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11.3 INTEGRATED OPERATION OF THE EMERGENCY CORE COOLING SYSTEMS

Learning Objectives:

1. Describe the operation of the emergency core cooling systems (ECCS) during the following operations:
   a. Injection phase
   b. Recirculation phase
2. State the purpose of the safety injection tanks (SIT).
3. List the order of ECCS injection during the following abnormal conditions:
   a. Inadvertent actuation at power
   b. Small break loss of coolant accident (slow depressurization)
   c. Large loss of coolant accident (LOCA)

11.3.1 Introduction

The purpose of the ECCS is to ensure that for any accident, up to and including the double ended rupture of the largest reactor coolant system pipe, the core will be re-flooded and cooled. These actions preclude fuel melting and minimize the amount of cladding that will be damaged. This is accomplished by designing 100 percent capacity redundant components for the ECCS.

The following minimum number of components operating will protect the core:

1. One high pressure safety injection (HPSI) pump,
2. One low pressure safety injection (LPSI) pump,
3. One emergency diesel generator, and
4. Three of the four safety injection tanks (SITs).

11.3.2 System Description

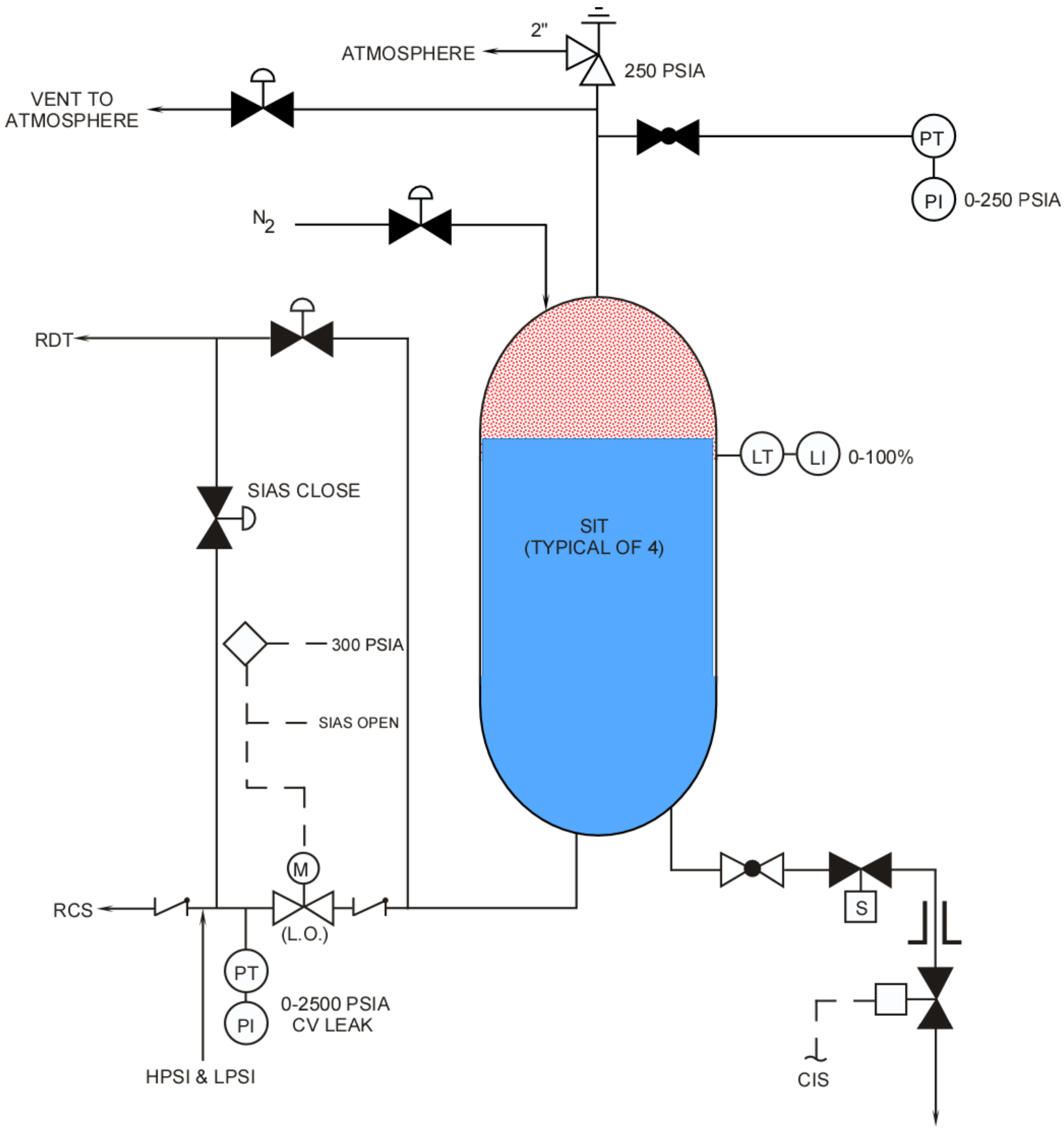


Figure 11.3-1 Safety Injection Tanks

The SITs as shown in Figure 11.3-1 are pressure vessels which contain borated water and are pressurized with nitrogen gas. The SITs are located inside the containment and are attached to the same injection piping used by the high pressure