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11.1 HIGH PRESSURE SAFETY INJECTION

Learning Objectives:

1. State the purpose of the high pressure safety injection (HPSI) system during the following plant conditions.
   a. Normal operations
   b. Injection phase following an accident
   c. Recirculation phase following an accident
2. State the purpose of the following major components:
   a. Refueling water tank (RWT)
   b. Recirculation sump
3. List the start signals for the high pressure safety injection system.
4. State the system realignments that occur when a recirculation actuation signal (RAS) is received.

11.1.1 Introduction

The purpose of the HPSI system is to inject borated water into the reactor coolant system (RCS) in the event of a loss of coolant accident (LOCA). If the break is small and the depressurization of the RCS is slow, the HPSI system is designed to provide sufficient flow to meet the ECCS design criteria as stated in 10 CFR Part 50.46. The HPSI system will also be used during the recirculation mode of operation to cool the core by supplying water to the core and matching decay heat boil off.

11.1.2 System Description

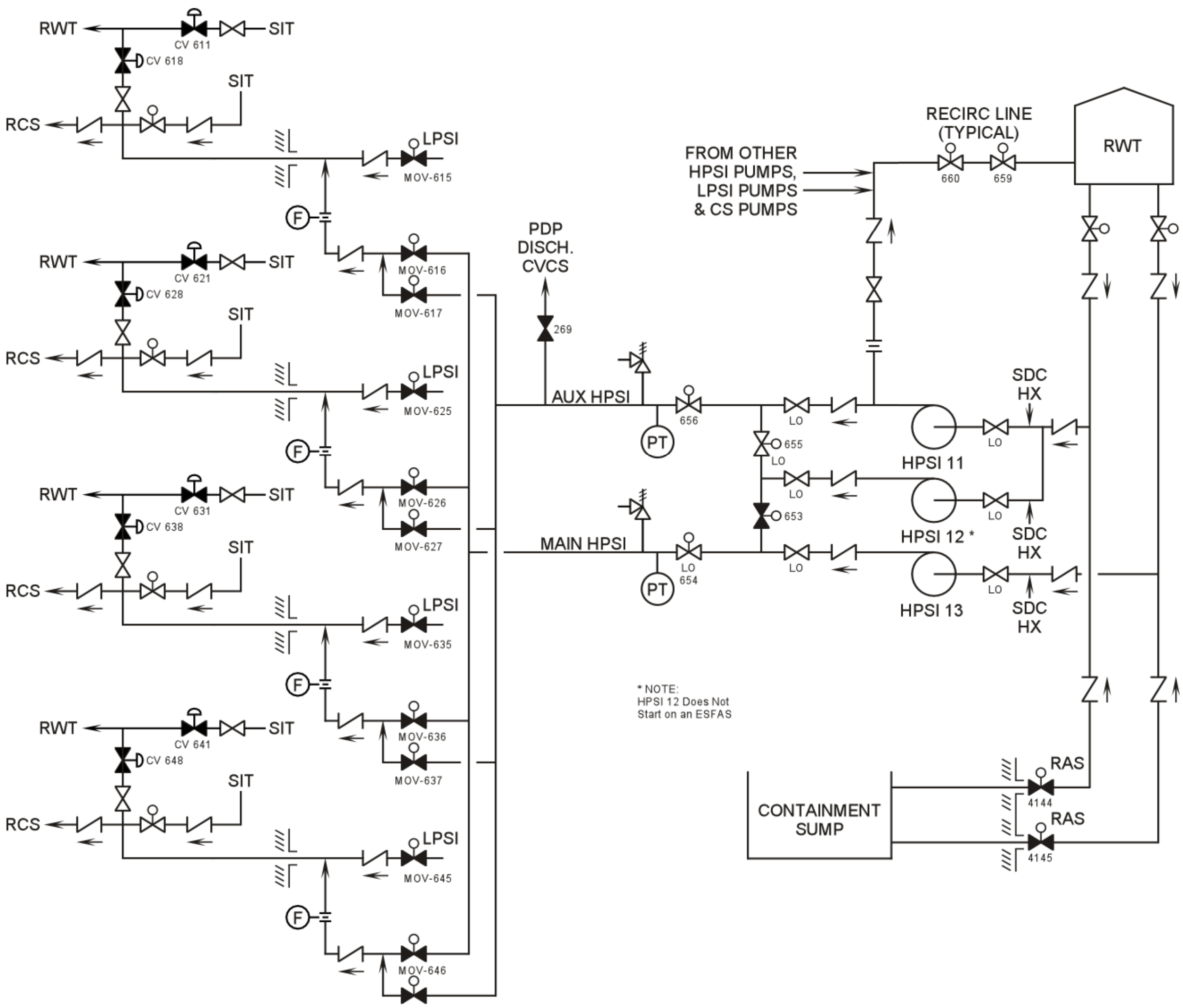


Figure 11.1-1 HPSI Flow Diagram

The HPSI system is aligned for operation as shown in Figure 11.1-1. The HPSI pumps are normally aligned to take a suction from the refueling water tank (RWT) or, during the recirculation mode of operation, from the containment recirculation sump

Upon actuation, the pumps start and the high pressure isolation valves open. The HPSI pumps discharge into the RCS, if the pressure in the RCS is below the shutoff head of the HPSI pumps. In the event that the pumps are started and the RCS pressure is greater than the shutoff head of the HPSI pumps, a minimum flow recirculates back to the RWT via recirculation valves. This minimum flowpath provides pump protection. The system is designed with two redundant pumps and flow paths so that either train will perform the function of cooling the core in the event of a LOCA.

