrity of the fuel cladding, the temperature of the primary coolant entering the reactor core is constantly maintained below the Safety Limit and the outlet temperature monitor initiates a rundown before any fuel damage can occur.

During power operations, the operator runs three of the four D_2O Main Circulating Pumps and either five or six of the Main Secondary Cooling Pumps; the number of secondary pumps is a function of the environmental conditions at the cooling tower. Since the flow rates in both the primary and the secondary systems are constant, the operator maintains a constant inlet temperature to the reactor's core by regulating the amount of secondary coolant bypassing the cooling tower. The Reactor Inlet Temperature Recorder Controller Channel, TRCA-3, controls the position of Secondary Coolant Bypass Valves, SCV-1, -2, and -3, to maintain a constant primary coolant inlet temperature. Section 5.2.2.6.2 discusses this temperature channel.

Immediately following a reactor shutdown, until decay heat has dropped to an insignificant level, the reactor operator runs the Secondary Shutdown Pump, as necessary, to cool the primary coolant by circulating secondary water through the Main Heat Exchangers.

Analysis showed that the reactor could be operated at power levels up to 10 kWt with reduced flow, including no flow, since the decay heat generated by the core is insufficient to significantly heat the primary coolant in the Primary Coolant System and the Reactor Vessel.

5.3.4.3 Transfer of Heat from the Secondary Coolant System to the Environment

The hybrid wet/dry Cooling Tower transfers all the heat generated in the reactor and the various auxiliary systems to the atmosphere.

The function of the Cooling Tower is to transfer heat from the primary coolant via the secondary coolant. A loss of the Cooling Tower during operation without an operator response would result in a primary coolant temperature increase, followed by a reactor shutdown due to high primary coolant temperature.

5.3.4.4 Reactor Shutdown

Section 5.2.4.3 discusses the Reactor Shutdown. The Secondary Cooling System is not needed for shutdown of the reactor.

5.3.4.5 Response of Secondary Coolant System to the Loss of Primary Coolant

If primary coolant is lost, the reactor Emergency Cooling System ensures adequate protection against melting of the reactor core and the associated release of fission products. Protecting the core does not depend solely on the operation of the Secondary Coolant System. Chapter 13, Accident Analysis, discusses the Loss of Coolant Accident event, while Chapter 6, Engineered Safety Features, discusses this in more detail.

5.3.4.6 Locations, Designs, and Functions of Essential Components

With the exception of the Helium Compressor Secondary Cooling Heat Exchanger, all of the heat exchangers and their associated instrumentation and isolation valves are located in the Process Room. A curb installed there captures any primary coolant that may leak from Main Heat Exchangers HE-1A and -1B and from Purification Heat Exchanger HE-2, and collects it in a sump. Leakage from other heat exchangers is collected in a separate sump and pumped to the Liquid Waste System before being released to the sewage system serving the NBSR site. The Helium Compressor Secondary Cooling Heat Exchanger is located in the main floor of the Pump House (D wing).

Most of the piping associated with the Secondary Cooling System is found outside the Process Room. The pumps, strainers, bag filter, and the N-16 monitors are located outside the confinement in the Pump House. The Cooling Tower and its associated piping, instrumentation and valves are sited in a freestanding structure outside the confinement to the west of the Guide Hall.

Vent and drain lines are provided where needed throughout the system piping. These lines have valves and are capped to prevent inadvertent leakage. Transfer of contaminated primary coolant to the secondary system is only possible by Main Heat Exchanger leakage or by deliberately cross-connecting the piping of the primary system with the vent and drain lines of the secondary system.

Secondary Coolant Makeup Valve, SCV-4, adds water directly to the cooling tower's basin to make up for losses in the Secondary Coolant System due to evaporation, leakage, and blow down. Since the discharge of this valve is far removed from the primary piping system and the outlet of the fill line is above the surface of the water in the cooling tower basin, primary coolant cannot be inadvertently released to the water supply.

5.3.5 Control and Safety Instrumentation

Section 5.3.2.6 discusses the instrumentation associated with the Secondary Coolant System. While the sensors for pressure, temperature, level, and other monitored parameters are located appropriately throughout the system, the readout devices and controllers are located in the Main Control Panel in the Control Room, giving the operator with a single, convenient location from which to control and operate the reactor.

The reactor operator can remotely control pumps and valves from the Main Control Panel. Five annunciators, mounted in this panel, alert the operator to changing conditions in the plant. The alarm channels receive their inputs from the various instrument channels located throughout the plant and from auxiliary contacts in monitored equipment. The isolated Instrument Power Bus, located within the Main Control Panel, supplies electrical power for all the instrumentation and control equipment.

5.3.6 Secondary Coolant System Radiation Monitors

The presence of radioactivity in the secondary coolant is indicative of a primary-to-secondary leak in either Main Heat Exchangers HE-1A or HE-1B or in the Purification Heat Exchanger HE-2. Tritium and ^{16}N are the isotopes of concern. Redundant Secondary Cooling N-16 Radiation Monitors, RM3-1 and RM3-3, monitor the activity of the secondary coolant. These monitors are discussed in Section 5.3.2.6.4.

5.3.7 Auxiliary Systems using Secondary Coolant

The heat load due to the reactor is approximately 93% of the capacity of the hybrid wet/dry, plume-abatement Cooling Tower. The remaining capacity is used by the auxiliary systems connected to the Secondary Coolant System. All the sources of heat are previously listed and discussed in Section 5.3.2.1, Heat Source (Heat Exchangers).

5.3.8 Technical Specification Requirements

Two Technical Specifications apply to the Secondary Coolant System.

5.3.8.1 Technical Specification 3.6, Secondary Cooling System

This Technical Specification applies to the Main Heat Exchangers in the Primary Coolant System. Its objective is to maintain tritium releases as low as practicable. The reactor is required to be shut down and corrective action taken if the leakage of primary coolant through a heat exchanger to the secondary system exceeds the daily, weekly, and yearly limits established in the specification. Using this value, the limits ensure that tritium concentrations in effluents will be as low as practicable, and below concentrations allowed by 10 CFR 20.303 for liquid effluents and 10 CFR 20.106 for gaseous effluents (Chapter 11, Radiation Protection and Waste Management). The specified daily and weekly leakage rates represent the lowest limits of positive detection of D_2O losses under both operating and shutdown conditions. The specified yearly leak rate represents an estimate of the smallest sized leak that can be positively located and repaired.

5.3.8.2 Technical Specification 4.5, Secondary Cooling System

This Technical Specification applies to activity in the secondary coolant. Its objective is to ensure adequate monitoring for radioactivity in the secondary cooling system. The specification requires that the operability of the N-16 monitor is tested at least monthly and calibrated at least annually. It also requires that, when the N-16 monitor is inoperable, the secondary cooling water is sampled and analyzed for tritium at least monthly. Should the N-16 monitor be inoperable, this specification requires, at least, the daily sampling and analysis of the secondary cooling water for tritium.

Technical Specification 3.6 places a limitation on leakage from the primary to the secondary coolant system. This limit can be maintained by monitoring for ^{16}N carryover, indicating a leak of water recently irradiated in the reactor, or by laboratory analysis for tritium. Both methods are employed. The N-16 monitor is a simple radiation-detection device sensitive to as little as 36 gallon/day (135 liter/day) leakage. Verification of its operability at least monthly is considered a reasonable frequency for such a device. An annual calibration is considered adequate to ensure that system sensitivity does not significantly deteriorate.

Assuming that the N-16 monitor is operable and there is no detectable loss of primary coolant (less than 36 gallon/day (135 liter/day) sensitivity), monthly sampling for tritium has been shown to be adequate to detect small tritium leaks. However, if the N-16 monitor is inoperable, then sampling is the primary means of leak detection and must be done more frequently. Daily measurements are judged adequate, since the level instruments would detect large leaks that would indicate a loss from the D_2O Storage Tank (sensitive to at least 300 gallons (1140 liters)).

5.4 Primary Coolant Purification System

5.4.1 Design Bases/Functional Requirements

The Primary Coolant Purification System is designed to maintain the chemistry and purity of the primary coolant by removing both soluble and insoluble corrosion products and other foreign materials. The chemistry of the primary coolant must be properly controlled to ensure that the components in contact with the primary coolant are not degraded over the life of the plant. The purification system maintains the primary coolant pH between 5.0 and 6.0 and the conductivity less than 1 μmho. Purity of the primary coolant is essential to minimize the contaminants that might be exposed to the neutron flux, thereby decreasing the radiation exposure of the operations personnel. Mechanical filtration of the primary coolant removes particles 0.2 mils (5 microns) and larger.

The system also provides an alternate means of supplying cooling water to the reactor through D_2O Injection Flow Valve DWV-39. This connection can supply primary coolant from the purification system to the reactor core through the normal primary inlet piping.

5.4.2 System Description

Figure 5.11 shows the Primary Coolant Purification System.

The Primary Coolant Purification System supplies heavy water to the D_2O Emergency Cooling Tank, the D_2O Experimental Cooling System, and the D_2O Injection System after first treating a portion of the primary coolant by the purification system filters and ion exchangers. The latter maintain the water chemistry of the primary coolant and the filters remove any suspended solids.

The D_2O Storage Tank, sized to hold the entire plant's inventory of heavy water, is the source of the water for the Primary Coolant Purification System. The storage tank receives primary coolant from the reactor vessel's overflow line and from the D_2O Experimental Cooling System. The primary coolant returned to the storage tank collects in its sump. D_2O Storage Tank Pumps DP-7 and DP-8, located in this sump, supply the heavy water to D_2O Purification Heat Exchanger HE-2. One pump is normally run with the second in standby to maintain a flow rate of approximately 35 gpm (132 lpm) in the purification system.

The D_2O Purification Heat Exchanger (HE-2) cools the D_2O from approximately 100 ^oF (38 ^oC) to 90 ^oF (32 ^oC) to prevent excessive temperatures damaging the ion exchanger beds and mechanical filters. After being cooled, approximately 15 gpm (57 lpm) of heavy water is diverted through the purification train, consisting of a pre-filter, two ion exchangers and a post-filter, while the remaining 20 gpm (76 lpm) of heavy water bypasses it. These two streams rejoin to supply heavy water to the D_2O Emergency Cooling Tank at a flow rate of approximately 20 gpm (76 lpm), and to the D_2O Experimental Cooling System at a flow rate of 15 gpm (57 lpm). Heavy water supplied to the Emergency Cooling Tank returns to the Primary Coolant System, while water sent to the D_2O Experimental Cooling System returns to the D_2O Storage Tank for reprocessing by the Primary Coolant Purification System.

