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11.2 LOW PRESSURE SAFETY INJECTION SYSTEM

Learning Objectives:

1. State the purpose of the low pressure safety injection (LPSI) system.
2. Describe the LPSI flow paths including suction supplies, discharge points, and major components during the following operations:
   a. Power operations
   b. Shutdown cooling
   c. Injection phase
   d. Recirculation phase
3. State the purpose of the shutdown cooling heat exchangers, when the heat exchangers are used, and the cooling medium for the heat exchangers.
4. Explain why RCS pressure and temperature limits are placed on the initiation of shutdown cooling.
5. Explain how the LPSI system is protected against over pressurization while operating in the shutdown cooling mode of operation.

11.2.1 Introduction

The purposes of the LPSI system are:

1. To serve as the low pressure injection portion of the emergency core cooling system (ECCS) following a loss of coolant accident (LOCA),
2. To remove heat from the RCS during normal cool down and maintain proper coolant temperatures during maintenance and refueling, and
3. To transfer refueling water from the RWT to the refueling pool and to return the water to the tank following refueling activities.

The primary function of the LPSI system is to provide a low pressure, high volume safety injection to cool the core following a loss of coolant accident during the injection phase. The LPSI system is automatically secured in the recirculation phase of the LOCA; however, the system may be manually aligned to provide a heat sink for long term core cooling.

The secondary function of the LPSI system is to complete the cool down of the RCS and to maintain the proper RCS temperatures while shutdown. This mode of operation is called shutdown cooling. In the shutdown cooling mode of operation, the LPSI system will take a suction from one of the two RCS hot legs and will discharge the hot RCS fluid to the shutdown cooling heat exchangers which are normally connected to the containment spray pump discharge header. The shutdown cooling heat exchangers transfer the RCS decay heat to the component cooling water (CCW) system. From the outlet of the shutdown cooling heat exchangers, the water is returned to the RCS via the normal LPSI discharge piping.

The final function of the LPSI system is to transfer water to and from the RWT during refueling operations. During refueling, the refueling pool is flooded to allow safe fuel handling activities. Water is transferred from the RWT to the refueling pool via the LPSI

pumps and piping. Once the refueling activities are completed, the water is returned to the RWT.