and the low pressure safety injection systems. The SITs are a passive system, meaning that it requires no automatic or operator action for this system to perform its intended function. Their function is to reflood and cover the core following a large LOCA.

11.3.3 Component Description

11.3.3.1 Safety Injection Tanks

There are four SITs located inside the containment, each tank is constructed of carbon steel and internally clad with stainless steel to prevent corrosion. Each tank is typically 2000 cubic feet in size (16,000 gallons), and is approximately half filled with water. The water in these tanks is borated to 2500 ppm boron, and pressurized to 200 psig. The size of the SITs is based on the assumption that one SIT dumps directly out the break leaving the remaining three SITs to inject their contents into the cold legs and completely recover the core, until safety injection pumps can provide core cooling. The boron concentration is sufficient to maintain the core in a sub-critical condition following an accident.

Each SIT is supplied with a pressure relief valve which is set at 250 psig and discharges to the containment atmosphere to protect the SIT from over pressure. In addition, each SIT is provided with the necessary valves and piping for filling, draining, venting, sampling, and adjusting the boron concentration. There are also redundant level and pressure instruments for each SIT in the control room to verify the technical specification limits on these tanks.

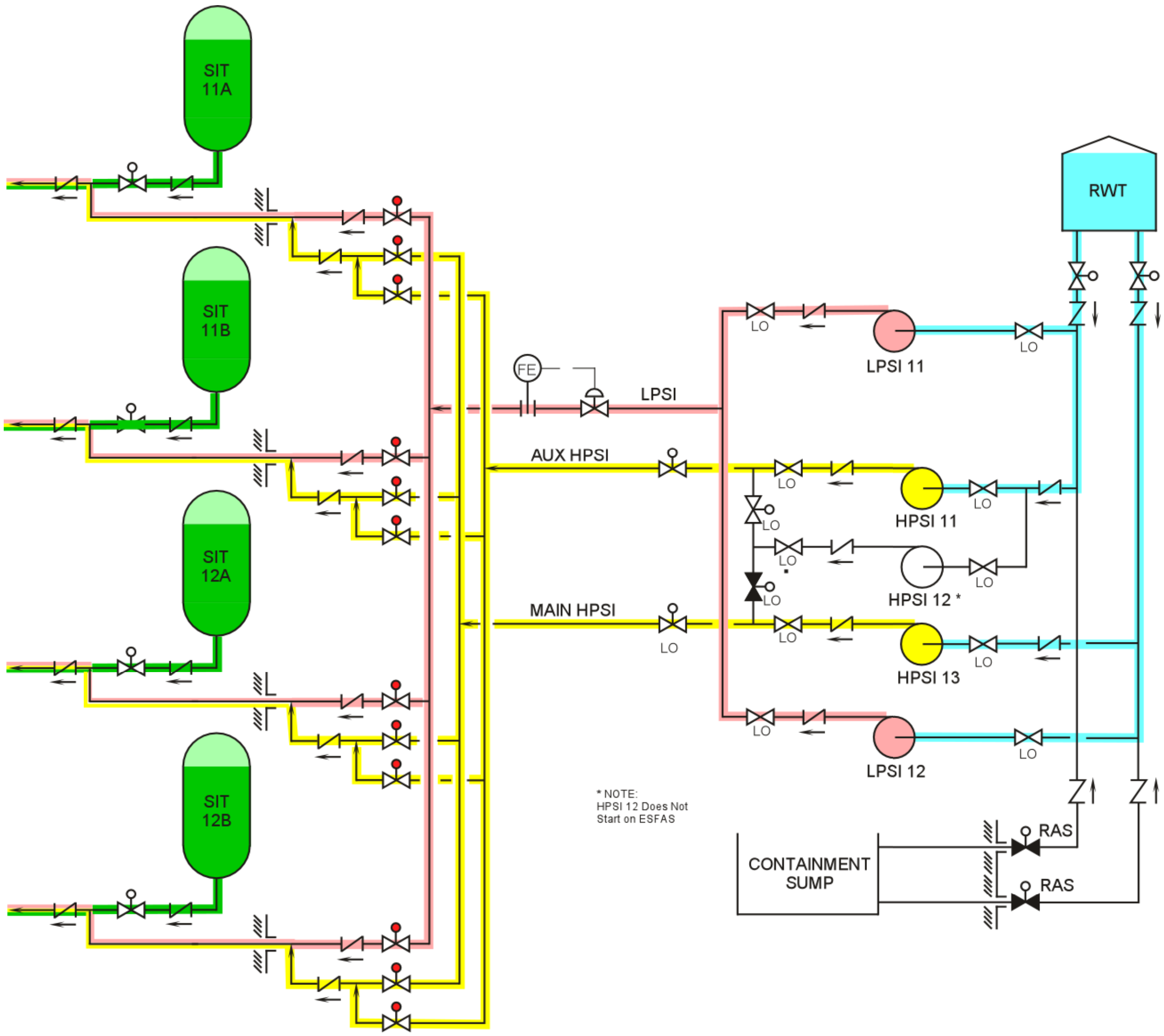
11.3.3.2 Safety Injection Tank Isolation Valves