With a nominal flow rate of heavy water through the purification system filters and ion exchangers of 15 gpm (57 lpm), and with a nominal primary coolant inventory of 11,100 gallons (42,000 liters), 12¼ hours is the minimum time necessary to treat all of the heavy water. However, approximately 43% (15 gpm (57 lpm)) of the flow processed by the purification system is supplied to the D_2O Experimental Cooling System, while the remaining 57% (20 gpm (76 lpm)) returns to the Primary Coolant System by way of the D_2O Emergency Cooling Tank. Consequently, the minimum time to treat all of the primary coolant is approximately 21½ hours.

5.4.2.1 D_2O Storage Tank

The D_2O Storage Tank, located in a pit below the Process Room floor, is sized to receive the entire plant's D_2O inventory. The total capacity of the tank is 14,650 gallons (55,500 liters), with a sump capacity of 326 gallons (1,230 liters). The first 50 inches (127 cm) of indicated storage tank level reflects the sump level. During normal operation, the sump is filled with D_2O to a level between 35 and 45 inches (89 and 114 cm). The tank is fabricated of 6061 Aluminum.

The storage tank acts as the reservoir for the purification system. It receives heavy water from the D_2O Experimental Cooling System and from the Reactor Vessel's overflow line. It also receives D_2O from the moderator dump line through Moderator Dump Valve DWV-9, and from the fuel-transfer chute through Fuel Transfer Overflow Valve DWV-37. Heavy water from the D_2O drain lines and traps located throughout the primary system drains by gravity to the storage tank. In an emergency, the Emergency Sump Pump can return the heavy water collected in the emergency sump to the storage tank.

5.4.2.2 D_2O Storage Tank Pumps (DP-7 and DP-8)

Heavy water for the Primary Coolant Purification System is supplied from two submersible pumps, D_2O Storage Tank Pumps, DP-7 and DP-8, mounted in the D_2O Storage Tank sump. They are single-stage, centrifugal, submersible, canned motor units. The motors are single speed, 480 volt, three-phase, 60 Hz rated at 15 hp. All parts in contact with heavy water are 316 stainless steel. The pumps are designed to deliver 102.5 gpm (390 lpm) at a discharge pressure of 75 psig (0.5 MPa). Pump DP-7 is powered from Emergency Power MCC A-5, while pump DP-8 is powered from Emergency Power MCC B-6.

The reactor operator can remotely control the pumps from the Main Control Panel located in the Control Room. During normal power operation, one pump is run to supply flow to the purification system, while the second pump remains in standby. The Storage Tank Pumps are interlocked with the D_2O Purification Heat Exchanger Secondary Cooling Water Control Valve, SCV-12. To ensure greater pressure on the primary side of the heat exchanger than on its secondary side, one of these pumps must be running before SCV-12 will open.

5.4.2.3 D_2O Purification Heat Exchanger (HE-2)

To ensure that excessive temperature does not degrade the performances of the filters and ion-exchanger beds, the heavy water supplied to the Primary Coolant Purification System by the D_2O Storage Tank Pumps is cooled before entering the purification train. At flows of 35 gpm (132 lpm) on the primary side and 170 gpm (643 lpm) on the secondary side, D_2O is cooled from 100 ^oF (38 ^oC) to approximately 90 ^oF (32 ^oC), depending on secondary water temperature. The ion exchangers are designed for 110 ^oF (43 ^oC) and the filters for 120 °F (96 ^oC).

D_2O Purification Heat Exchanger, HE-2, is a $1.18x10^6$ BTU/hr (0.35 MW), plate-and-frame type, single-pass, counter-flow, heat exchanger that transfers heat from the Primary Coolant Purification System to the secondary cooling water. The design pressure of this heat exchanger is 150 psig (1 MPa) at a design temperature of 200 °F (93 ^oC). The heat exchanger has a carbon steel frame and stainless steel plates.

Two embossed stainless steel plates, or “cassettes” are welded together forming a chamber through which primary water flows; they are the heat transfer medium. The heat exchanger has a carbon steel plate (or pressure plate), 20 cassettes, and another pressure plate. D_2O flows down into a cassette and H_2O flows up the outside of the cassette. Gaskets prevent the primary and secondary water from mixing.

The heat exchanger is located in the Process Room.

5.4.2.4 Ion Exchanger

Installed ion exchangers (IX) purify the primary coolant. Four mixed D_2O resin bed columns are installed to remove dissolved materials from the heavy water. Two ion exchangers are normally on line, while two others act as installed spares. However, only one IX is used at a time.

Each IX column is approximately 6½ ft^3 in volume and is constructed of 304 stainless steel. The IX vessels are designed to operate at 110 psig (0.8 MPa) at 110 ^oF (43 ^oC), with a flow of 25 gpm (95 lpm). The ion exchangers are located in the Process Room. To protect personnel from exposure to any activated material that may become trapped in the resin bed, an engineered shield surrounds the columns.

5.4.2.5 Ion Exchanger Filters

Two filters mechanically filter the heavy water. The IX pre-filter and the after-filter are identical units containing six replaceable, cellulose, acetate cartridges which remove particles 5 microns and larger from the coolant. The after-filter also prevents any resin beads from the ion exchangers entering the Primary Coolant System.

The design pressure for the filters is 125 psig (0.9 MPa) at 120 °F (96 ^oC). The filter housings are constructed of 304 stainless steel. Both filters are located in the Process Room. To protect personnel from exposure to activated material that may become trapped in the filter medium, lead bricks are stacked around the filter housing as shielding.

5.4.2.6 Valves

Several remotely controlled valves in the Primary Coolant Purification System piping allow the reactor operator to control the distribution of heavy water from the Main Control Panel in the Control Room. These valves all have pneumatic positioners. The 150 psi (1 MPa) air to operate them is supplied by the Instrument Air System, discussed in Auxiliary Systems, Chapter 9. Control power to operate the solenoid valves in the Instrument Air System comes from the Instrument Power Bus in the Main Control Panel.

The D_2O Storage Tank Pump Isolation Valves, DWV-14 and -15, are 2-inch (5-cm), pneumatically positioned valves used to isolate the discharge lines from the D_2O Storage Tank Pumps. Valve DWV-14 is on the discharge of storage tank pump DP-7, while valve DWV-15 is for DP-8.

The Reactor Pump-Up Valve, DWV-11, and Reactor Pump-Up Isolation Valve, DWV-134, are used to add heavy water directly to the reactor outlet piping of the Primary Coolant System from the discharge header of the D_2O Storage Tank Pumps, bypassing the Primary Coolant Purification System. Both valves are 3-inch (7.6-cm), pneumatically positioned valves.

The D_2O Purification Train Inlet Isolation Valve, DWV-16, is a 1½-inch (3.8-cm), pneumatically positioned valve used to isolate the inlet line to the purification filters and ion exchangers.

The D_2O Purification Train Bypass Control Valve, DWV-22, is a 2-inch (5-cm), pneumatically positioned fugitive-emission throttle valve used to control the flow of heavy water bypassing the D_2O Purification Train. This valve controls the amount of bypass around the IXs and is positioned to allow flows and tank levels throughout the primary system to come to acceptable equilibrium conditions, given any initial state for the heavy water systems.

The D_2O Experimental Cooling System Inlet Isolation Valve, DWV-26, is a 2-inch (5-cm), pneumatically positioned valve used to control the flow of purified heavy water supplied by the Primary Coolant Purification System to the D_2O Experimental Cooling System. It is located on the common inlet header to the D_2O Experimental Cooling System Pumps.

The D_2O Emergency Cooling Tank Inlet Isolation Valve, DWV-40, is a 2-inch (5-cm), pneumatically positioned valve that controls the flow of purified heavy water supplied by the Primary Coolant Purification System to the D_2O Emergency Cooling Tank. It is located in the tank's inlet line.

The D_2O Injection Control Valve, DWV-39, is a 1-inch (2.5-cm), pneumatically positioned valve used to directly inject purified heavy water supplied by the Primary Coolant Purification System into the common reactor inlet header of the Primary Coolant System.

The Purification System to Emergency Sump Pump Discharge Cross-connect Isolation Valve, DWV-20, is a 1½-inch (3.8-cm), pneumatically positioned valve connecting the Emergency Sump Pump discharge line to the Primary Coolant Purification System discharge header after the IXs and filters. This provides a direct flow path of heavy water collected in the Emergency Sump back to the Primary Coolant System. Heavy water returned through this arrangement bypasses the purification system's filters and ion exchangers.

5.4.2.7 Instrumentation

Instrumentation is installed to provide remote read-out of the D_2O Storage Tank level, purification flow rate, heat-exchanger inlet and outlet temperature, ion exchanger influent and effluent conductivity, ion exchanger outlet flow, and injection flow. Differential pressure is measured across the heat exchanger, and the pre-filters and after-filters.

5.4.2.7.1 Flow

The D_2O to Purification Heat Exchanger (HE-2) Flow Indicator Channel, FIA-5, measures the flow of heavy water in the inlet line to the D_2O Purification Heat Exchanger HE-2. Ultrasonic Flow Element, FE-5, and Flow Transmitter, FT-5, supply a flow signal to Flow Indicator, FI-5, and Flow Alarm, FA-5. The ultrasonic flow element is mounted on the inlet piping of the purification side of the heat exchanger. The alarm unit alerts the operator to a low-flow condition. The range of the channel is 0-120 gpm (0-455 lpm).

The D_2O IX Flow Indicator Channel, FIA-6, measures the flow of heavy water through the purification train. Flow is measured by a 1 ½-inch (3.8-cm) orifice, FE-6, in the train's piping on the outlet of the after-filter. Sensing lines connect the high- and low-pressure ports on the orifice to Flow Transmitter, FT-6. This transmitter supplies an electrical signal to Flow Indicator, FI-6, and Flow Alarm, FA-6. The alarm unit alerts the operator to a low-flow condition through the filters and ion exchanger beds. The channels' range is 0-30 gpm (0-113 lpm).