11.2.2 System Description

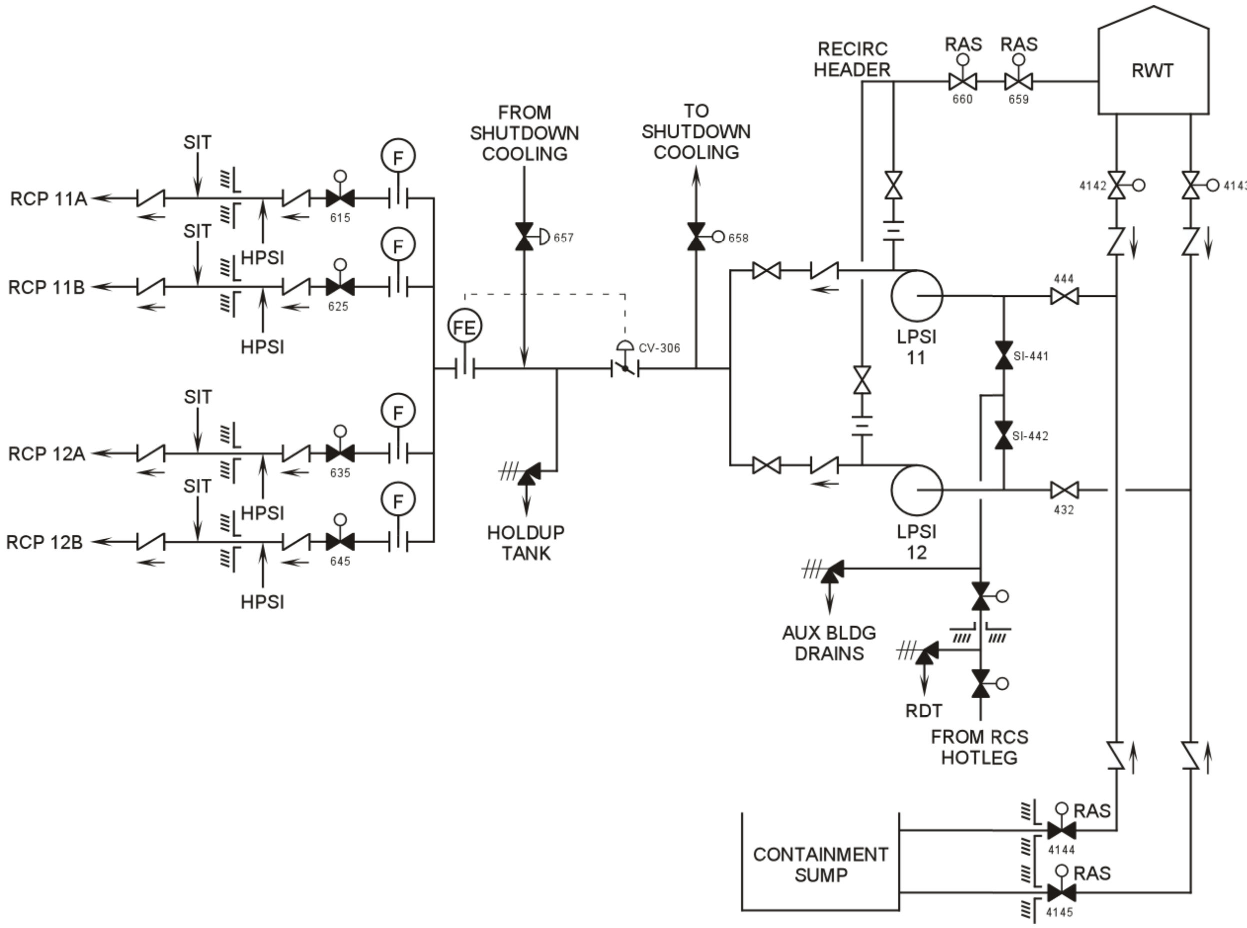
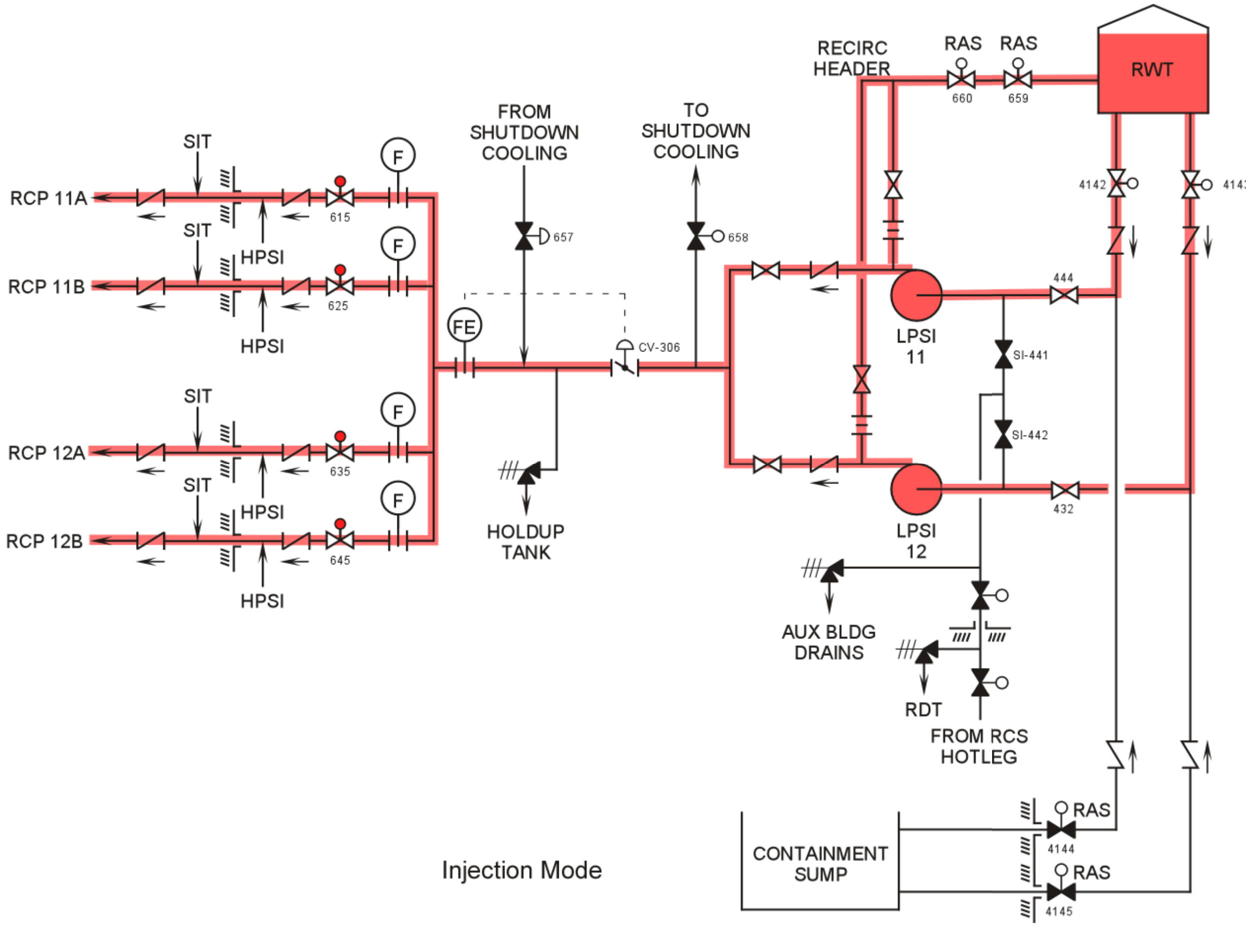


Figure 11.2-1 LPSI Flow Diagram

The LPSI system, as shown in Figure 11.2-1, consists of a suction supply from the RWT, two LPSI pumps, and four RCS injection points. During power operations, the LPSI system is aligned for its accident mode of operation with the suction supply valves from the RWT open and the four injection valves closed.



Injection Mode

If a LOCA occurs, the LPSI pumps will be started by a safety injection actuation signal (SIAS). The SIAS will also open the four injection valves. The pumps will recirculate water back to the RWT until RCS pressure drops to below the shut-off head of the pumps (approximately 180 psia). Once the RCS has depressurized below this value, flow from the LPSI system starts to provide core cooling. The pumps will continue to provide flow to the RCS until a low RWT level is reached and a recirculation actuation signal (RAS) is generated. The RAS stops the LPSI pumps.