11.1.3 Component Description

11.1.3.1 Refueling Water Tank

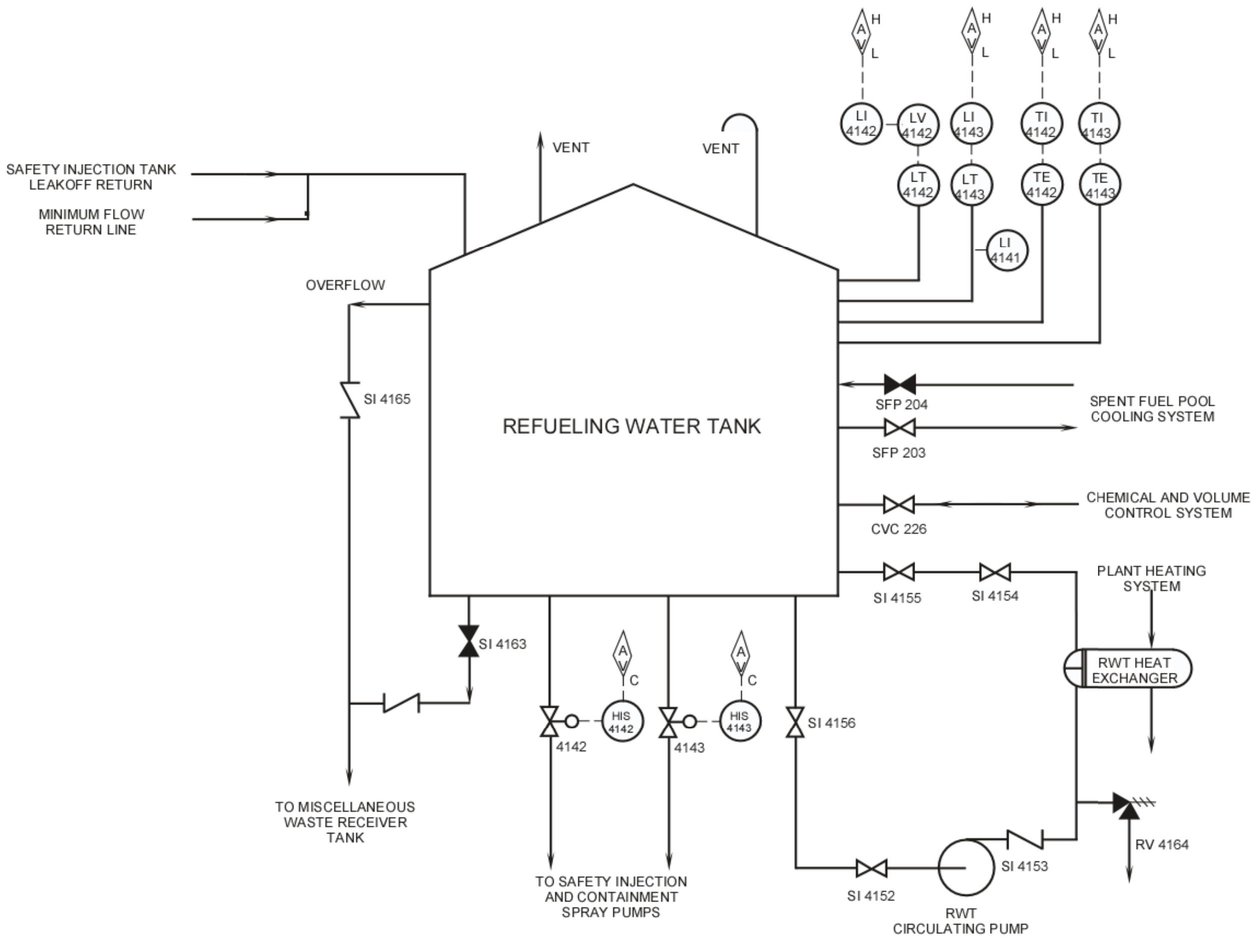


Figure 11.1-2 Refueling Water Tank

The RWT is constructed to meet the requirements of a seismic category I structure or component and is normally used to fill the refueling canal and transfer tube for refueling operations. Figure 11.1-2 shows the normal piping and instrumentation associated with the RWT.

The RWT is sized to contain approximately 420,000 gallons of water of which about 400,000 gallons are required for the availability of the safety injection and containment spray systems. The RWT is vented to the atmosphere through the overflow line. The vent line is sized for tank integrity during all thermal and pumping transients.

The volume of water required by the safety injection and containment spray systems is approximately 400,000 gallons. This provides sufficient water so that the engineered safety features pumps can take a suction from the RWT for a minimum of 36 minutes after initiation of the emergency core cooling systems and provides adequate water for long-term recirculation. This sizing requirement is based upon all the following pumps operating and injecting into the RCS or the containment: two high pressure safety injection pumps, two low pressure safety injection pumps, and two containment spray pumps.