5.4.2.7.2 Temperature

The HE-2 D_2O Outlet Temperature Indicator Channel, TIA-6, records the temperature of the heavy water leaving the D_2O Purification Heat Exchanger HE-2. Thermocouple, TE-6, is mounted in the 4-inch (10.16-cm) outlet piping from the heat exchanger. Temperature Transmitter, TT-6, applies a signal to Temperature Indicator, TI-6, and Temperature Alarm, TA-6. The alarm unit alerts the operator when the temperature of the water leaving the heat exchanger is high. The range of the channel is 50-125 ^oF (28-70 ^oC).

The HE-2 D_2O Inlet Temperature Indicator Channel, TI-7, measures the temperature of the heavy water entering the D_2O Purification Heat Exchanger HE-2. Thermocouple, TE-7, is mounted in the 4-inch (10-cm) inlet piping to the heat exchanger. Temperature Transmitter, TT-7, applies a signal to Temperature Indicator, TI-6. The range of the channel is 50-125 ^oF (28-70 ^oC).

5.4.2.7.3 Pressure

The HE-2 Primary/Secondary Differential Pressure Indicator, PIA-32, measures the differential pressure between the primary- and secondary-sides of D_2O Purification Heat Exchanger HE-2. Pressure Transmitter, PT-32, supplies a signal to Pressure Indicator, PI-32, and Pressure Alarm, PA-32. An alarm alerts the operator to a low ΔP condition across the heat exchanger. The channel's range is 0-50 psid (0-0.35 MPa).

5.4.2.7.4 Level

The D_2O Storage Tank Level Channel, LIA-3, measures the level of the heavy water in the D_2O Storage Tank. Level Transmitter, LT-3, applies a signal to Level Indicator, LI-3, and to Level Alarm, LA-3 that is proportional to the level of D_2O in the storage tank. An alarm alerts the operator to an abnormal level. The range of the channel is 0-175 inches (0-445 cm). The first 50 inches (127 cm) of indicated storage-tank level reflects the sump level.

5.4.2.7.5 Conductivity

The Primary D_2O IX Inlet Conductivity Recorder Channel, CRA1-2A, and Primary D_2O IX Outlet Recorder Channel, CRA1-2B, measure the conductivity of the heavy water processed by the purification train. Measuring conductivity before and after the resin beds monitors the effectiveness of the ion exchangers. Conductivity Cell, CC1-2A, is mounted in the 2-inch inlet piping to the ion exchanger columns while Conductivity Cell, CC1-2B, is installed in the outlet piping. Cell CC1-2A connects to Conductivity Transmitter, CT-2A. The transmitter supplies a signal to Conductivity Recorder, CR1-2A, and to the annunciator system. Cell CC1-2B connects to Conductivity Transmitter, CT-2B that supplies a signal to Conductivity Recorder, CR1-2B. It also supplies a signal to the annunciator system. An alarm alerts the operator to a high conductivity level on either the inlet to, or the outlet from, the ion exchangers. The range both channels is 0-2 μS.

5.4.3 Design and Operating Parameters and Specifications

Table 5.5 lists the design and operating parameters for the Primary Coolant Purification System.

5.4.4 Schedules for Replacing the Ion Exchangers and Filters

The frequency with which the resin in an ion column needs to be replaced depends on the rate of introduction of impurities. For a properly maintained closed system, this rate is very low and a given charge of resin may last for several years. Impurities may be introduced whenever any maintenance is performed on primary systems containing heavy water, or during refueling. Precautions are taken during these times to minimize the amount of contamination of the system. Consequently, the ion exchangers last several years under normal use.

There is no set schedule for replacing the ion exchanger resin beds or the filters. The effectiveness of the ion-exchanger resin beds and the differential pressure drops across the IX columns and the filters are monitored. When the effectiveness drops unacceptably or when the pressure becomes too great, then they are replaced. When the resin beds are determined to be ineffective, they are removed and replaced by spares. Once short-lived activities have decayed, the spent resin is discharged, dewatered, and packaged for proper disposal offsite.

The ion exchanger is not regenerated. The purification train is designed to have one of the four IX columns on line; with the other three as installed spares. Spool pieces are installed between the on-line columns and the two filters and the spare columns are capped off.

5.4.5 Minimizing Exposure During Routine Operation

The Process Room contains all of the Primary Coolant Purification System components and is designated as a high radiation area during power operations; access is restricted to operations personnel. Certain areas in the Process Room are designated as high radiation areas during shut down due to local radiation sources. Health physics personnel routinely survey the Process Room to identify and appropriately mark these areas. Entry to the Process Room for routine and special maintenance is conducted under approved radiation work permits. These steps preclude any inadvertent exposure during reactor operations and shutdown maintenance. The resin and filters are discharged and replaced following approved, written procedures.

In addition to these steps, the IX columns and filters are designed and constructed so their contents can be easily removed. The IX column housings and the pre- and after-filter housings are wrapped with lead bricks to shield operations staff from any radioactivity trapped within the resin beds or the filter medium.

Chapter 11 discusses the radiation protection plan and waste management at the NBSR.

5.4.6 Minimizing Exposure During Accidents

Should excess radioactivity be released inadvertently into the primary coolant with the resultant deposition of radioactive products in the ion exchangers or filter medium, the same practices and shielding that minimize exposure during routine operation would prevent personnel being exposed. Specifically, all of the equipment associated with the Primary Coolant Purification System is located in the Process Room where access is restricted to authorized personnel, and entrance conducted under approved radiation work permits.

Chapter 11 discusses the radiation protection plan and waste management at the NBSR.

5.4.7 Loss of Primary Coolant

Appropriate points of the Primary Coolant Purification System are equipped with leak detectors. The Leak Detection System and the impact any leakage has on the facility and its surroundings are described in detail in Section 5.2.11.

5.4.8 Technical Specification Requirements

There are no Technical Specifications applicable to the Primary Coolant Purification System.

5.5 Primary Coolant Makeup

5.5.1 Design Bases/Functional Requirements

The D_2O Storage Tank has sufficient capacity to hold the entire coolant inventory used by the Primary Coolant System and its associated heavy water systems. Accordingly, the NBSR reactor does not have a dedicated system for adding make-up water to the system. Heavy water is added directly from 55-gallon (210 liter) drums on an "as needed" basis.

5.5.2 System Description

Figure 5.1 shows the Primary Coolant System with its primary coolant makeup connections. Fresh heavy water is added to the D_2O Storage Tank from a 55-gallon (208 liter) drum. These valves are located in the trench around the top of the reactor and connect directly to the D_2O Experimental Cooling System's return line. Once the purity of the heavy water in a drum is tested and verified, it is piped to one of these two valves. A slight helium pressure is applied to the drum and the valve is opened. Heavy water flows from the drum to the storage tank due to the differential pressure between the system and the drum.

5.5.3 Instrumentation

There is no instrumentation specific to this system. Before adding make-up water, the purity of the heavy water is tested and verified using appropriate test equipment. The D_2O Storage Tank Level Channel, LIA-3, discussed in Section 5.4.2.7.4, monitors the level in the storage tank.

5.5.4 Safety Systems and Administrative Controls

Make-up water is added to the D_2O Storage Tank using an approved procedure. The drum containing the heavy water is connected to isolation valves mounted in the D_2O Experimental Cooling System return line. Water is manually injected in under the direct control of a reactor operations staff member. Since the make-up water is added through existing return lines, the operation will not result in loss of primary coolant and cannot contaminate any potable water supply. Normal precautions are taken during this operation to prevent losses.

5.5.5 Technical Specification Requirements

There are no Technical Specifications applicable to the Primary Coolant Makeup.

5.6 Nitrogen-16 Control

By design and procedure, ^{16}N is minimized as a source of radiation exposure for the NBSR. For a complete discussion of the design and procedural control, see Chapter 11.

5.7 D_2O Experimental Cooling System

5.7.1 Design Bases/Functional Requirements

The D_2O Experimental Cooling System distributes heavy water from the Primary Coolant Purification System to cool the NBSR experimental equipment as follows: Cold Neutron Source, Rabbit Tubes RT-1, RT-2, and RT-4, and other experimental facilities. The system utilizes cooled primary coolant from the discharge of the D_2O Purification Heat Exchanger HE-2 and returns to the D_2O Storage Tank after cooling the experimental equipment.

5.7.2 System Description

Figure 5.12 shows the D_2O Experimental Cooling System.

The D_2O Experimental Cooling System supplies heavy water to the NBSR experimental facilities at a flow rate of approximately 15 gpm (60 lpm). The system receives its cooling water from the Primary Coolant Purification System. One of the two D_2O Experimental Cooling Pumps takes suction on the purification system piping through valve DWV-26. This connection point is downstream of the purification filters and resin beds. The discharge of the pump supplies connections in the reactor's upper trench and at the reactor face on the first-floor level, including the cold source and the rabbit tubes.

Backpressure regulating valve DWV-25 controls the experimental supply pressure, thus preventing over-pressure or under-pressure whenever flow is established or secured to a given component that could affect the cooling of the other components supplied by the system. The heated D_2O is then returned to the D_2O Storage Tank where it is cooled via the D_2O Purification Heat Exchanger HE-2.

In an emergency, heavy water is available from the D_2O Emergency Cooling Tank to cool the system's components. An emergency back-up supply of cooling water is also available from the domestic water system.

5.7.2.1 Heat Sources

The total heat load of the D_2O Experimental Cooling System is approximately 1.54×10^5 BTU/hr (45 kW). Most of this heat load is due to the Cryogenic Neutron Cold Source. The rabbits and individual reactor experimental facilities contribute negligibly to this heat load.

5.7.2.2 Heat Sink(s)

The system utilizes the D_2O Purification Heat Exchanger HE-2 to remove the heat generated in the components cooled by the D_2O Experimental Cooling System. The approximately 60×10^3 BTU/hr (18 kW) removed is a small fraction of the heat exchanger's design capacity. The Primary Coolant Purification System is described in detail in section 5.4.

5.7.2.3 Sources of Water

The heavy water distributed by the D_2O Experimental Cooling System comes from the Primary Coolant Purification System and is returned to the D_2O Storage Tank.

In an emergency, heavy water is available from the D_2O Emergency Cooling Tank. The domestic water system may also serve as an emergency back-up supply of cooling water.

5.7.2.4 D_2O Experimental Cooling Pumps

The D_2O Experimental Cooling Pumps ECP-1 and -2 are single-stage, centrifugal units with a nominal capacity of 36 gpm (140 lpm). The motors are single speed, 480 volt, three-phase, 60 Hz rated at 3 Hp and 3450 rpm. Pump ECP-1 is powered from Emergency Power MCC A-5, while pump ECP-2 is powered from Emergency Power MCC B-6.