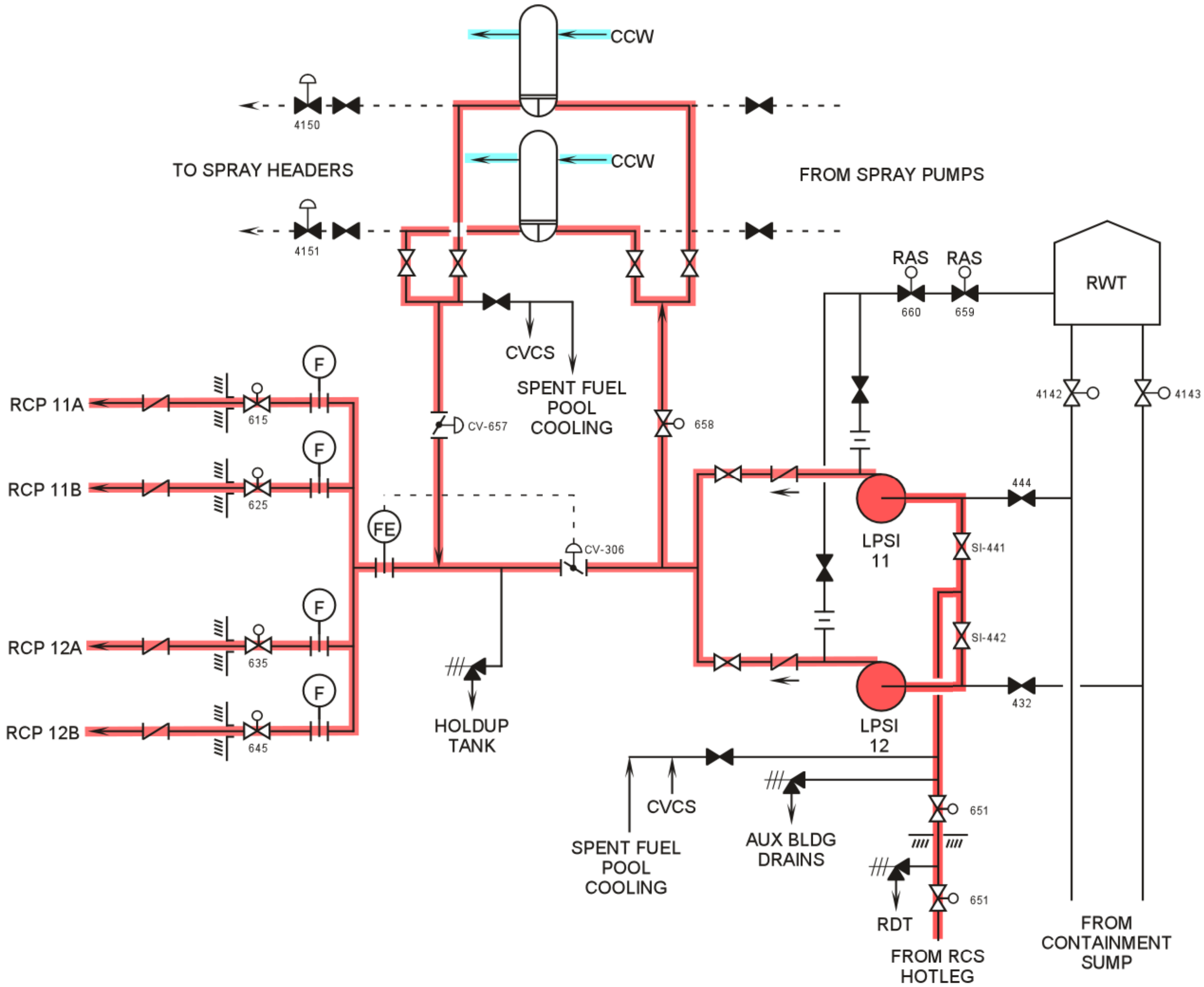


Figure 11.2-2 Shutdown Cooling Flow Diagram

The LPSI shutdown cooling alignment is shown in Figure 11.2-2. After RCS temperature and pressure are reduced to < 300°F and 270 psia, the shutdown cooling heat exchangers are valved into the discharge of the LPSI pumps, and the suction supply from the RCS hot leg is established. Water is circulated from the RCS, through the shutdown cooling heat exchangers, and back to the LPSI discharge piping. The return flow to the RCS is controlled by two valves, a flow control valve on the discharge of the LPSI pumps that is set to control a constant flow, and the other on the outlet of the shutdown cooling heat exchangers. The two valves are used to control RCS temperature in the shutdown cooling mode of operation. For example, if the temperature of the RCS is to be decreased, the control valve on the outlet of the heat exchangers is opened to route additional flow through the heat exchangers. When the valve is opened, the total LPSI flow increases and the flow control valve will throttle down to maintain a constant flow. The final result is an increase in flow rate through the shutdown cooling heat exchangers and less flow bypassing the heat exchangers. Total LPSI flow remains constant.

The flow path described in the previous paragraph is also applicable in the refueling mode of operation. In addition, when the refueling pool is to be filled, one of the two LPSI pumps can be aligned to the RWT. Water will be pumped from the tank, through

the injection valves, and into the RCS. Since the head is removed or detensioned, water will exit the vessel and fill the pool. When refueling is completed, the water is pumped back to the RWT by a connection just downstream of the shutdown cooling heat exchangers.