The water in the RWT is maintained at a boron concentration between 2300 and 2700 ppm. Since the RWT contains boric acid, there is a minimum temperature specification of 40°F to prevent boron precipitation. Proper boron concentration in the RWT is maintained by the chemical and volume control system (CVCS). A connection from the RWT to the CVCS is provided to supply RWT water to the suction of the charging pumps when the volume control tank (VCT) reaches a low-low level set point. This connection can also be used to allow borated make-up water to be supplied to the RWT from the CVCS.

The RWT has two outlet lines which supply borated water to the HPSI pumps, LPSI pumps, and containment spray pumps. These two outlet lines are physically separated to minimize the possibility of simultaneous plugging. Each outlet has a protective screen such that any particle size passed can also be passed by all components in the systems using this water. In addition, each RWT outlet line has a motor operated isolation valve which is controlled by hand switches located in the control room. Each hand switch has an open and shut position indication, in addition to a shut position annunciator.

The RWT has instrumentation which provides indication of RWT level and temperature. RWT level provides inputs to the engineered safety features actuation system (ESFAS) for the recirculation actuation signal (RAS). When two of the four level switches sense a low level (30 inches) in the RWT, a RAS is generated by the ESFAS. RWT temperature indication is provided by two redundant temperature elements. Each temperature channel provides a high/low (95°F / 55°F) alarm signal.

A refueling water heat exchanger and circulating pump are used to maintain the RWT contents above the minimum temperature. The plant heating system supplies hot water to the refueling water heat exchanger which will provide the necessary heat source for the RWT. The circulating pump takes a suction on the RWT and discharges RWT water through the heat exchanger and back to the RWT.

The RWT has a drain line and an overflow line which combine and send RWT water to the miscellaneous waste receiver tank. Two other lines allow the RWT contents to be transferred to and from the spent fuel pool and the refueling pool via the spent fuel pool cooling and purification system. Additional technical data for the RWT is presented in Table 11.1-1.

11.1.3.2 High Pressure Safety Injection Pumps

The HPSI pumps are located in the auxiliary building. Each pump is a 100 percent capacity pump. One pump and its associated four high pressure injection valves receives power from one of the two emergency diesel generators, the other pump and its associated injection valves receives power from the other diesel generator. This ensures the automatic operation of one full capacity train in the unlikely event of simultaneous accident, loss of offsite power, and the failure of an emergency diesel generator to start.

The HPSI pumps can be started or stopped from the control room as long as a safety injection actuation signal (SIAS) is not present. The starting of the pumps by a SIAS signal is governed by the availability of the offsite power sources.

If offsite power is available (normal power supply breaker to the ESF bus closed), the pumps will start immediately. If offsite power is not available, the HPSI pumps will start 25 seconds (time delay) after the diesel generator output breaker closes and supplies power to the ESF bus. The last possible situation is to have offsite power at the beginning of the accident and to lose the power source some period of time later.

Upon receipt of a SIAS, HPSI pumps 11 and 13 would start from their respective offsite power source. The loss of offsite power would actuate the load shed circuitry, and the pumps would stop. When the diesel generator starts to supply power to the ESF bus, the load shed signal is cleared, and the pumps will then restart after satisfying a time delay.

HPSI pump 13 was originally intended as an installed spare and was normally aligned as an “A” train pump. This pump can receive power from either the “A” or “B” train vital power. Its power supply is selected to the train to which the pump is aligned. Cross connecting power from two different trains is prevented by a key interlock breaker arrangement for this pump. This pump also received an automatic start signal from either SIAS train. The SIAS start signal to the 13 HPSI pump was controlled by the power supply source and the status of the other HPSI pump that shares the ESF bus.

The present alignment is with HPSI pump 11 powered from the 11 4kV vital bus and HPSI pump 13 selected to the 14 4kV vital bus. Both pumps receive a start signal on an SIAS. The 12 HPSI pump does not receive a start signal on an SIAS. This alignment does not provide for a “swing” pump capability.

Each HPSI pump is a multiple stage centrifugal pump. The pumps are provided with a mechanical seal at each end of the shaft. The seals are designed for operation with temperature in excess of 300°F, but are cooled to increase seal life and reduce maintenance. Seal cooling is accomplished by circulating a portion of the water from the first stage through a centrifugal separator and a cooler, then flushing the cooled water into the seal cavity. Leak off connections, both vent and drain, are provided between the mechanical seal and the backup shaft packing which is part of the seal cartridge. In addition to the vent and drains associated with the seal cartridge, dual casing vents and drains are installed on each pump to permit flushing to reduce radiation levels during maintenance operations.

The stuffing box jackets and two bearing housings on each HPSI pump are directly cooled by component cooling water (CCW). In addition, the CCW flows through the pump cooler to transfer heat from the seal cooling water described above.

The HPSI pumps each have a design capacity of 345 gpm and a maximum flow capability of 640 gpm with a minimum allowable flow of 30 gpm. Each pump is driven through a coupling by a 400 hp, 4000 Vac induction motor. The motor is capable of accelerating the pump to full speed in 8 seconds with 75% of the name plate voltage applied. HPSI pump 11 receives class 1E power from 4.16 kV unit bus 11 and pump 12 receives class 1E power from 4.16 kV unit bus 14. HPSI pump 13 can receive power from either bus 11 or bus 14 (normally lined up to bus 14) through the use of disconnect switches controlled by key operated handswitches. Redundant power sources provide maximum reliability for pump operation.