The reactor operator controls the pumps remotely from the Main Control Panel in the Control Room. One pump is run, as required, to supply cooling water to the reactor facility experiments. The other pump is placed in standby.

5.7.2.5 Valves

One automatically controlled valve in the D_2O Experimental Cooling System maintains a constant system pressure. Pressure Regulating Valve DWV-25 is a 2-inch (5.08-cm), pneumatically positioned valve used to regulate the pressure at the common pump's discharge header. The valve opens on an over-pressure condition to relieve the pressure by dumping heavy water to the D_2O Storage Tank, and closes the valve on an under-pressure condition.

5.7.2.6 Instrumentation

Installed instrumentation provides remote read-out of the flows and temperatures at appropriate points in the system. Local pressure gages and temperature indicators are mounted in the piping for local indication where appropriate.

5.7.2.6.1 Flow

Redundant channels, Cold Source D_2O Cooling Water Flow Channels FIA-8A and -8B measure the flow of cooling water to the Neutron Cold Source. Flow is measured by a 1½-inch (3.8-cm) venturi, FE-8, installed in the cold source's cooling water outlet piping. Sensing lines connect the high- and low-pressure ports on the venturi to redundant Flow Transmitters, FT-8A and -8B that supply an electrical signal to Flow Indicators, FI-8A and -8B, and to Flow Alarm, FA-8A and -8B, respectively. The alarm unit has outputs that send signals to annunciate a low-flow condition. The range of both channels is 0-25 gpm (0-95 lpm).

5.7.2.6.2 Temperature

The Cold Source Inlet Indicator Channel, TI-34, measures the temperature of the D_2O cooling water entering the cold source. A resistance temperature detector (RTD), TE-34, is mounted in a thermowell located the 1½-inch (3.8-cm) piping. An R-to-I converter, TT-34, transforms the resistance measurement to an electrical signal that is transmitted to the cold source's computer. The range of the channel is 50-200 ^oF (28-110 ^oC).

The Cold Source Outlet Indicator Channel, TI-35, measures the temperature of the D_2O cooling water leaving the cold source. A resistance temperature detector (RTD), TE-35, is mounted in a thermowell in the 1 ½-inch (3.81-cm) piping. An R-to-I converter, TT-35, transforms the resistance measurement to an electrical signal that is applied to the cold source's computer and to Temperature Indicator, TI-35. The channel's range is 50-200 ^oF (28-110 ^oC).

5.7.2.6.3 Pressure

All local pressure measurements are made with local Bourdon-tube-type pressure gauges. Suction and discharge pressure of the pumps are sensed.

The D_2O Experimental Cooling Pressure Indicator Control Channel, PIC-2, maintains a constant pressure on the discharge of the Experimental Cooling Pumps by varying the position of the Pressure Regulating Valve DWV-25. Pressure Transmitter, PT-2 measures the pressure on the common pump's discharge header. This transmitter supplies an electrical signal to Pressure Controller, PIC-2, and to Pressure Alarm, PA-2. The operator sets the pressure for the controller to maintain. The actual pressure signal is compared to the set pressure and a current signal is sent to the valve position, ECP-6. The positioner opens the valve on an over-pressure condition to relieve the pressure by dumping heavy water to the D_2O Storage Tank, and closes it on an under-pressure condition. The alarm unit has outputs that supply signals to annunciate a low-pressure condition. The range of the channel is 0-100 psig (0-0.7 MPa).

5.7.3 Shielding Requirements

There are no special shielding requirements for the D_2O Experimental Cooling System. Most components are located in the Process Room. Due to the lengths of piping associated with the Primary Coolant System, the Primary Coolant Purification System, and the D_2O Experimental Cooling System, any ^{16}N activity in the primary coolant has decayed by the time it reaches any of the facilities cooled by the system.

5.7.4 Preventing Interference with Reactor Shutdown

The D_2O Experimental Cooling System, by design, cannot interfere with the safe shutdown of the reactor under all conditions, since this system is independent of the Primary Cooling System, which is primarily used to remove the decay heat during reactor shutdown.

5.7.5 Preventing Uncontrolled Release of Primary Coolant

Appropriate points of the D_2O Experimental Cooling System are equipped with leak detectors. The Leak Detection System and the impact any leakage has on the facility and its surroundings are detailed in Section 5.2.11.

5.7.6 Requirements for Minimum Water Quality

The Primary Purification system provides the water used by the D_2O Experimental Cooling System. Therefore, the quality of D_2O is maintained at its highest purity. Section 5.4, describes the Primary Coolant Purification System in detail.

5.7.7 Technical Specification Requirements

There are no Technical Specifications applicable to the D_2O Experimental Cooling System.

Table 5.1: Design and Typical Operating Parameters for the Primary Coolant System

Subject	Parameters
Primary Coolant:	Heavy Water (D_2O)
Flow Rates:	
Inner Plenum	2,300 gpm (8,700 lpm)
Outer Plenum	6,700 gpm (25,400 lpm)
ΔT Across the Reactor Vessel:	13.9 ^{o}F (8 ^{o}C)
Reactor Vessel Elevations:	
Overflow Line	159 inches (404 cm)
Drop Out Chute	70 inches (178 cm)
Bottom of Upper Grid Plate	65 inches (165 cm)
Moderator Dump Line	42 inches (107 cm)
Top of Core	41 ½ inches (105 cm)
Centerline of Core	27 inches (69 cm)
Bottom of Core	12 ½ inches (32 cm)
Bottom of Lower Grid Plate	0 inches (0 cm)
Inlet/Outlet Piping Penetrations	-21 ¾ inches (-55 cm)
Reactor Vessel Operating Levels:	
Nominal	159 inches (404 cm)
Refueling	70 inches (178 cm)
Moderator Dump	42 inches (107 cm)
Construction Materials:	
Reactor Vessel	5052 and 6061 Aluminum
Piping	6061 Aluminum and Stainless Steel
D_2O Storage Tank	6061 Aluminum
D_2O Emergency Cooling Tank	6061 Aluminum
Pressure:	
Pump Discharge	65 psig (0.5 MPa)
Top of Core	Atmosphere
Chemistry:	
pH	5-6
Conductivity	1 μmho
Capacities:	
Reactor Vessel	4,043 gal. (15,300 liters)
Inner Reserve Tank	800 gal. (3,000 liters)
D_2O Storage Tank	14,650 gal. (55,500 liters)
D_2O Emergency Cooling Tank	3,300 gal. (12,500 liters)

Table 5.2: Limiting Safety System Settings

Parameter	Setting
Reactor Power (max.)	130 %
Reactor Outlet Temperature (max.)	147 ^{o}F (64 °C)
Coolant Flow (min.)	Inner Plenum - 60 gpm (230 lpm)/MW
	Outer Plenum - 235 gpm (890 lpm)/MW

Table 5.3: Primary Coolant System Safety Instrumentation

Parameter	Channel	Safety Function	Setpoint
Flow	FRC-3	Scram	5,000 gpm (18,900 lpm) (decreasing)
	FRC-4	Scram	1,400 gpm (5,300 lpm) (decreasing)
	FIA-40	Scram	6,500 gpm (24,600 lpm) (decreasing)
ΔT	TIA-40A	Scram	20 ^{o}F (11 °C) (increasing)
	TIA-40B	Scram	20 ^{o}F (11 °C) (increasing)
Level	LRC-1	Scram	140 inches (356 cm) (decreasing)
	LIA-40	Scram	140 inches (356 cm) (decreasing)
		Rundown	145 inches (368 cm) (decreasing)
Temperature	TRA-2	Rundown	130 ^{o}F (54 °C) (increasing)

Table 5.4: Design and Operating Parameters for the Secondary Coolant System

Parameter	Specification/Range
Heat Sink:	Hybrid Wet/Dry Cooling Tower
Location:	Stand alone unit outside confinement
Secondary Coolant:	Light Water (H_2O)
Source:	NIST Domestic Water Supply
Secondary Flow Rates:	8,000-10,000 gpm (30,300-37,900 lpm)
Cooling Tower Construction Materials:	Wood, fiberglass, galvanized metal and stainless steel
Cooling Tower Design Specifications:	
Wet Operating Mode:	
Inlet Water Temperature:	98 ^oF (37 ^oC)
Outlet Water Temperature:	80 ^oF (27 ^oC)
Inlet Air Wet-bulb:	75 ^oF (24 ^oC)
Ambient Air Wet-bulb:	73 ^oF (23 ^oC)
Ambient Air Dry-bulb:	90 ^oF (32 ^oC)
Ambient Air Relative Humidity:	45 %
Hybrid Operating Mode:	
Cooling Range Delta T:	18 ^oF (10 ^oC)
Ambient Air Wet-bulb:	10 ^oF (6 ^oC)
Ambient Air Dry-bulb:	11 ^oF (6 ^oC)
Ambient Air Relative Humidity:	85 %
Design Flow:	8,550 gpm (32,300 lpm)
Wind:	Load resulting from 100 mph (160 kmph) wind
Seismic:	Designed for 0.1g ground acceleration
Cooling Tower Basin Level:	28-48 inches (70-120 cm)
Chemistry:	
pH	9.2 (max.)
Conductivity	1,500 μmhos (max.)
Total Dissolved Solids	100-200 ppm

Table 5.5: Design and Operating Parameters for the Primary Coolant Purification System

Fluid:	Heavy Water (D_2O)
Flow Rates:	
Total:	35 gpm (130 lpm)
Purification Train:	15 gpm (60 lpm)
Outlet Temperature:	90 ^{o}F (32 ^{o}C) nominal
Chemistry:	
pH	5-6
Conductivity	1 μmho