11.2.3 Component Description

11.2.3.1 Refueling Water Tank

The refueling water tank (RWT) performs the following functions:

1. Provides borated water to the HPSI, LPSI, and the containment spray pumps,
2. Provides makeup water to the spent fuel pool and
3. Stores refueling water.

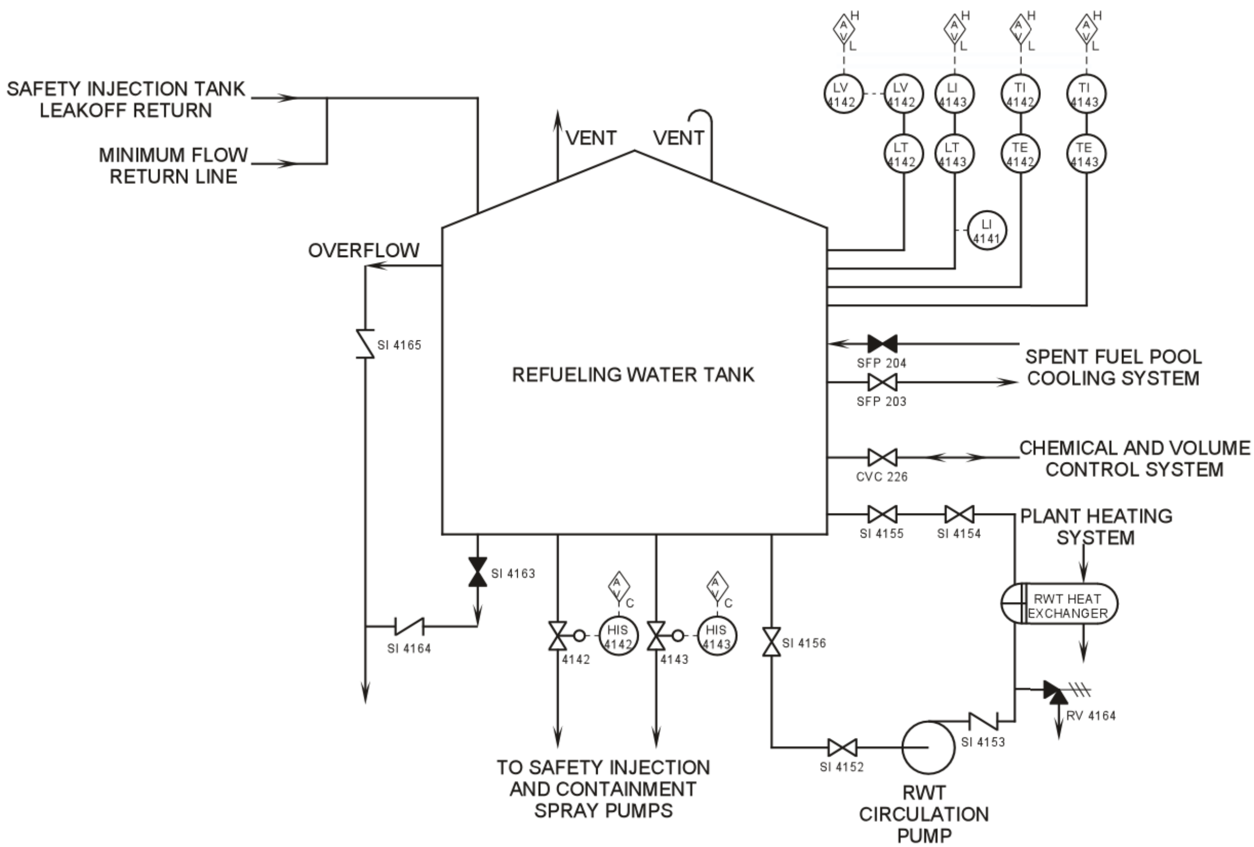


Figure 11.2-3 Refueling Water Tank

The RWT (see Figure 11.2-3) is a flat-bottomed, cylindrical tank with a conical roof, and is fabricated from stainless steel. The tank has a total capacity of 420,000 gallons and must be filled to at least 400,000 gallons during power operations. The volume of 400,000 gallons will provide thirty-six minutes of safety injection during a LOCA with the HPSI, LPSI, and the containment spray pumps operating at design flow rates.

The RWT is borated to a concentration of 2300 to 2700 ppm, and the tank contents are maintained at the proper concentration by the chemical and volume control system (CVCS). A recirculation pump and heat exchanger are used to maintain the RWT temperature >40°F. The heat exchanger is heated by the plant heating system.

The RWT has two outlet lines, one for each ECCS train, that supply water to the ECCS and containment spray pumps. The lines are physically separated to minimize the possibility of simultaneous plugging. Each outlet line has a protective screen with a mesh size such that any particle that passes through the screen will also pass through the ECCS and containment spray system components. Motor operated valves are installed in each line. The valves are normally open and are controlled from the control room. An annunciator is energized if the valves are shut.

Four level transmitters are installed on the RWT to provide inputs to the RAS. In addition to the RAS level instrumentation, two level indicators are installed to provide control room indication and annunciation. One of the transmitters is a narrow range indicator (444 to 468 inches) and is used to maintain the tank level within technical specification requirements. The other level indicator is wide range (0 to 39 feet) and is used when transferring the tank contents to the refueling pool. Temperature indication (0°F to 200°F) and alarm functions are also provided for the RWT.