Each SIT is connected to a reactor coolant system (RCS) loop cold leg through two check valves in series. The check valves are normally held shut by the higher RCS pressure. When the RCS pressure drops below approximately 200 psig, the check valves open and the SITs discharge into the RCS. Each tank discharge line is equipped with a motor operated valve to isolate the tank from the RCS when the system is cooled down and depressurized. These valves are manually closed when the pressure in the RCS decreases to < 300 psig.

During a plant startup, the SIT discharge valves are manually opened when the pressure in the RCS reaches 250 psig; however, if these valves are inadvertently left closed, they will automatically open when the RCS pressure reaches 300 psig. After the valves are open, each valve is key locked to the open position on the control board and the supply breaker to its motor operator is opened. In addition, a safety injection actuation signal (SIAS) open command is provided to each valve during an accident .

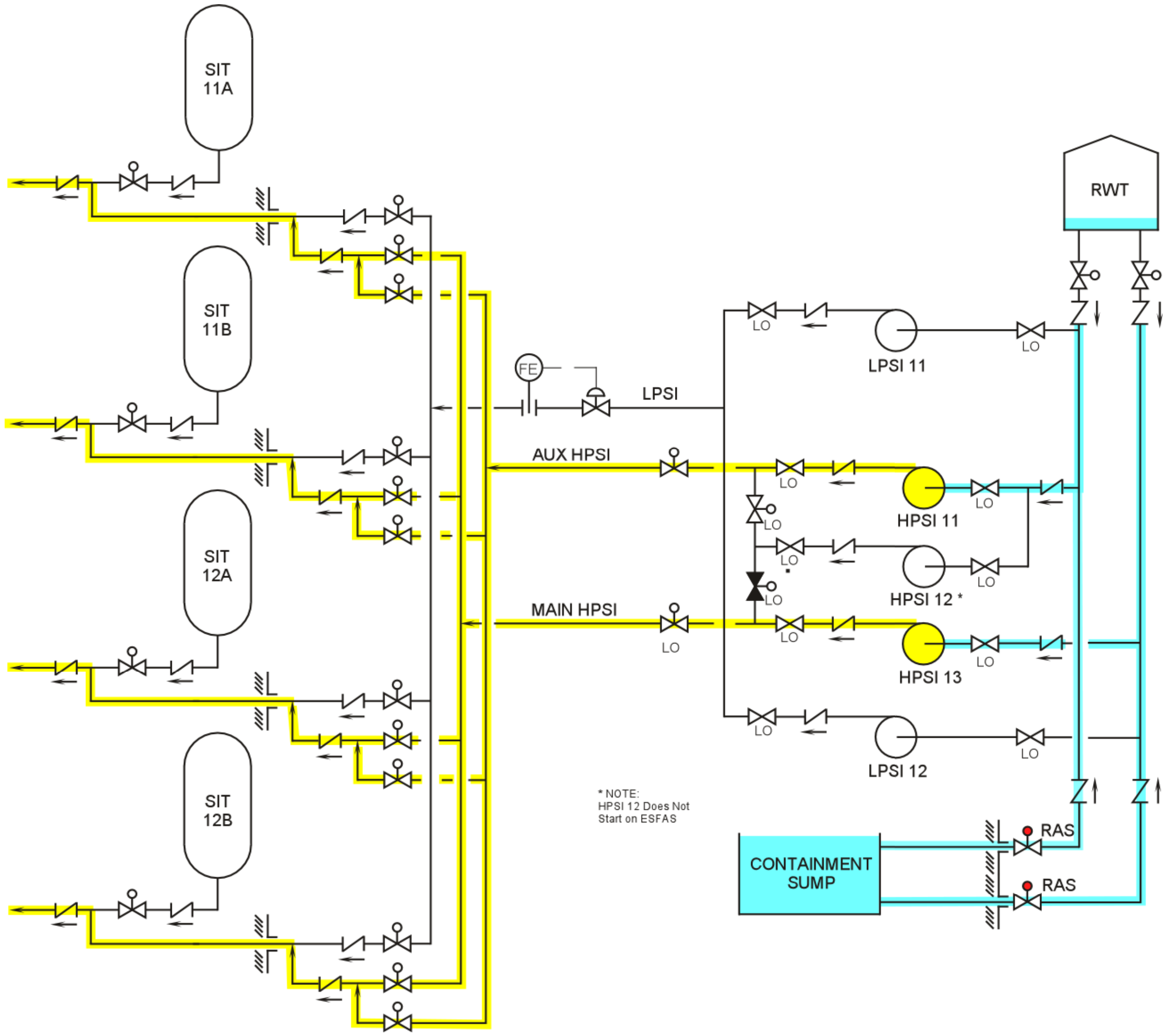
11.3.4 System Operation

11.3.4.1 Integrated Operations



Injection Mode

The operation of the ECCS (Figure 11.3-2) following a LOCA is divided into two modes of operation, the injection phase and the recirculation phase. The injection phase is that time when the active components of the ECCS take a suction from the RWT and discharge into the RCS cold legs. This mode of operation will continue until the RWT reaches its low level setpoint.



Recirculation Mode

When the refueling water tank reaches a low level condition a signal is sent to shift the active components from the injection phase to the recirculation phase, this signal is called the recirculation actuation signal (RAS). During the recirculation phase the mini flow recirculation valves receive a close signal and the LPSI pumps receive a stop signal. The HPSI pumps will continue to operate except that they now take a suction from the containment sump and return the fluid to the RCS and the core.