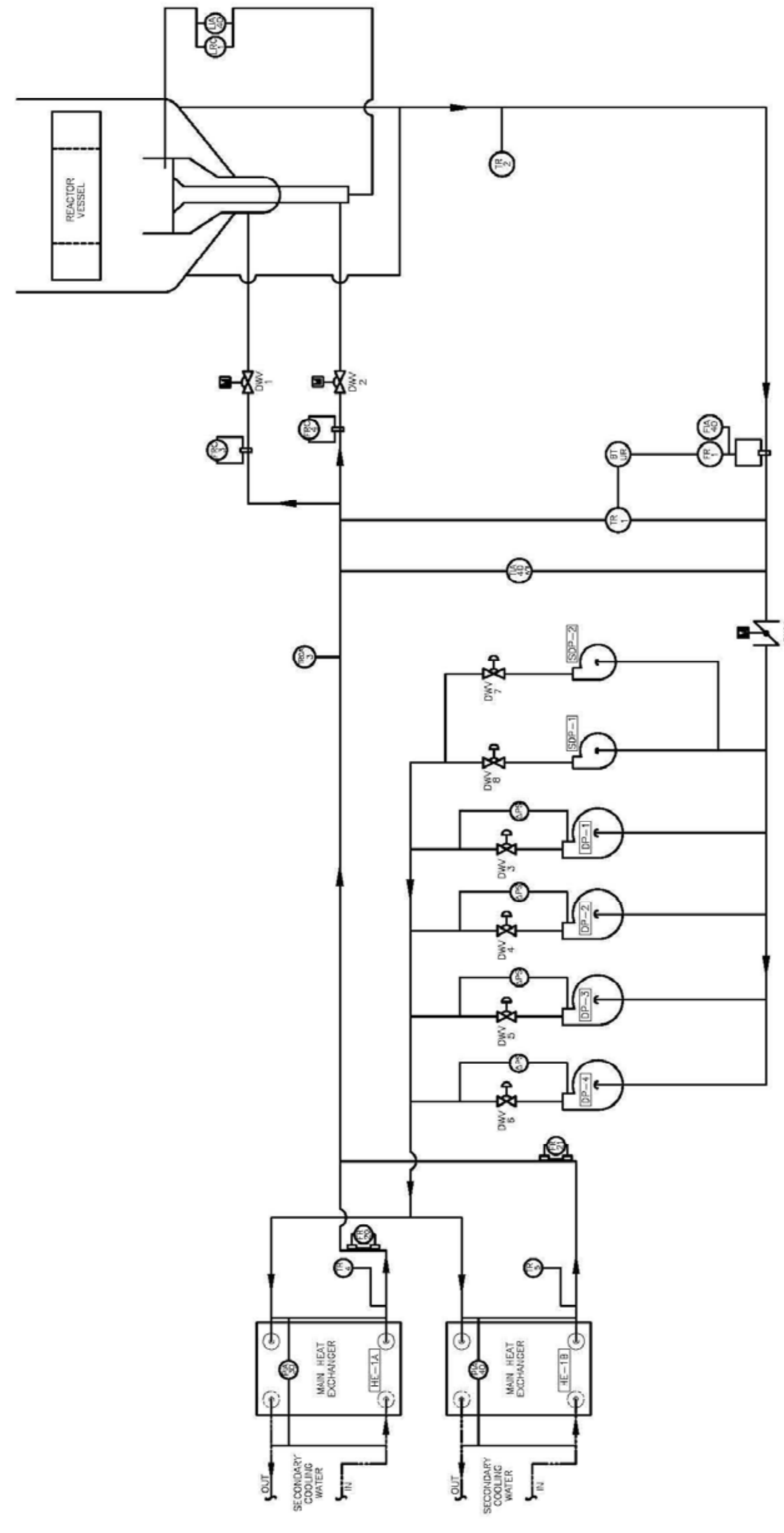

Figure 5.1: Primary Coolant System

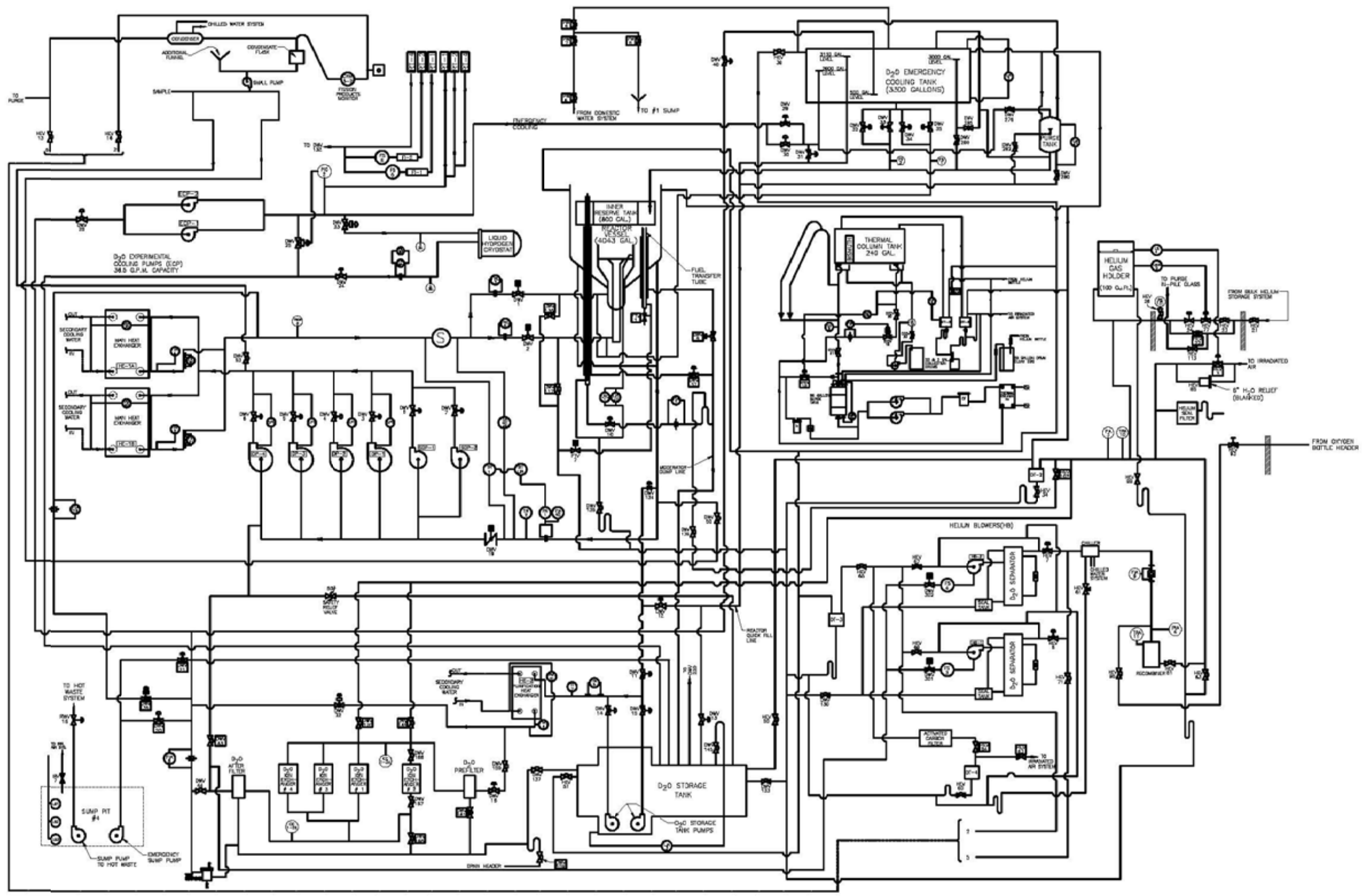

Figure 5.2: Primary Coolant System and Associated D_2O Systems

Instrumentation Designators

TRC	TEMPERATURE RECORDER CONTROLLER	PG	PRESSURE GAGE
TIA	TEMPERATURE INDICATOR ALARM	PIC	PRESSURE INDICATOR CONTROLLER
LIA	LEVEL INDICATOR ALARM	PR	PRESSURE RECORDER
TD	TEMPERATURE DETECTOR	PS	PRESSURE SWITCH
CRA	CONDUCTIVITY RECORDER , ALARM	PT	PRESSURE TRANSMITTER
CA	CONDUCTIVITY ALARM	SPA	SCRAM PRESSURE ALARM
CC	CONDUCTIVITY CELL	TA	TEMPERATURE ALARM
CI	CONDUCTIVITY INDICATOR	TC	TEMPERATURE CONTROL
CR	CONDUCTIVITY RECORDER	TI	TEMPERATURE INDICATOR
CS	CONDUCTIVITY SWITCH	TIC	TEMPERATURE INDICATOR CONTROLLER
FA	FLOW ALARM	TR	TEMPERATURE RECORDER
FD	FLOW DETECTOR	TS	TEMPERATURE SWITCH
FC	FLOW CONTROLLER	TT	TEMPERATURE TRANSMITTER
FI	FLOW INDICATOR	STA	SCRAM TEMPERATURE ALARM
FR	FLOW RECORDER	BTUR	BTU RECORDER
FS	FLOW SWITCH	FRC	FLOW RECORDER CONTROLLER
FT	FLOW TRANSMITTER	LIC	FLOW INDICATOR CONTROLLER
SFA	SCRAM FLOW ALARM	FIT	FLOW INDICATOR TRANSMITTER
LA	LEVEL ALARM	HIC	HAND CONTROL INDICATOR
LC	LEVEL CONTROLLER	EPC	ELECTRO PNEUMATIC CONVERTER
LI	LEVEL INDICATOR	FIC	FLOW INDICATOR CONTROLLER
LR	LEVEL RECORDER	FCA	FLOW CONTROL ALARM
LS	LEVEL SWITCH	FIA	FLOW INDICATOR ALARM
LT	LEVEL TRANSMITTER	CIA	CONDUCTIVITY INDICATOR ALARM
SLA	SCRAM LEVEL ALARM	PRC	RADIATION RECORDER & CONTROLLER
PA	PRESSURE ALARM	PI	PRESSURE INDICATOR
PC	PRESSURE CONTROLLER	AN	ANNUNCIATOR