11.2.3.2 LPSI Pumps

Two pumps are installed in the LPSI system. Table 11.2-1 contains the design data for the LPSI pumps. The pumps are horizontal, single-stage, centrifugal pumps. The pump shaft seal is a mechanical seal that is compatible with boric acid solutions. The seal is designed for operation at temperatures greater than 300°F, but to increase seal life, a portion of the LPSI pump inlet water is diverted by a pumping ring, cooled by the component cooling water system, and injected back into the seal. The water cools the seal and returns to the pumping ring, A throttle bushing is installed to back up the mechanical seal.

Table 11.2-1 LPSI Pump Data

Number Installed	2
Design Pressure	500 psig
Design Temperature	350°F
Design Flow	3000 gpm
Developed head	130 psig
Shut-off head	181 psig
Minimum flow	40 gpm
Construction Material	Stainless Steel

Each LPSI pump is driven by a 400 hp, 4160 Vac electrical induction motor powered from the class 1E distribution system. The pump motor is capable of accelerating the pump to full speed in eight seconds with 75% of the nameplate voltage applied. The LPSI pumps are automatically started by a SIAS and automatically stopped by a RAS.

11.2.3.3 Shutdown Cooling Heat Exchangers

The shutdown cooling heat exchangers are used to remove core decay heat during plant shutdowns and in cold shutdown. The heat exchangers are designed to maintain the RCS at the refueling temperature (approximately 140°F) 27 1/2 hours after shutdown from an extended period of full power operations. The heat exchangers also cool the containment spray water during containment spray operations.

The heat exchangers are of the U-tube and shell design with component cooling water (CCW) flowing through the shell and RCS/RWT fluid flowing through the tubes. The tubes are constructed of stainless steel and the shell is made of carbon steel. The shutdown cooling heat exchanger data is located in Table 11.2-2.

Each shutdown cooling heat exchanger is protected against tube side over pressurization by relief valves. The relief valves have a setpoint of 500 psig and are sized to accommodate the pressure developed by a sudden increase in temperature of the tube side fluid.

Table 11.2-2 Shutdown Cooling Heat Exchanger Design Data

	Tube Side	Shell Side
Fluid	RCS/RWT	CCW
Temperature	450°F	250°F
Flow (lb/hr)	1.5×10^6	2.4×10^6
Material	Stainless Steel	Carbon Steel

11.2.3.4 LPSI Valves

Shutdown Cooling Suction Isolation Valves

The #12 RCS loop supplies shutdown cooling suction supply to the LPSI pumps via a 12-inch drop line that contains two series motor-operated valves (SI-652 and SI-651). These valves are interlocked with wide range pressurizer pressure and cannot be opened remotely when pressurizer pressure exceeds 295 psia. The purpose of this interlock is to prevent over pressurization of the LPSI suction and discharge piping. The interlock setpoint is chosen to ensure that the pressure rating of the LPSI suction piping is not exceeded, and an assumption of operation at the setpoint plus the differential pressure developed by the LPSI pump (300 psia + 180 psid pump head = 480 psia) will not exceed the discharge piping pressure rating. A final assumption is that the shutdown cooling system temperature is less than the design temperature rating of the piping. The temperature requirement of 270°F is administratively maintained.

A relief valve is installed between the two shutdown cooling isolation valves to protect the piping between the motor-operated valves from pressure developed due to sudden temperature increases in the containment. The setpoint of this relief valve is 2500 psia. This valve could function after the shutdown cooling system is removed from service

and the section of piping between the closed suction isolation valves is hydraulically solid. An ambient temperature increase would increase pressure in the isolated section of piping and the relief valve prevents over pressurization.

A second relief valve is installed downstream of the second suction isolation valve (SI-651). This relief valve has a setpoint of 330 psia and is sized to protect the suction piping from over pressure assuming:

1. The pressurizer is solid,
2. All three charging pumps are started, and
3. The shutdown cooling pumps are operatting.

If the pressurizer is completely filled with water (solid), and the charging pumps are started, the increase in system mass could increase RCS pressure above the allowable value for shutdown cooling operations. The relief valve's capacity exceeds the capacity of the three charging pumps (132 gpm) and over pressurization is prevented.

Shutdown Cooling Flow Control and Bypass Valves

The shutdown cooling flow control valve (CV-306) is used to maintain the shutdown cooling system flow rate as measured by the flow orifice in the common pump discharge line. Normal shutdown cooling flow is 3000 gpm with one pump and heat exchanger in service and 6000 gpm if both pumps and heat exchangers are used. Since this valve is in series with the four LPSI injection motor-operated valves, it must be fully open to ensure that LPSI flow is available. The valve is locked open when the plant is operating at power.

The bypass valve (V-657) is used to determine the amount of shutdown cooling flow that is diverted through the shutdown cooling heat exchangers. As previously discussed, RCS temperature is controlled by positioning V-657 to the desired position and valve CV-306 throttles to maintain a constant shutdown cooling system flow. Since the valves are manually isolated when the shutdown cooling system is removed from service, no special provisions are required for normal LPSI or containment spray operations.

LPSI Injection Motor Operated Valves

Four LPSI injection motor-operated valves are installed in parallel flow paths. Each flow path supplies safety injection flow to one of the RCP discharge lines. Two of the four valves are powered from one 480 Vac Class 1E electrical distribution train, and the other two valves are powered from the opposite train. This power arrangement ensures LPSI flow in the event of a loss of one Class 1E train. The valves are normally closed and are automatically opened by a SIAS. The capability to throttle LPSI flow exists by driving the valve to the desired position and overriding the SIAS signal with the valve control hand switch. An alarm is annunciated if a LPSI valve has been overridden.