Each pump hand switch has four positions (stop / auto / start / pull-to-lock). The start and stop positions allow manual control of the pumps, while the auto position aligns the pump for automatic operation. The pull-to-lock (PTL) position removes the pump from service by preventing pump start signals from being processed.

The number 11 and 13 HPSI pumps will start automatically upon receipt of a SIAS (in AUTO). An improper breaker lineup alarm actuates when a pump has its breakers and disconnects in any combination other than a breaker racked in with its associated disconnect shut. Each HPSI pump has a SIAS blocked auto start alarm which actuates when one of the following conditions exists:

1. Pump hand switch in PTL
2. Pump breaker racked out
3. Pump breaker not shut within one second after receiving a SIAS or hand switch start signal

The HPSI pumps will be used not only during the injection phase of the LOCA but also during the recirculation mode. The HPSI pumps are sized to ensure at the start of the recirculation mode one HPSI pump alone has sufficient capacity to keep the core covered, assuming 25% flow spillage, and match the boil off from core decay heat. If recirculation is initiated 36 minutes after a LOCA, the safety injection flow required to match core boil off is approximately 410 gpm. One HPSI pump with 25% spillage injects 450 gpm into the RCS when RCS pressure is at its maximum containment pressure. Thus flow from one HPSI pump is sufficient to prevent core damage at this time. Additional HPSI data is presented in Table 11.1-2.

11.1.3.3 Minimum Flow Recirculation Valves

The HPSI pumps are provided with minimum flow protection to prevent damage to the pumps which could result from operation against a closed discharge. The HPSI pumps are designed to operate with a minimum recirculation flow rate of 30 gpm without suffering damage. The pumps are also protected from run-out damage by system valve adjustments and/or orifice sizing downstream of the pumps.

The minimum flow recirculation valves are normally open and will automatically close upon receipt of a RAS. These valves close to prevent the recirculation of potentially radioactive material from the containment sump to the RWT which is outside the containment.

11.1.3.4 High Pressure Isolation Valves

There are four high pressure isolation valves on each train of the high pressure injection system. Train “A” isolation valves, on the discharge of the 11 HPSI pump, receives vital power from the Train “A” vital electrical distribution network, and the valves on Train “B”, on the discharge of the 13 HPSI pump, receive their power from Train “B” vital electrical distribution. These valves are normally closed and receive an open signal from the SIAS. All the high pressure isolation valves have locking control switches and position indicators in the control room, which allows the operator to change the position of these valves if needed.

11.1.3.5 Safety Injection Actuation Signal (SIAS)

The SIAS is used to automatically actuate the HPSI system. The SIAS is actuated by either of the following signals:

1. Low pressurizer pressure, or
2. High containment pressure

The low pressurizer pressure SIAS is a two-out-of-four signal set at 1740 psia at normal plant operating conditions. When pressurizer pressure decreases to 1785 psia the operator may manually block the low pressure SIAS. When plant pressure is being increased and pressurizer pressure exceeds 1785 psig the set point will automatically be reinstated.

The high containment pressure SIAS is a two-out-of-four signal and is set at 2.8 psig. In addition to starting the safety injection systems, this signal also generates a containment isolation and starts the containment cooling systems.