The sequence of events for a loss of coolant accident that results in a slow depressurization of the RCS is as follows:

1. As inventory is lost, letdown will be reduced to minimum and additional charging pumps will be placed in service by the pressurizer level control system,
2. Since the LOCA is larger than 132 gpm, pressurizer level will continue to decrease, and pressure will also drop,
3. More than likely, a reactor trip will be generated by the thermal margin low pressure (TMLP) reactor trip or possibly high containment building pressure,

4. A SIAS will be generated by low pressurizer pressure or high containment building pressure. The SIAS signal will start the charging pumps (if not already running), the HPSI pumps, and the LPSI pumps,
5. The SIAS signal is generated at 1740 psia. The shutoff head of the HPSI and LPSI pumps is ~1300 and ~180 psia, respectively, ECCS flow is initially provided by the charging pumps,
6. As RCS pressure continues to decrease, flow from the HPSI pumps will begin when pressure is less than 1300 psia. When RCS pressure decreases to less than 200 psia, the SITs will begin to empty. Finally, the LPSI pumps will provide flow when RCS pressure decreases to less than 200 psia and
7. The charging pumps will be manually stopped when low level conditions are reached in the boric acid storage tanks. When a low level is reached in the RWT, a RAS will be generated. When the RAS is generated, the LPSI pumps will be tripped, and long term core cooling will be supplied by the HPSI pumps.

If a loss of offsite power occurs simultaneously with the LOCA, the sequence of events will be modified slightly. First, the charging pumps will not be powered (until the diesel-generator starts) and cannot respond to the decrease in pressurizer level. Next, the reactor trip will be caused by a loss of RCS flow because RCP power is lost. Finally, the diesel generator must start and its output breaker must close before charging and HPSI flows will be available. The timing of accident flows, with the exception of SIT flow, is dependent upon the sequencing of loads onto the vital 4160 Vac buses.