Recirculation Isolation Valves

The minimum recirculation flow for the LPSI pumps is assured by flow orifices that pass 40 gpm flow through the pump recirculation lines to the RWT. Two series isolation valves (V-659 and V-660) are installed in this line and automatically close when a RAS

is received. The valves are closed to prevent the transfer of radioactive containment sump water to the RWT during the recirculation phase of the loss of coolant accident.

11.2.4 System Operations

11.2.4.1 Plant Cool down

The initial phase of RCS cool down is accomplished by transferring heat from the steam generators to the condenser by using the turbine bypass valves to dump steam. The RCS is depressurized by using the pressurizer spray valve(s). When the RCS is cooled down to 300°F and depressurized to 270 psia, the shutdown cooling system is placed in service. The basic steps for placing the shutdown cooling system in service are:

1. Isolate the shutdown cooling heat exchangers from the containment spray system to prevent inadvertent containment spray. This is accomplished by disabling the spray pumps and manually closing the spray pump discharge isolation valves. In addition, the spray header isolation motor-operated valves are closed and power is removed from the valve motor,
2. Manually align the shutdown cooling heat exchangers to the discharge of the LPSI pumps,
3. Place the shutdown cooling flow and bypass control valves in service,
4. Ensure that cooling water is being supplied to the shutdown cooling heat exchangers,
5. Open the LPSI injection motor-operated valves and the shutdown cooling suction isolation valves,
6. Start the LPSI pumps.

The flow path for the shutdown cooling system is from the #12 hot leg to the suction of the LPSI pumps, a parallel flow path through the heat exchangers and the flow control valve, through the four LPSI injection valves back to the RCP discharge lines, and into the core. The shutdown cooling system will be used in this alignment to reduce RCS temperatures to the desired value and at the desired cool down rate. Once the desired temperature is reached, the shutdown cooling system is used to maintain stable conditions.

11.2.4.2 Accident Operations

During power operations, the LPSI system is aligned as an emergency core cooling system with the RWT suction valves open and the four LPSI injection valves closed. The flow control valve (V-306) is locked open. When a SIAS signal is received, the LPSI pumps start and the four injection motor operated valves open. When system pressure drops below LPSI discharge pressure, LPSI flow starts. The system continues to operate in this mode until a RAS is generated by low RWT level. When the RAS is received, the LPSI pumps are automatically stopped, and the recirculation line motor operated valves are closed. The level of water in the containment building sump following a loss of coolant accident is not sufficient to ensure net positive suction head for the LPSI pumps during the recirculation phase; therefore, the pumps are stopped. Long term core cooling is provided by the HPSI system.

11.2.5 PRA Insights

The reactor safety study (WASH 1400) identified a potential core melt scenario that involves the LPSI system. The scenario assumes that there is a failure of the two series check valves installed in the interface between the RCS and LPSI systems.

The failure pressurizes the LPSI piping, from the RCS injection point to the LPSI injection motor-operated valves, to RCS pressure. The LPSI injection valves are opened for testing and the high pressure RCS fluid over-pressurizes and ruptures the low pressure LPSI piping located in the auxiliary building. A loss of coolant accident has occurred with a significant difference, the coolant is not being collected in the sump. Since the sump is not available for the recirculation phase, and there is no way to recover the RWT and RCS water from the auxiliary building, a core melt will occur when the RWT empties. This scenario is identified in WASH 1400 as Event V and is also known as an inter-system LOCA. Generically, the inter-system LOCA is a major contributor to core melt frequency.

11.2.6 Summary

The LPSI system is an emergency core cooling system that provides a high volume of coolant at a low pressure. In addition, the LPSI pumps and piping are used in conjunction with the shutdown cooling heat exchanger to provide a method of reducing RCS temperatures to cold shutdown values.

In the emergency core cooling mode of operation, the LPSI pumps take a suction from the RWT and discharge to the four RCP discharge lines. The LPSI pumps are stopped by an RAS signal.

In the shutdown cooling mode of operation, the LPSI pumps take a suction from the RCS hot leg and discharge to the RCP discharge lines via the shutdown cooling heat exchangers