11.1.3.6 Recirculation Actuation Signal (RAS)

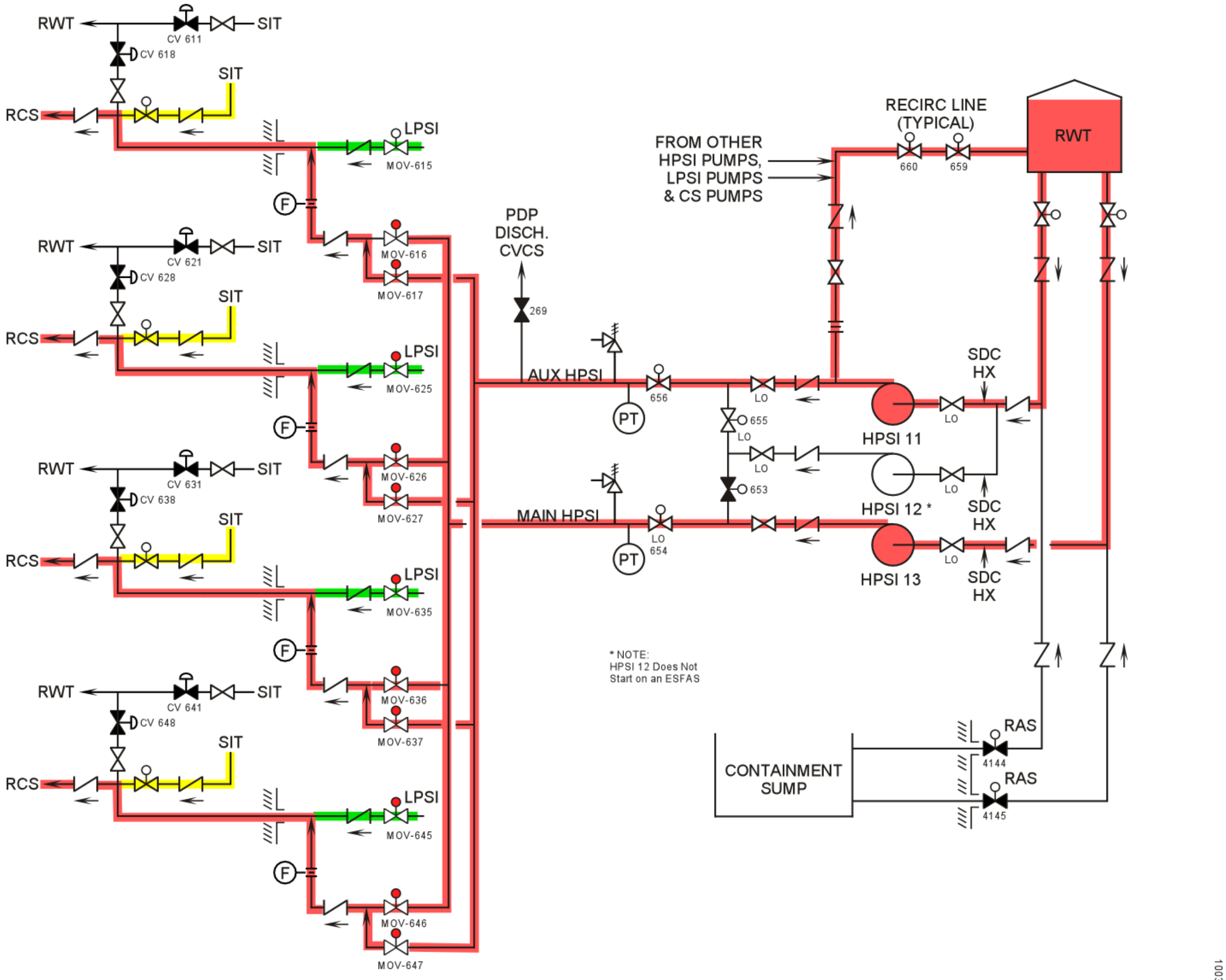
The RAS is used to automatically change the safety injection systems from the injection mode of operation to the recirculation mode of operation. When the RWT reaches a low level (30 inches), the RAS will be generated. This signal is a two-out-of-four logic and once received will automatically stop the LPSI pumps and transfer the suction of the HPSI pumps from the RWT to the containment sump. This signal will also close the minimum flow recirculation valves.

11.1.4 System Operation

11.1.4.1 Normal Operation

During normal plant operation, the HPSI system is maintained in a standby mode with all of its components lined up for emergency injection (Figure 11.1-1). During this time none of the system components are operating. This system does provide the means to adjust the level in the safety injection tanks (SITs).

11.1.4.2 Injection Phase



If a leak in the RCS is small enough so that one charging pump can maintain reactor coolant pressure, an SIAS is not generated and the use of the safety injection systems is not required. However, if the break is large enough to cause the pressure in the RCS to decrease below 1740 psia, then an SIAS is initiated. Large ruptures up to and including the double-ended rupture of the largest pipe in the RCS are dealt with by the high and low pressure safety injection pumps and the safety injection tanks.

If standby power (offsite power) is not available following a SIAS the plant emergency diesel generators will automatically start and all loads on the engineered safety features buses will be tripped. Once the diesel generator is up to speed and voltage, its corresponding output breaker is closed and the loads will be sequenced onto the bus. The loads are sequenced on in a prescribed order to prevent overloading the diesel generators. The loading sequence is as follows:

1. Two low pressure injection valves and four high pressure injection valves open,
2. One high pressure safety injection pump is started and
3. A low pressure safety injection pump is started.

Two separate suction headers supply the three HPSI pumps with water from the RWT through two suction lines each having a motor-operated isolation valve. These valves

are normally open to line up RWT water to the HPSI pumps for the injection mode of operation. Once the recirculation mode begins, the two RWT isolation valves must be shut by the operator.

HPSI pumps 11 and 12 are lined up to take a suction on one RWT header, while pump 13 is lined up to take suction on the other RWT header. The three HPSI pumps discharge through check valves to a common discharge header. In this discharge header there are two motor-operated isolation valves controlled by key operated hand switches. As indicated on Figure 11.1-1, MOV-653 is normally shut and MOV-655 is normally open. Control of these valves allow realignment during normal operations or in the event of a casualty to the main or auxiliary discharge headers.