Figure 5.3: Instrumentation Designators

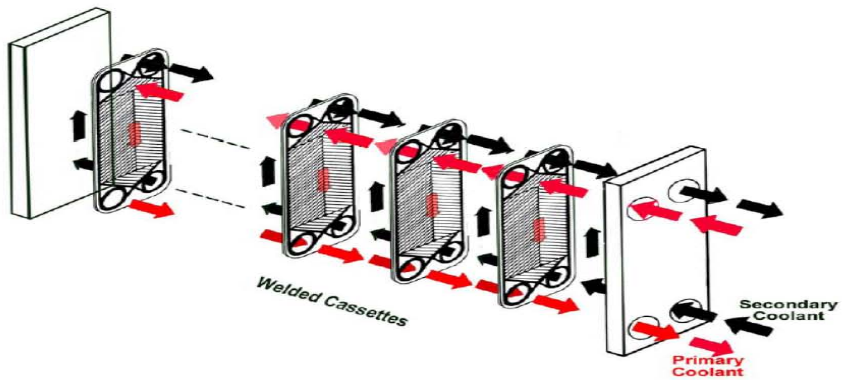

Figure 5.4: Main Heat Exchanger

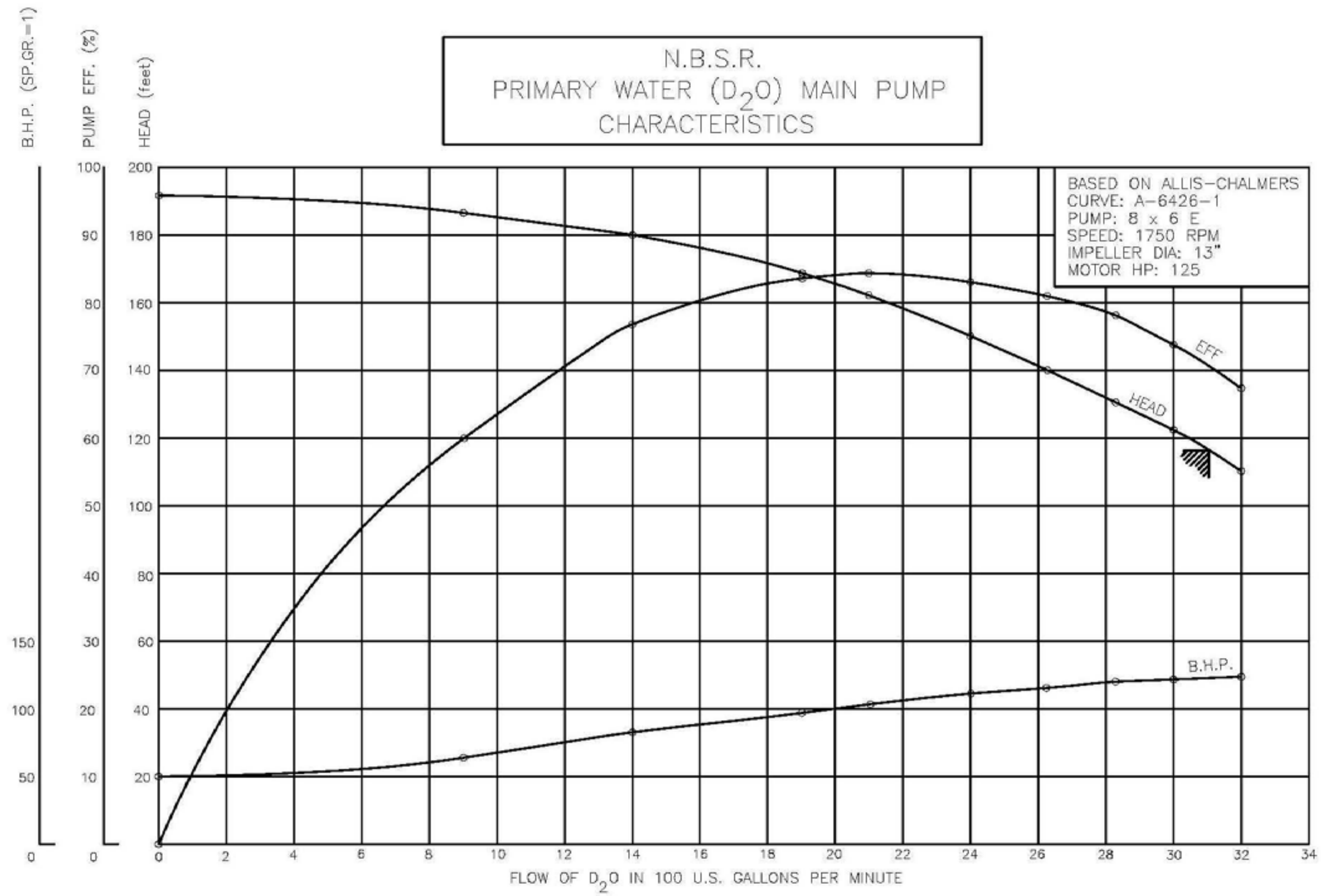

Figure 5.5: D_2O Main Circulating Pump Characteristics

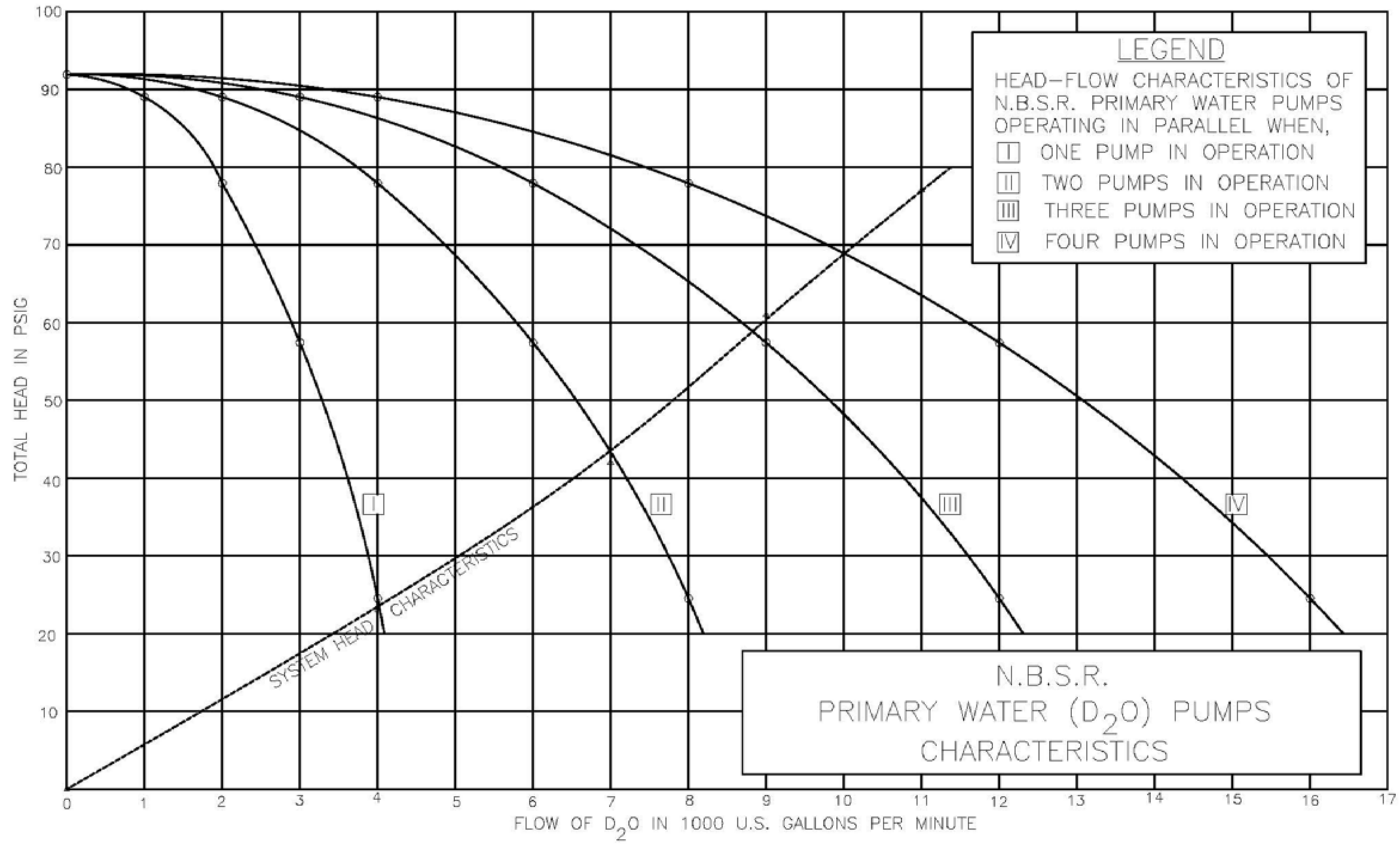

Figure 5.6: D_2O Main Circulating Pump Characteristics – With Different Operating Conditions