If a large break LOCA occurs, items 1 through 7 above happen in a much shorter time frame. If a large break LOCA and a loss of offsite power occur simultaneously, the SITs will probably empty before the diesel generators can start and energize the 4160 Vac buses.

11.3.4.2 Generic LOCA Considerations

The length of time that the ECCS is in the injection phase is dependent upon the size of the break and any operator action. The rate at which the volume of water is lost and the pressure reduction of the RCS is break size dependent and is analyzed in the FSAR. These analysis include various size small break LOCAs (SBLOCA) and the break of the largest piping in the RCS, normally called the large break LOCA (LBLOCA).

As documented in CEN-114, the designation of a particular break size, type , and location as the worst break must be accompanied by a list of assumptions. The assumptions may be on the specific plant design (SIT pressure), system performance (minimum HPSI flow), or system availability (number of HPSI pumps). Despite the fact that the worst break will change given a change in the assumptions, certain features of the break can be generalized and discussed independently of the individual assumptions.

With feedwater available (main feedwater until reactor trip and then auxiliary feedwater), the worst break falls within a narrow range of possibilities. For CE designed plants, the worst location has been the RCP discharge leg. This location results in the slowest depressurization and the least amount of liquid available for core cooling.

The small break spectrum from an Appendix K perspective, is bounded on the large end by the small/large break dividing point, typically taken to be 0.5 ft^2. For the larger break sizes in this range (0.1-0.5 ft^2), the core will uncover relatively early (the larger the break, the earlier the uncovery) but since the RCS depressurizes quickly and completely, the SIT flow ensures a rapid recovering of the core. Due to the short uncovery duration, the fuel cladding has little time to heat up and consequently acceptable low clad temperatures result.

For intermediate break sizes (0.02 - 0.1 ft^2) the RCS does not depressurize to the SIT set point and if core uncovery occurs, recovery must be accomplished by the HPSI pumps alone. While these breaks uncover later than the larger breaks, the uncovery can be of a longer duration. As the break size decreases in this range, the core begins to uncover later, is of shallower depth, and may stay uncovered longer. For very small breaks (0.0 - 0.02 ft^2), the HPSI pumps are able to inject sufficient flow to prevent core uncovery, because the core heat generation rate has decayed to a point where the HPSI pumps are injecting at a rate exceeding core boil off before the core uncovers.

Since the very small breaks do not uncover the core, the clad temperature remains at a low value. As stated above, the larger breaks, due to rapid core uncovery also experience low clad temperatures. Therefore, the worst break size occurs in the intermediate range defined on the large end by SIT pressure and on the small end by core power (assumed decay heat generation rate) and HPSI pump performance. The worst break normally is the largest break in this range which relies on HPSI injection to terminate clad temperature rise). For plants with SIT pressure of 200 psi this break size is approximately 0.1ft^2 For plants with SIT pressure of 600 psi this break size is on the order of 0.05 ft^2. It is possible, given sufficient HPSI flow or low core power (best estimate) that these breaks may not experience any significant core uncovery. In this case, there would be no intermediate class of breaks and the worst break would have a significantly lower clad temperature and be one of the larger break sizes resulting in core uncovery.

There are two possible types of LOCAs associated with a loss of all feedwater (LOAF), those occurring concurrent with a LOAF, and those caused by the LOAF due to high RCS pressure. LOAF implies a loss of both main and auxiliary feedwater capability. For breaks > 0.02 ft^2 concurrent with a LOAF, the energy transferred to the secondary is insignificant and a loss of feedwater during the transient is of little consequence. These breaks result in similar system behavior with and without available feedwater.

As the break size decreases, (LOCA concurrent with LOAF) the availability of the steam generator as a heat sink becomes more important. For a range of break sizes, feedwater is beneficial but not necessary. Smaller breaks require feedwater to obtain acceptable results. For LOCAs caused by LOAF, feedwater is also a requirement. Therefore, to realistically define a worst break coupled with a LOAF, a criterion must be set to judge which is worst. The criterion chosen was the break which has a significant dependence on feedwater availability, and that requires initiation of auxiliary feedwater in the least amount of time to prevent core uncovery. An intermediate break size of 0.02 ft^2 is shown to have a significant dependence of feedwater availability and requires auxiliary feedwater flow be initiated at the earliest time after the break (< 1 hour).