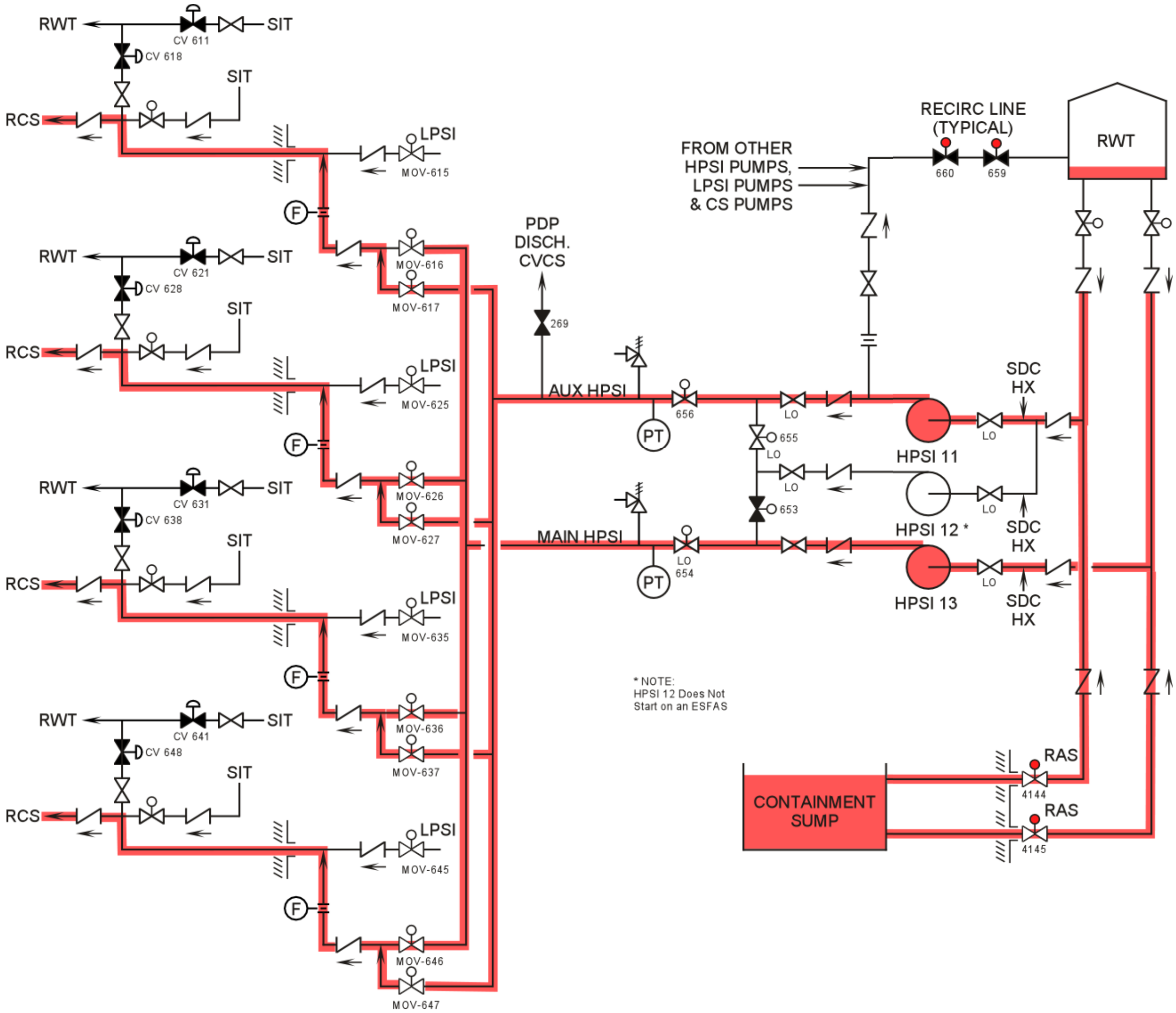
Each HPSI header has a motor-operated isolation valve (MOV-654 and MOV-656) which are controlled by key operated hand switches. Both valves receive an open signal when a SIAS is generated by the ESFAS.

Downstream of each header isolation valve is a pressure transmitter to provide pressure indication to the operator. A system relief valve in each header provides over pressure protection due to a possible sudden increase in temperature. After the relief valve, the auxiliary header has a connection to the discharge of the charging pumps in the CVCS. This connection provides an alternate charging path to the RCS.

After the header relief valve, each header (main and auxiliary) splits into four parallel lines. Each HPSI line has a motor-operated isolation valve controlled by a hand switch. All the isolation valves are normally shut, and open automatically upon receipt of a SIAS. The valves can be positioned to throttle HPSI flow. A percent valve position indicator is provided next to each hand switch. Each of the main HPSI lines then joins a respective auxiliary HPSI line forming a common HPSI line. The common HPSI lines passes through a check valve and a flow element prior to combining with a respective LPSI line and SIT to form one of four injection paths into the RCS.

The safety injection systems will inject water into the RCS via the penetrations on the four cold legs. The size of the break will determine how long the water in the refueling water tank will last. For the large break LOCA , the level will decrease to the low level alarm set point at which time the RAS will automatically shift the safety injection systems from the injection phase to the recirculation phase.

11.1.4.3 Recirculation Phase



When the water in the RWT reaches a low level (6%) the RAS is initiated. The RAS opens the containment sump isolation valves, stops the low pressure safety injection pumps, and closes the minimum flow recirculation valves. The HPSI pumps continue to operate during this switch over. The safety injection systems are now aligned for the recirculation phase. Once initiated, recirculation continues until terminated or modified by operator action.

A recirculation line is provided from the outlet of each shutdown cooling heat exchanger to the HPSI pump suction. Heat exchanger 11 connects to HPSI pump 11 and 12 and heat exchanger 12 connects to HPSI 13. Each recirculation line has a motor-operated isolation valve controlled by a hand switch. These two isolation valves are normally shut. They are opened by the operator if HPSI pump cavitation occurs during the recirculation mode of operation. Recirculation of the cooler containment spray water from the heat exchanger outlet maintains the HPSI pump's suction sufficiently subcooled to prevent cavitation.

During long term core cooling following a LOCA, if the reactor coolant is not sub-cooled it will boil off as steam. The boiling process concentrates the boric acid and other solution additives in the core. For a hot leg break, safety injection flow via the cold leg

travels down the annulus, through the core, and out the break. A flushing path is established through the reactor vessel, precluding the build-up of solids in the core region.