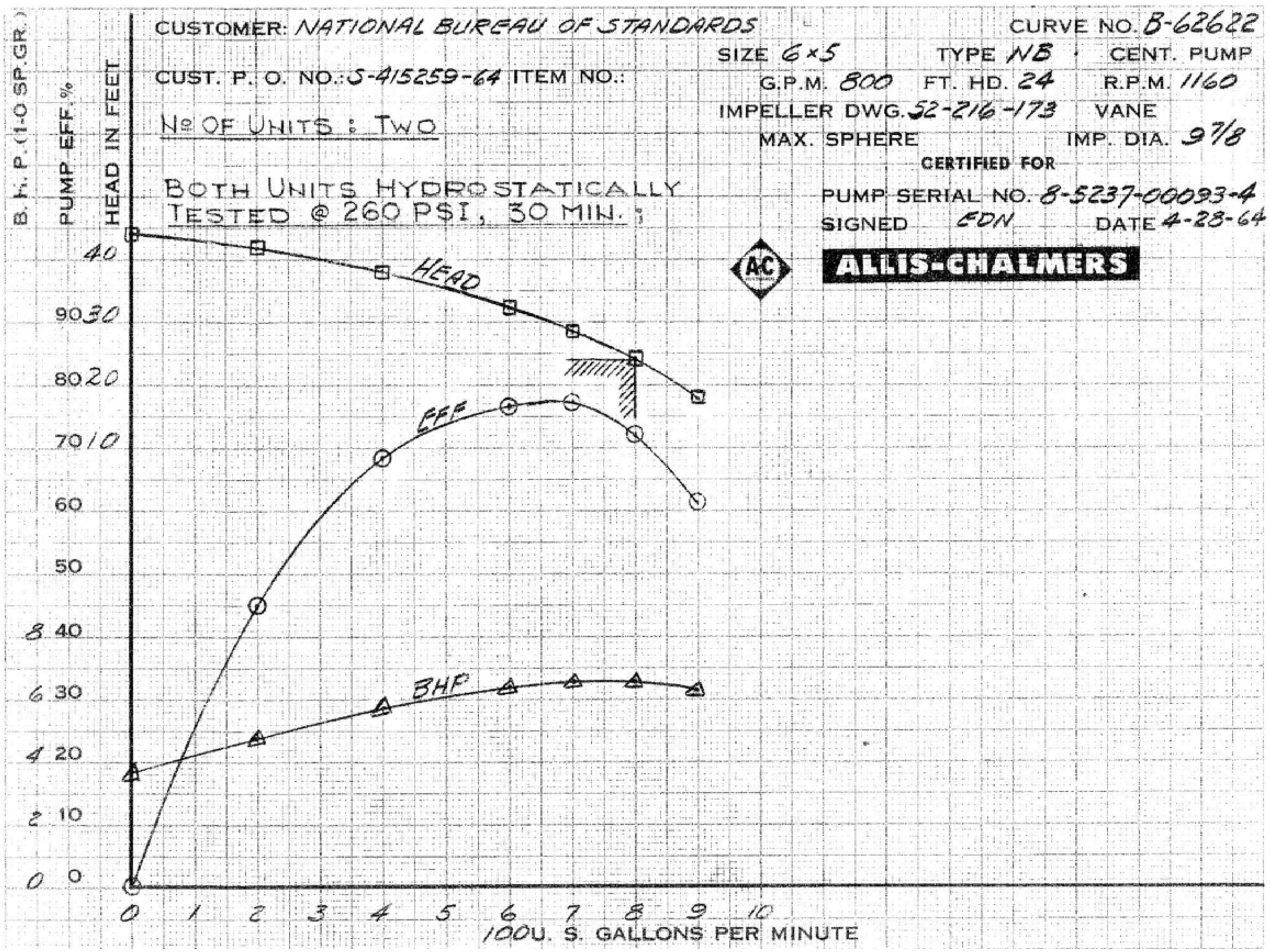

Figure 5.7: D_2O Shutdown Pump Characteristics

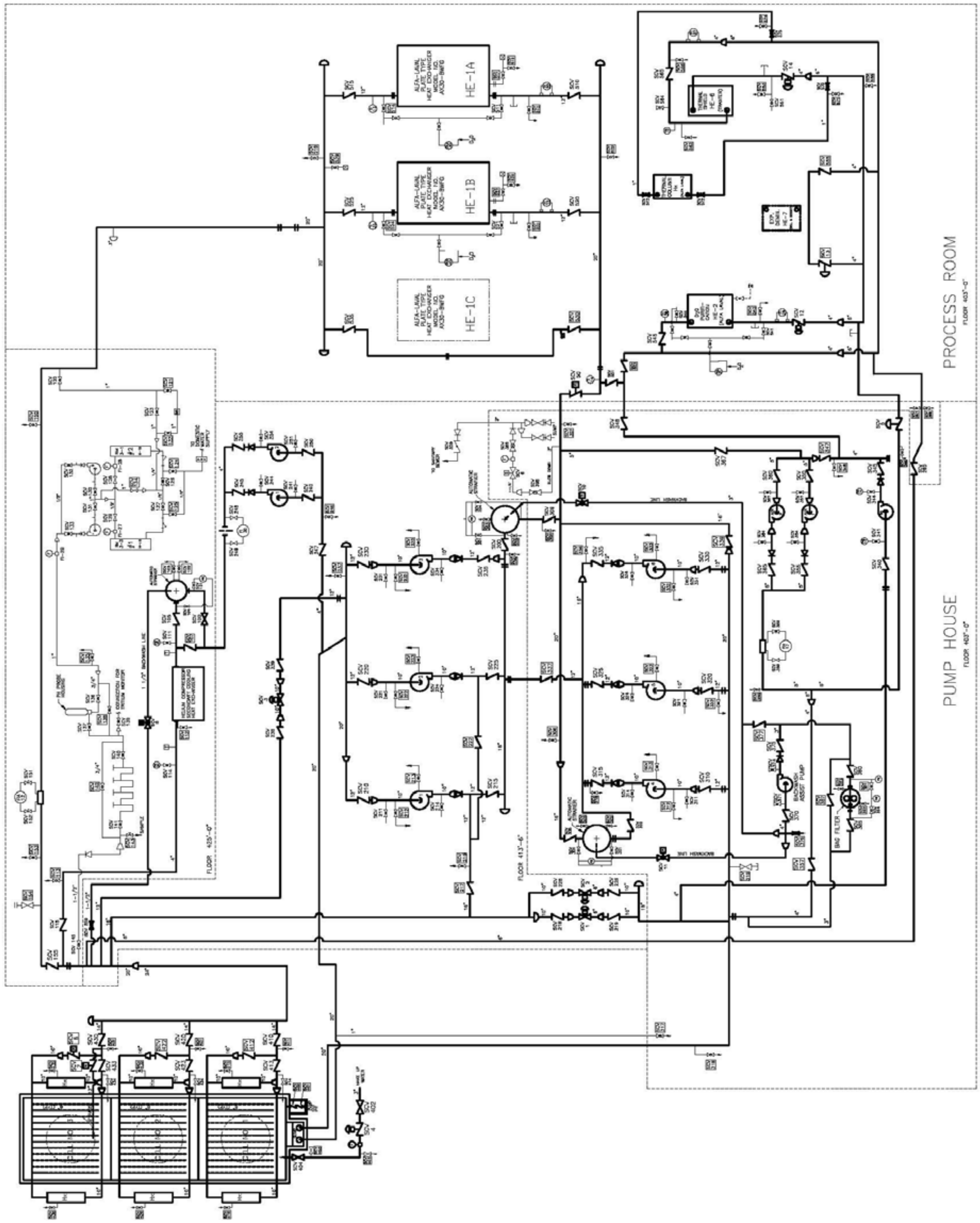

Figure 5.8: Secondary Cooling System

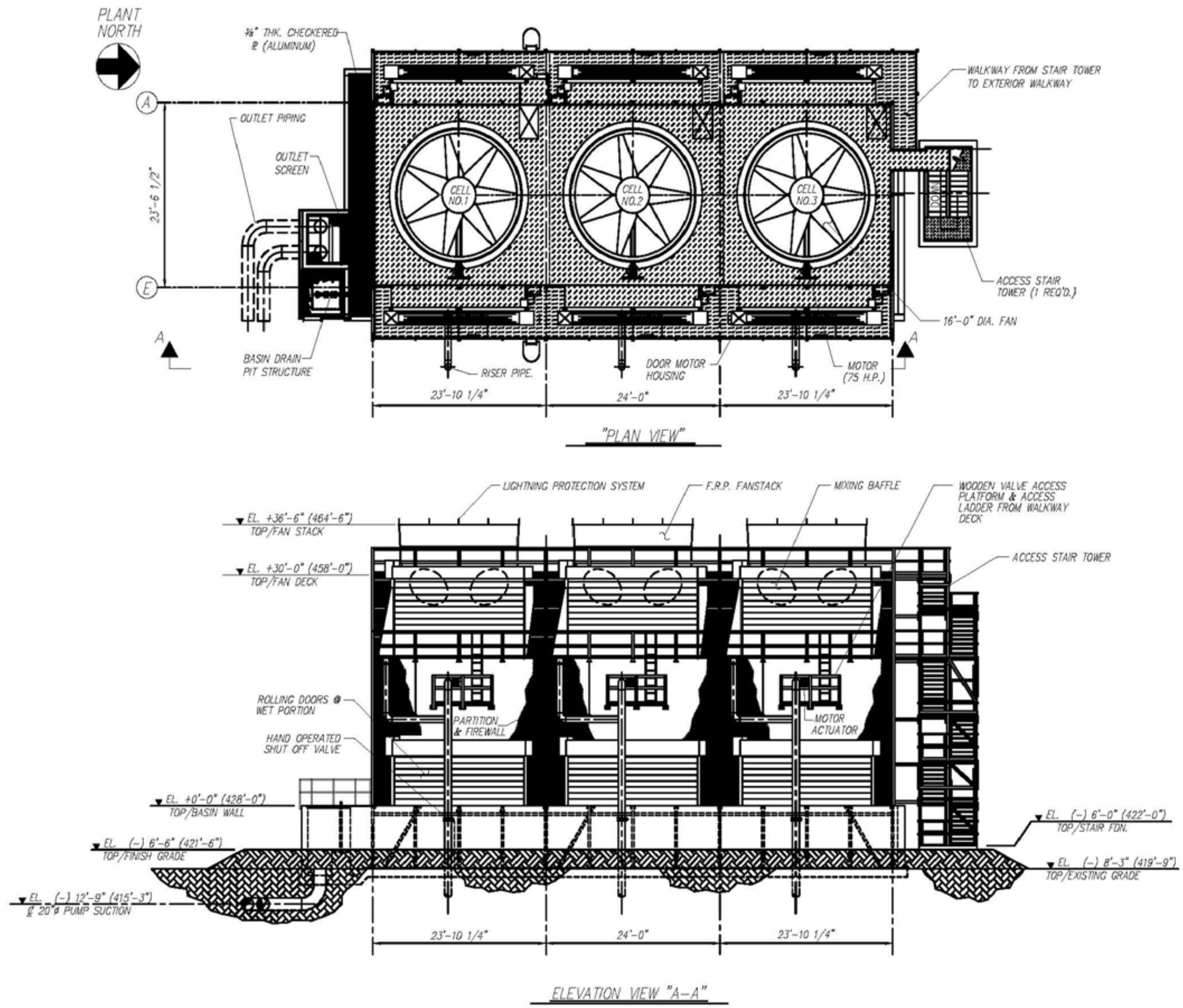

Figure 5.9: Cooling Tower