11.3.4.3 Small Break Loss of Coolant Accident (SBLOCA)

The major concern with the SBLOCA is that it takes a long period of time for the pressure to decrease to a point where the ECCS will start to inject the cooling water to the core. The smaller the break, the longer it takes for the pressure to decay to the injection point. After the actuation signal is generated, all active components of the ECCS will actuate assuming no failure of individual components. The HPSI pumps will start to inject and the LPSI pumps, which have started, will circulate water back to the RWT. As the pressure in the RCS slowly decays more and more flow from the HPSI will be injected into the RCS. However, water is continuing to flow out the break causing a net loss of reactor coolant. As pressure continues to drop the next component to inject will be the safety injection tanks at a pressure of less than 200 psig.

Since the break is not isolated, water inventory will continue to decrease and pressure will drop until the LPSI pumps start to inject. As described in this hypothetical accident it takes a certain amount of time for the different ECCS components to begin to inject their contents and replenish the loss of inventory from the RCS, which means a higher void fraction in the RCS

11.3.4.4 Large Break Loss of Coolant Accident (LBLOCA)

If a LBLOCA were to occur the first component to inject would be the SITs due to the fact that they are passive components and require no actuation signal or component to change position.

Assuming a concurrent loss of offsite power, the diesel generators would start and the high pressure safety injection and then the low pressure safety injection would be started. The injection phase will last for approximately 30 minutes when the recirculation actuation signal will actuate.

11.3.4.5 Abnormal Operations

If there was an inadvertent actuation of the SIAS when the plant was at power, the consequences would be minimal. All active components in the ECCS would actuate, but since the reactor coolant pressure is at or near 2200 psig, which is well above the discharge pressure of the HPSI or LPSI pumps, no water from the RWT will be injected into the RCS.

11.3.5 PRA Insights

Since the ECCS are required to mitigate the consequences of accidents, the failure of these systems during transients and accidents greatly increases the probability of core melt. In particular, the failure of the HPSI system in either the injection phase or the recirculation phase of operation is a major contributor to increases in core melt frequency. According to the Calvert Cliff's PRA, the HPSI system failure contribution to core melt frequency is 25%. Many of the failure sequences are caused by operator error.

The following sequences provide information on system failures and their consequences.

For certain small break sizes (< 1.9 inches in diameter), the proper operation of all ECCS components is very important. A scenario that increases core melt frequency is outlined below:

1. A LOCA occurs that results in the actuation of the ECCS,
2. All ECCS components function properly in the injection phase of the LOCA,
3. The RWT reaches a low level, but the switchover of the ECCS suctions to the containment sump is unsuccessful,
4. The failure of the sump suction lineup results in a loss of suction to the ECCS pumps, and no core cooling flow is available and
5. With no cooling flow, the core heats up and eventual melts.

The significant cut sets involve failure of pump seals or ECCS pump room cooling. For pump seal cooling, since only CCW heat exchanger #11 is normally in service, the most important recovery action is for the operator to manually open the discharge valve on CCW heat exchanger #12 in order to place it in operation. CCW seal cooling failure is assumed to fail the HPSI pumps as well as the LPSI and containment spray pumps. For pump room cooling, the operator can manually start the pump room coolers for local control faults. If the sump valves fail due to control faults, the operator can manually open the valves.

In a similar sequence, involving a SBLOCA, a failure of the HPSI system is considered such that no makeup is assumed in the injection phase of the accident.

This initiating event can be divided into two parts: RCP seal LOCAs ($2x10^{-2}$/yr) and other SBLOCAs ($1x10^{-3}$/yr). The other SBLOCA portion of the sequence is negligible when included with the failure probability of the HPSI system ($1.3x10^{-4}$) since the product result is less than $1x10^{-6}$. Work done by EG&G for the station blackout program indicates that for a leak of the maximum expected RCP seal LOCA (< 500 gpm), with secondary cooling available, approximately three hours is available to isolate the leak or start primary makeup.

The dominant HPSI pump failure is attributed to the closure (fail close) of the valves in the common minimum flow recirculation line. This pump failure is due to the slow drop in primary pressure from 1600 to 1275 psi resulting in pump heat up and failure due to pumping against a shutoff head for a significant period of time (greater than 10 minutes). These minimum flow recirculation valves are common to all HPSI, LPSI and containment spray pumps.

Another sequence that illustrates the importance of the ECCS to risk is the intersystem or interfacing LOCA (also known as event V). In this sequence, a failure of both of the series check valves that separate the high pressure RCS from the low pressure systems is postulated. With the LPSI header motor-operated valves in an open position (operability test), the LPSI discharge piping is exposed to full RCS pressure. The discharge piping is over pressurized and fails. The largest risk achievement factors are associated with local faults for the minimum flow recirculation valves and the CCW valves. All had a risk achievement factor of 163. The risk reduction factors were negligible.