However, for a cold leg break, only that amount of injected water required for decay heat removal is delivered to the core; the remainder spills out the break. Due to the RCS geometry, there is minimal flushing flow through the core for a cold leg break, and boric acid concentration may increase along the core surfaces.

To prevent the restriction of core flow due to boron crystallization, the safety injection system is lined up during long term core cooling to establish a circulation flow path which adequately flushes the core.

Two safety injection lineups can be used to establish a core flush. The preferred lineup is called pressurizer injection. The four auxiliary HPSI line isolation valves are shut and the HPSI pump discharge is directed to the CVCS through the cross-connect from the HPSI auxiliary header. The charging loop isolation valves are closed, then the auxiliary spray valve is opened. Flow is from the auxiliary header to the CVCS and into the pressurizer through the auxiliary spray line, and then into the core via the hot leg.

11.1.5 Summary

The HPSI system is designed to supply water from the RWT to the RCS to provide core cooling for all size breaks up to and including the double ended rupture of the largest piping in the RCS. Redundancy is built into the HPSI system by incorporating three 100 percent capacity pumps and two separate trains of injection. During long term cooling of the core (recirculation mode), heat is removed by returning water from the containment sump via the HPSI system to the core, and allowing the core to boil off this liquid.

TABLE 11.1-1 REFUELING WATER TANK

Quantity	1 per unit
Type	Vertical cylinder
Total volume	420,000 gallons
Minimum water volume	400,000 gallons
Design pressure	Atmospheric
Design temperature	0°F
Contained liquid	Borated water
Liquid temperature	Ambient (40°F to 100°F)
Material	Type 304 stainless steel
Seismic requirement	Class I

TABLE 11.1-2 HIGH PRESSURE SAFETY INJECTION PUMPS

PUMP

Quantity	3 per unit
Manufacturer	Bingham
Type	7-stage, horizontal, centrifugal
Material	Stainless steel
Design flow rate	345 gpm
Design head	2500 ft.
Maximum flow rate	640 gpm
Head at max, flow rate	1360 ft.
Minimum allowable flow rate	30 gpm
Shutoff head	2930 ft.
NPSH available, minimum	28 ft.
NPSH required for 640 gpm	20 ft.
Design temperature	350°F
Design pressure	250 psig, suction 1750 psig, discharge

MOTOR

Quantity	3 per unit
Manufacturer	General Electric Co.
Horsepower	400 hp
RPM, full load	3560 rpm
Voltage rating	4000 V, 3 phase, 60 Hz.