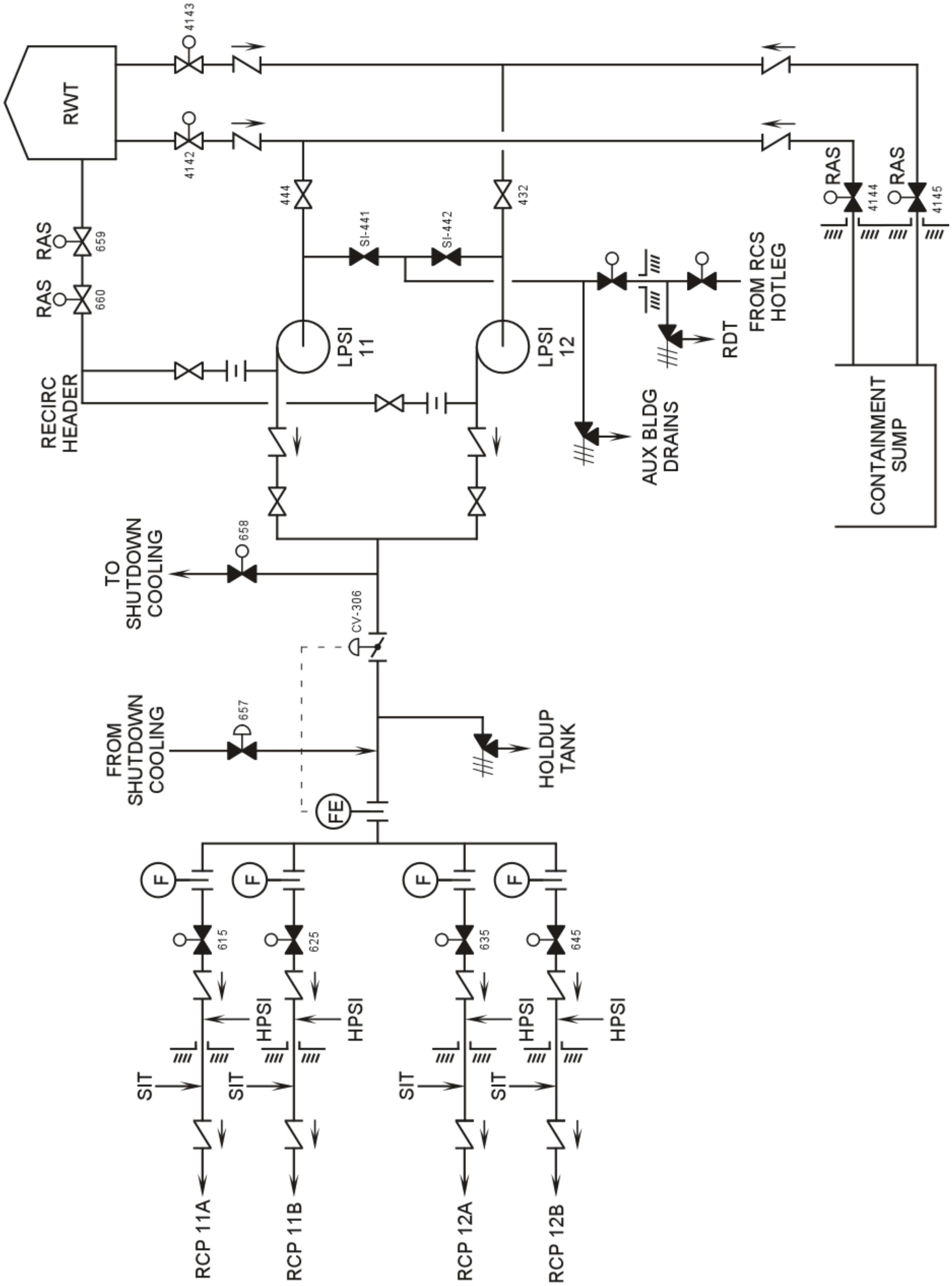


Figure 11.2-1 LPSI Flow Diagram

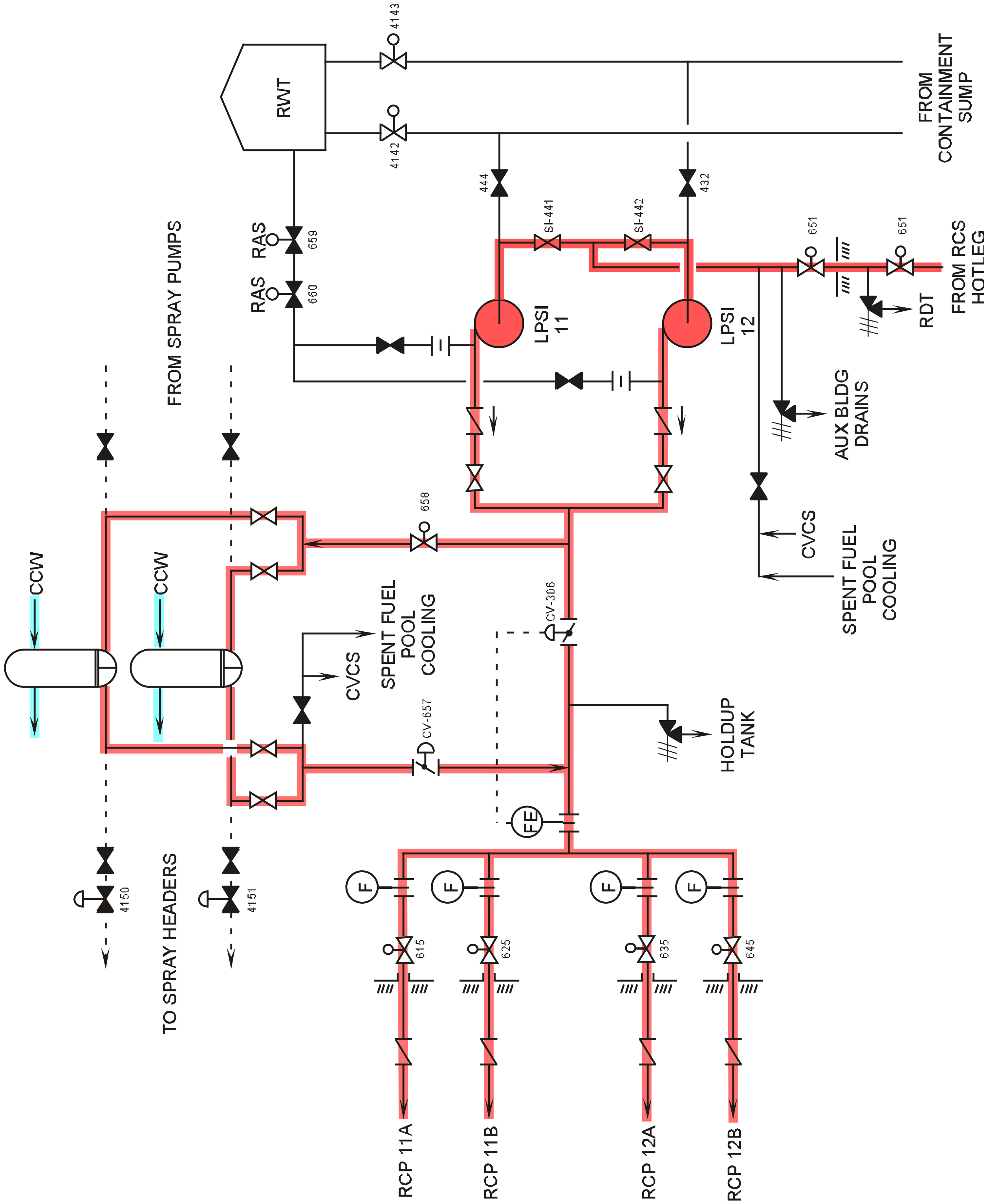