The failure results in a LOCA with some unique features. First, the LOCA is outside of the reactor building; therefore, the containment barrier is lost. Next, the assumed failure has the potential to also fail both trains of LPSI. Finally, the leakage from the RCS is not collected in the reactor building sump. When the refueling water tank empties, no cooling fluid is available for long term core cooling. With no cooling, the core overheats.

11.3.6 Summary

The purpose of the ECCS is to provide initial filling of the reactor vessel after a LOCA and to provide long term cooling of the core after the initial blow down of the RCS is over. The purpose of the SITs is to completely cover the core following a LBLOCA. The sizing and number of SITs is selected considering that one of the tanks spills its contents directly out the break, and the remaining three SITs inject into the cold legs and completely cover the core following a LBLOCA.

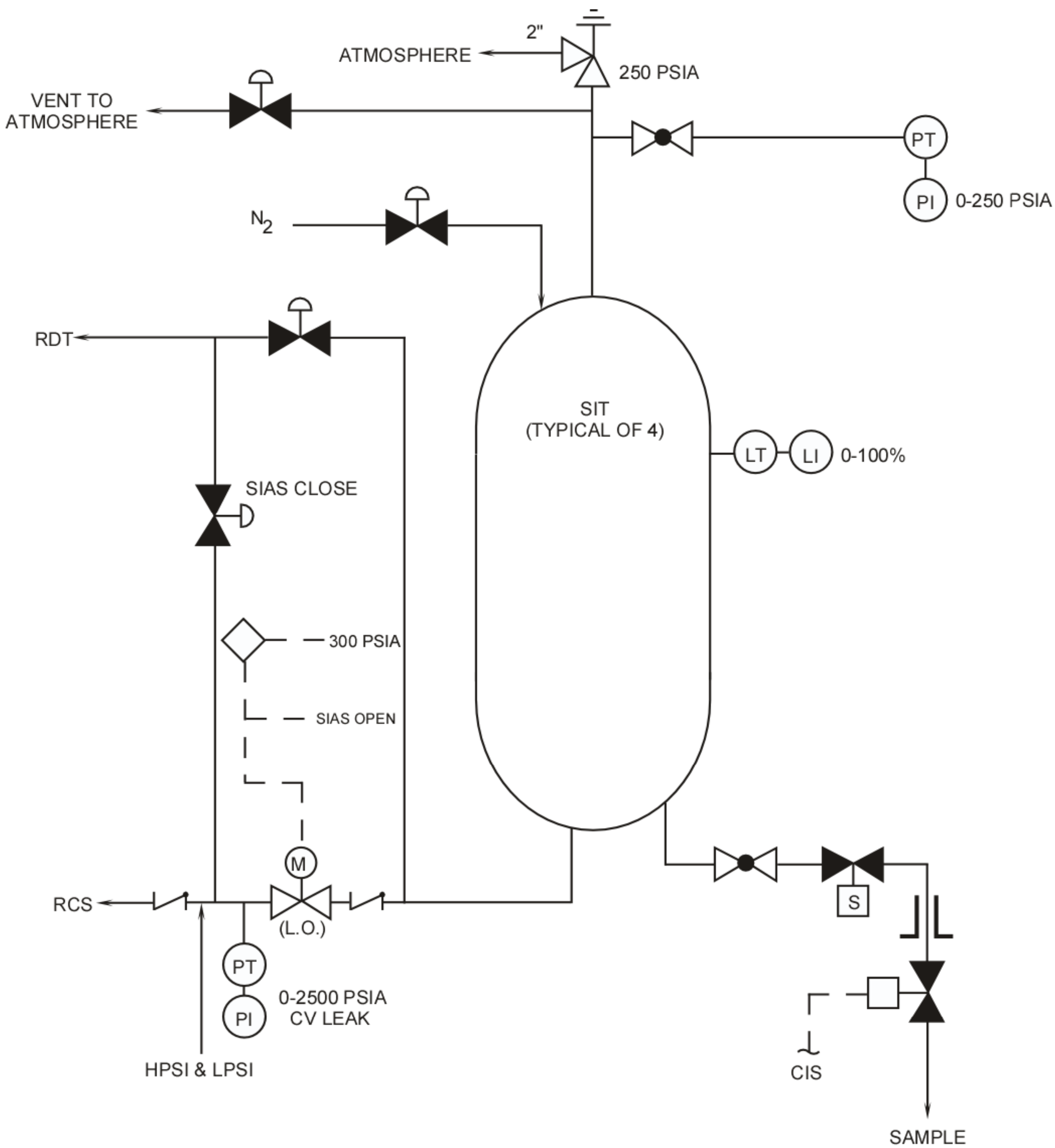


Figure 11.3-1 Safety Injection Tanks

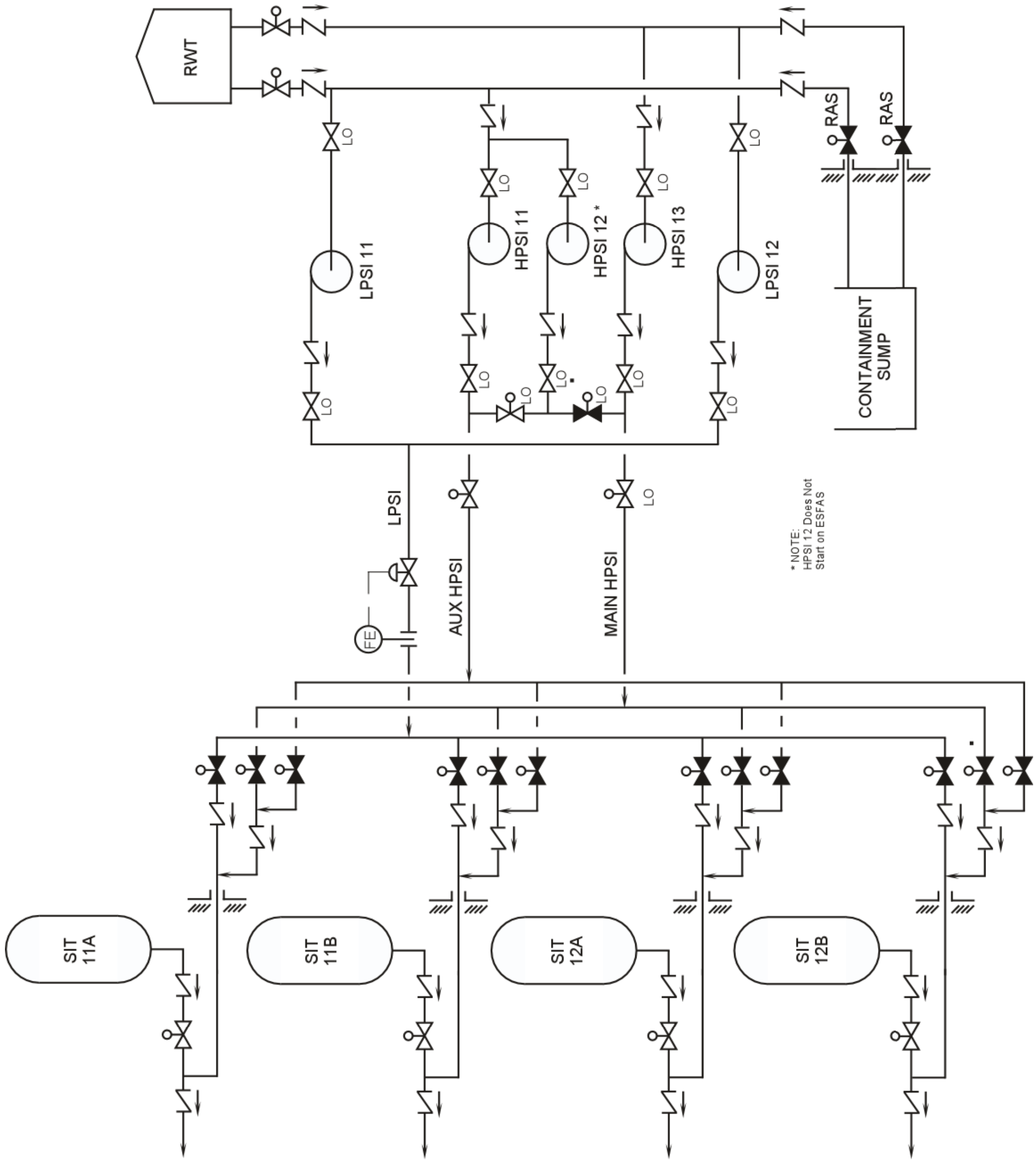


Figure 11.3-2 Emergency Core Cooling System