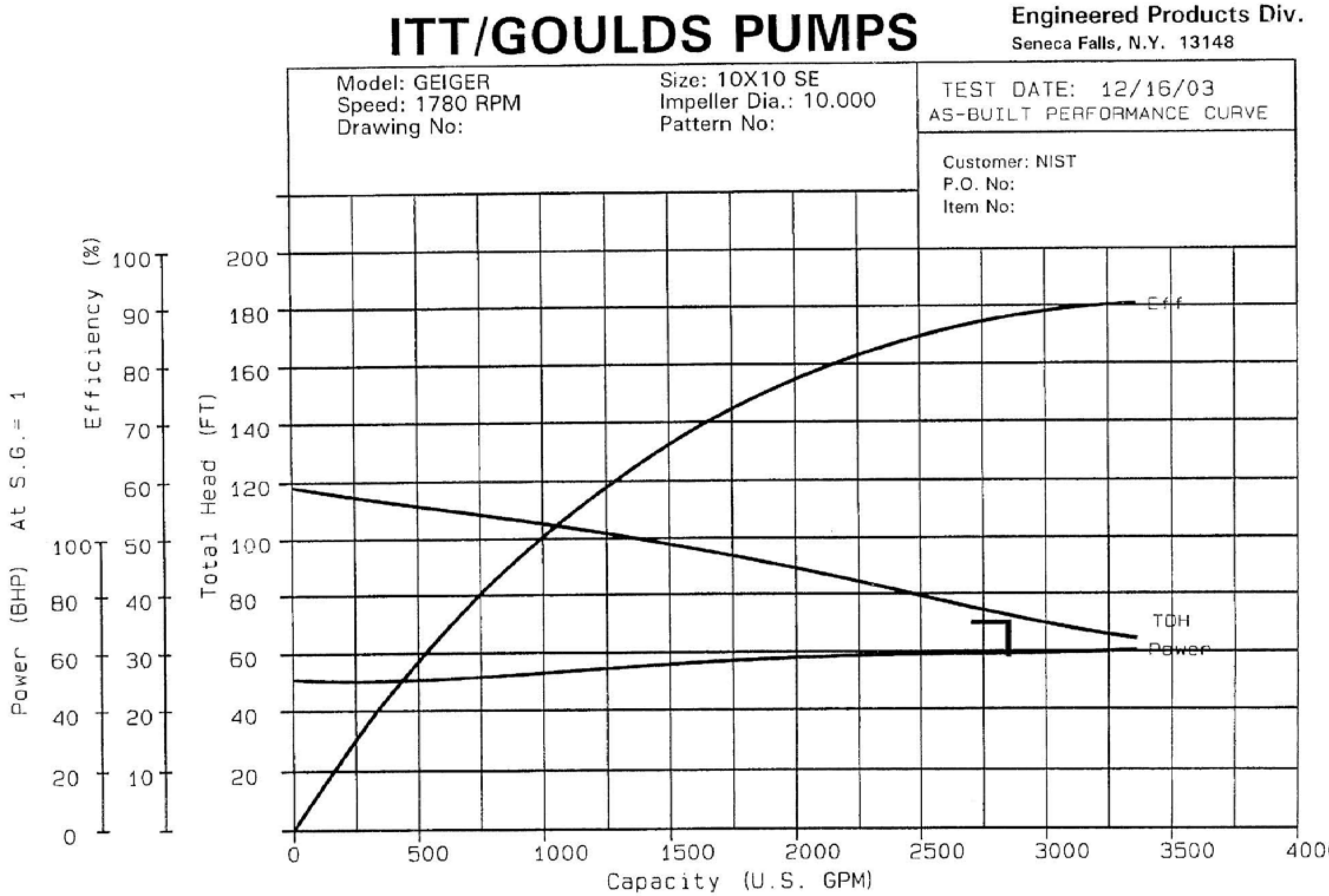

Figure 5.10: Main Secondary Cooling Pump Characteristics

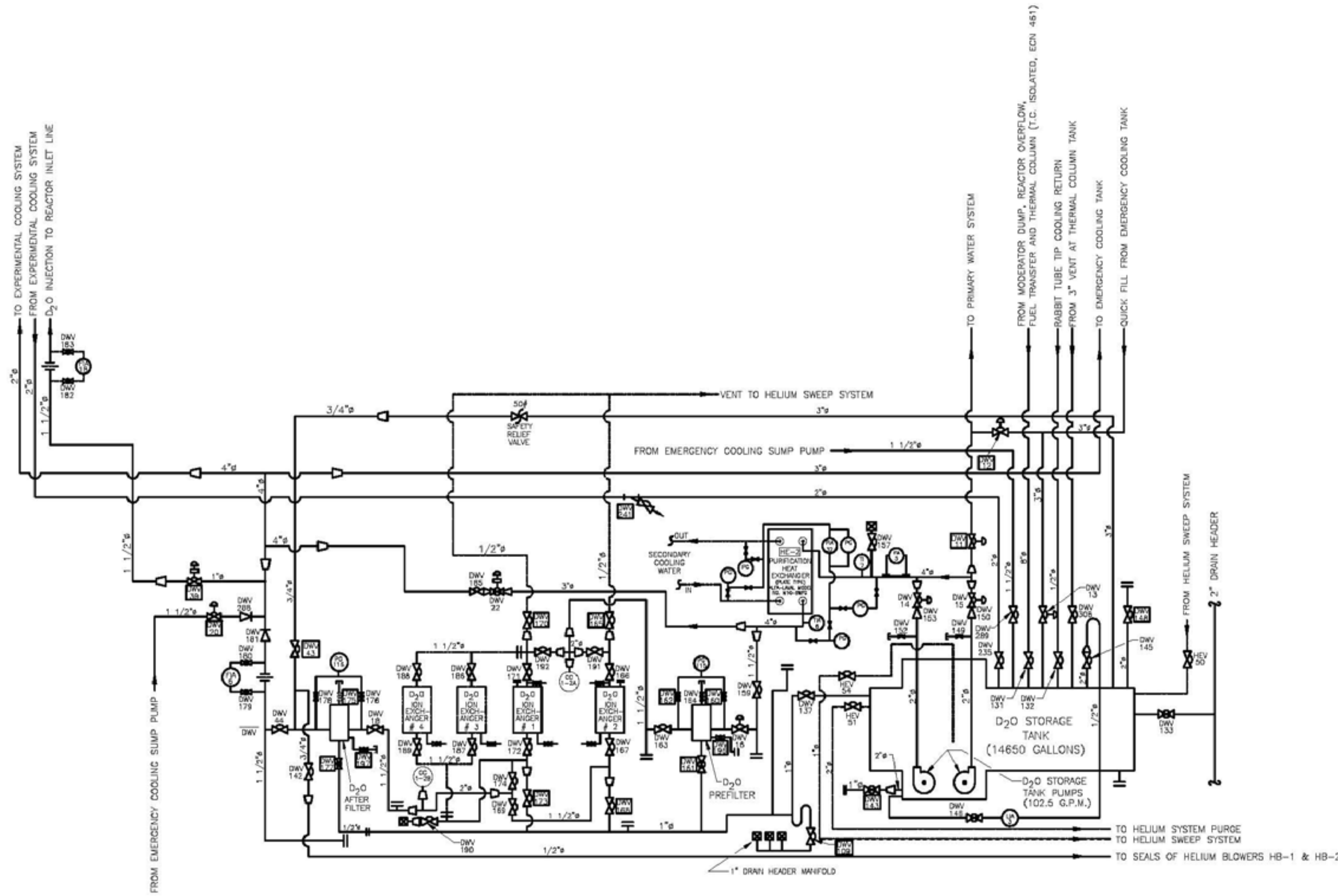

Figure 5.11: Primary Coolant Purification System

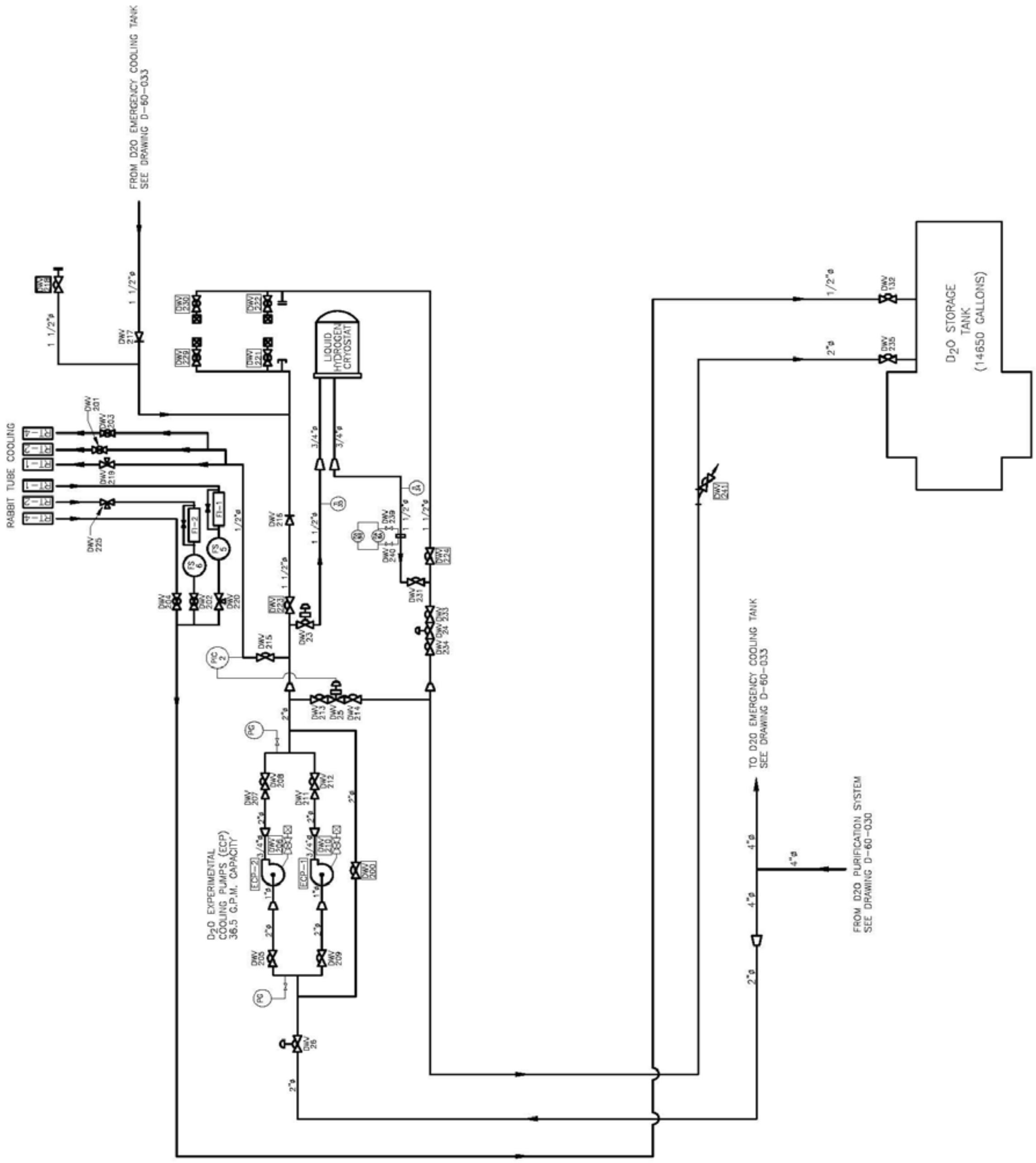

Figure 5.12: D_2O Experimental Cooling System