Figure 11.2-2 Shutdown Cooling Flow Diagram

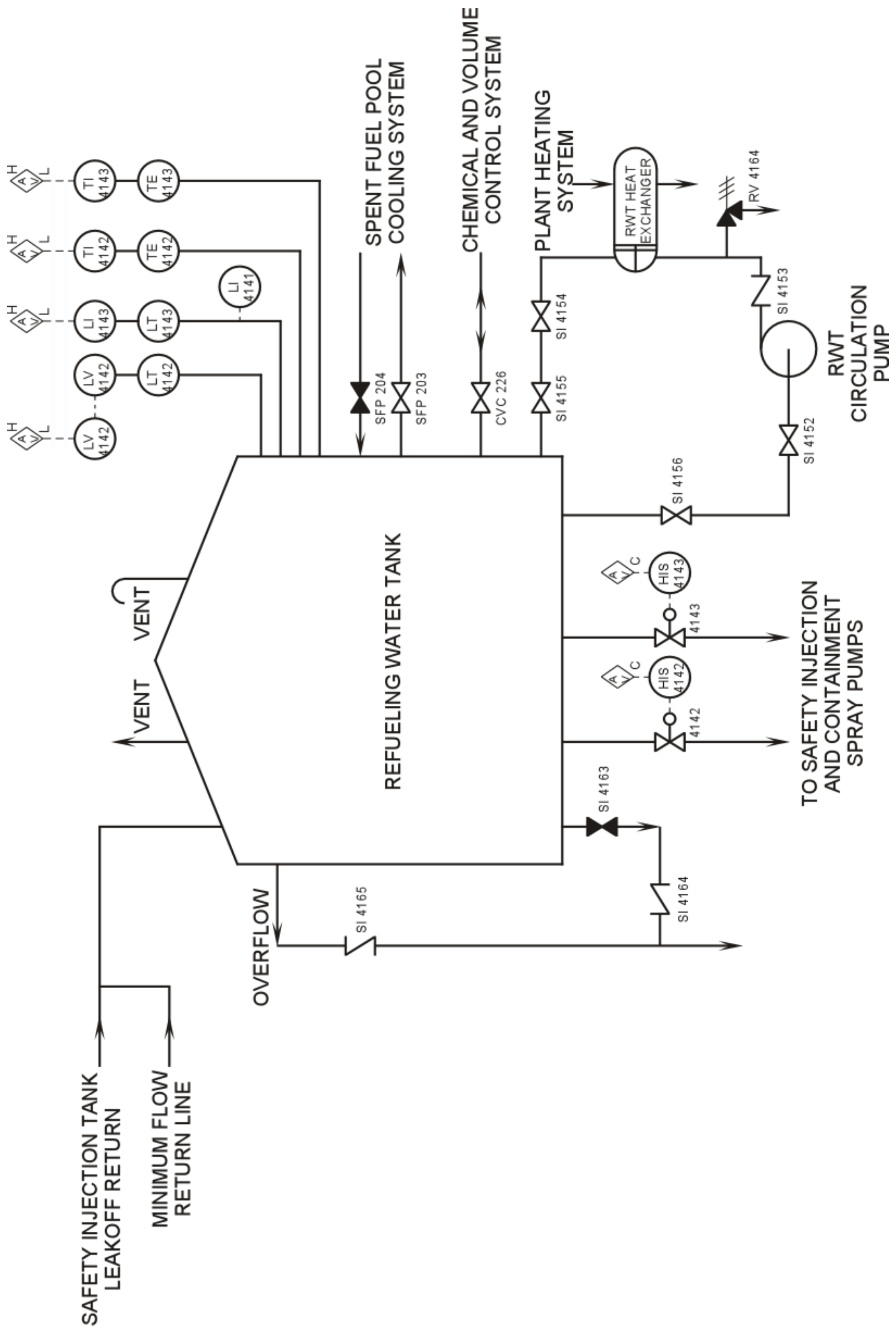


Figure 11.2-3 Refueling Water Tank