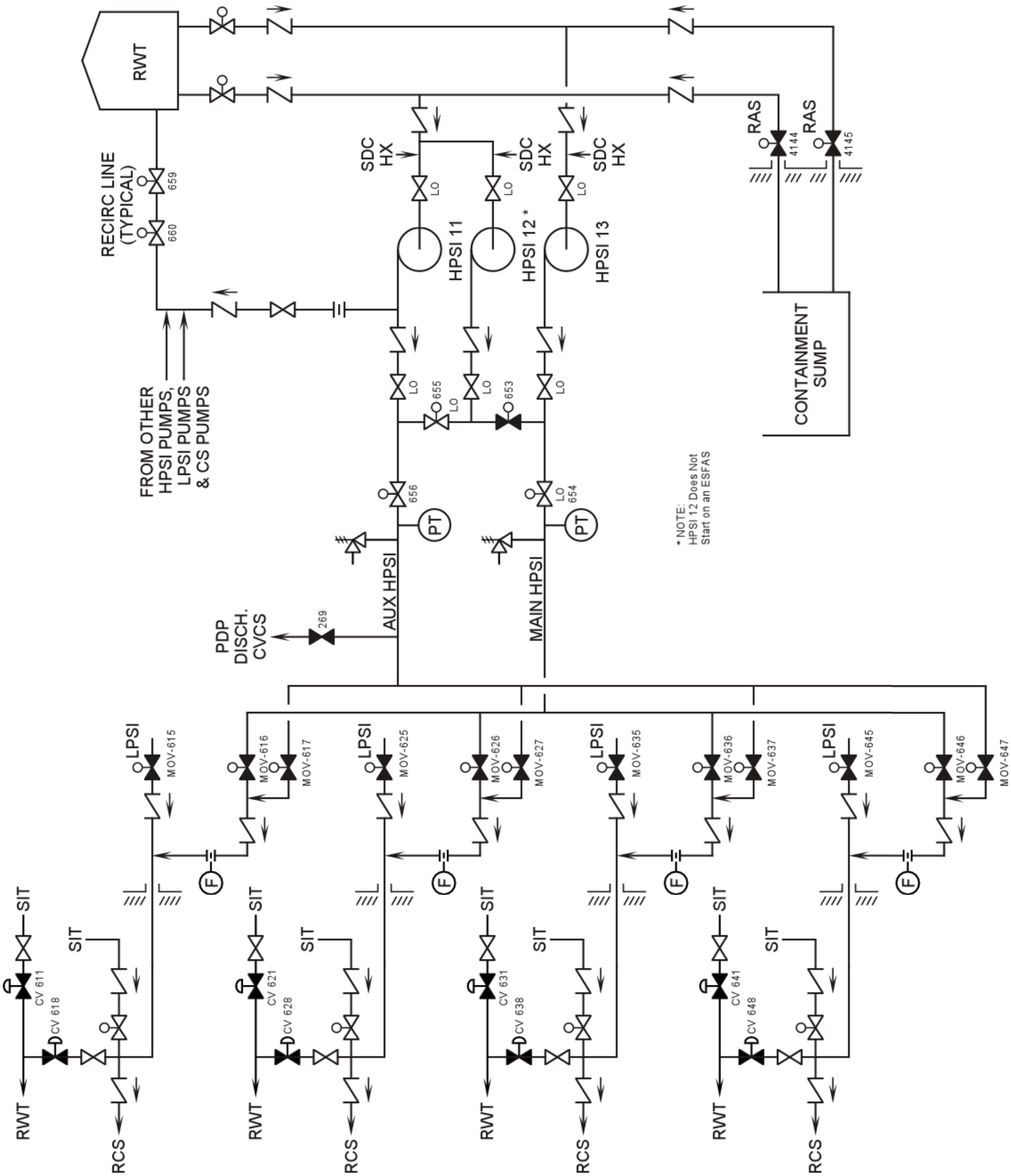


Figure 11.1-1 HPSI Flow Diagram

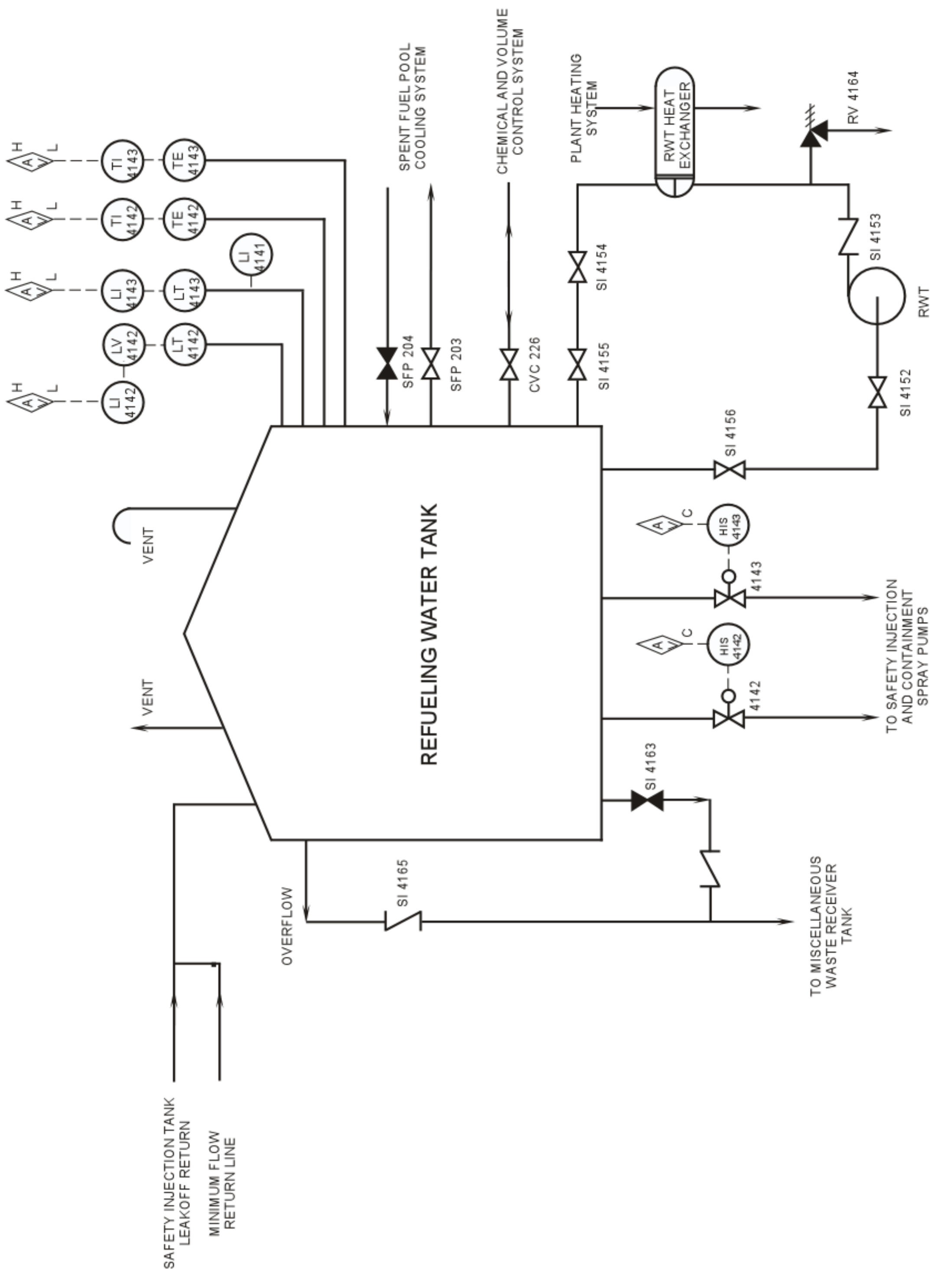


Figure 11.1-2 Refueling Water Tank