US-EPR Technology Manual

Chapter 5.0

<u>SAFETY-RELATED SYSTEMS</u>

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5.0 SAFETY-RELATED SYSTEMS

Learning Objectives:

1. State the purposes, and describe the operation, of the following safety-related systems:

    a. Safety injection system/residual heat removal system,
    b. Component cooling water system,
    c. Essential service water system,
    d. Emergency feedwater system,
    e. Extra borating system, and
    f. Fuel pool cooling and purification system.

2. Explain the N+2 four-train safety concept.

3. List the systems that are arranged in four-train and two-train safety configurations.

4. Describe the major differences between the safety-related systems of the US-EPR design and those of currently operating PWRs.

5.1 Introduction

This chapter describes the following major safety-related systems of the US-EPR design:

- Safety injection system (SIS)/residual heat removal system (RHRS),
- Component cooling water system (CCWS),
- Essential service water system (ESWS),
- Emergency feedwater system (EFWS),
- Extra borating system (EBS), and
- Fuel pool cooling and purification system (FPCPS).

The first five systems listed above can be involved in the mitigation of potentially core-damaging accidents and provide the means to execute a safe shutdown of the plant. The last system has the safety-related function of removing decay heat from the spent fuel pool. The SIS/RHRS, CCWS, ESWS, EFWS, and EBS are illustrated in the composite fluid system diagram of Figure 5-1.

The SIS/RHRS, CCWS, and ESWS are arranged into four separate trains based on the N+2 safety philosophy. This philosophy provides that:

- One train may be out of service for maintenance,
- One train may fail to operate (single-failure criterion), and
- One train might be rendered ineffective as a consequence of the accident.

This combination of impaired trains leaves one 100%-capacity train available to mitigate the accident.

The design of the four-train EFWS differs slightly from the totally independent four-train safety concept. Two remaining operable EFWS trains supplying two steam generators (SGs) are adequate for decay heat removal, given a single failure of one EFWS train and the unavailability of a second train due to maintenance, with operator action as necessary to redirect feedwater flow from an SG affected by an accident to an intact SG.

The four-train arrangement for these systems, corresponding to the four-loop configuration of the reactor coolant system (RCS), leads to a simplified design in that each system is connected to a single loop (or SG) with no or limited operator action required to balance flow between loops. This arrangement also allows flexibility and redundancy during plant shutdown conditions when capacity requirements for heat removal and other functions are reduced relative to the needs associated with normal power operations. The four-train configuration also allows extending maintenance intervals on parts of the systems; this practice can be beneficial for preventive maintenance or general repair requirements. For instance, preventive maintenance of one complete safety train can be performed during power operation.

The major components of the SIS/RHRS (except the accumulators in the reactor building), the CCWS, and the EFWS, and portions of the ESWS are housed in train-specific safeguard buildings. These Seismic Category I buildings are physically separated to protect the systems necessary for reaching safe shutdown in the event of an external hazard such as an aircraft crash or an explosive pressure wave. Structural separation also protects the safety trains within each building from an internal hazard, such as a fire, a high-energy line break, or flooding, that occurs within another safeguard building. Each building is divided into a “hot” mechanical area housing systems containing potentially radioactive fluids, and a radiologically separate “cold” electrical area containing systems not expected to be contaminated as well as electrical and instrumentation and control equipment. The building arrangement is illustrated in Figure 5-2.

Four train-specific essential service water (ESW) buildings house the ESW pumps, suction sources, and cooling towers of the four ESWS trains. These structurally separate, Seismic Category I buildings are arranged with two on one side of the reactor building and two on the opposite side.

The EBS and the fuel pool cooling portion of the FPCPS are arranged in two-train (divisions 1 and 4) configurations. In each system, each 100%-capacity train is housed in a physically separate area of the fuel building. The Seismic Category I, crash-hardened fuel building protects the systems within from external hazards.

5.2 Safety Injection System

The safety injection system provides emergency core cooling for the US-EPR. Four supply-and-return trains comprise the system, one for each of the reactor coolant system loops. Individually, each of these trains can supply the required core cooling. The four supply trains, which serve the safety injection function, charge through parallel paths from a low head safety injection (LHSI) pump, a medium head safety injection (MHSI) pump, and an accumulator in each train. The injection pumps draw water from the in-containment refueling water storage tank (IRWST) in satisfying their emergency functions.

The MHSI pumps and the accumulators inject directly into the cold legs. The LHSI pumps inject through the LHSI heat exchangers to the cold legs. Closed-loop cooling (in the residual heat removal mode) for post-accident heat removal is also available by aligning the LHSI pump suctions to the RCS hot legs. The LHSI pump discharges may be realigned during accident recovery for hot-leg injection to prevent boron precipitation and to mitigate steaming from the break.

The residual heat removal (RHR) function of the SIS/RHRS for normal shutdown cooling of the reactor is described in section 5.3.

5.2.1 Design Bases

The SIS limits fuel assembly damage during core flooding and emergency core cooling following a loss-of-coolant accident (LOCA). The SIS removes post-accident decay heat from the RCS and provides post-accident containment cooling via the LHSI heat exchangers. The system consists of four independent and separated trains, each housed and protected in its own seismically qualified safeguard building. This separation and independence provides protection from physical damage due to natural phenomena and hazards and allows fulfillment of the system safety functions in the event of a single failure.

Following postulated LOCAs, the SIS satisfies the emergency core cooling system acceptance criteria specified in 10 CFR 50.46. SIS actuation mitigates the following postulated transients, accidents, and operational events:

- Main steam line break (MSLB): Following a small or large MSLB, the MHSI trains provide RCS boration and coolant inventory control during the plant cooldown.

- Steam generator tube rupture (SGTR): Following an SGTR, the MHSI trains inject borated water to provide sufficient coolant inventory.

- Small-break LOCA (SBLOCA, break size less than or equal to 0.5 ft^2): The SIS, in conjunction with the automatic secondary-side partial cooldown, provides borated coolant injection, which limits RCS draining and keeps the core covered and cooled throughout the event. The system provides this function even if there is a loss of a train due to the most limiting single failure coincident with one train unavailable because of maintenance.

- Large-break LOCA (LBLOCA, break size greater than 0.5 ft^2 up to a complete rupture of an RCS hot or cold leg): To avoid exceeding the limits of 10 CFR 50.46, the SIS provides sufficient core cooling even if there is a loss of a train due to the most limiting single failure coincident with one train being unavailable due to maintenance.

- Inadvertent opening of a pressurizer safety relief valve (PSRV): The MHSI pumps provide RCS makeup in the event of an inadvertent opening of a PSRV.

- RCS loop level decrease during shutdown or mid-loop operation: The MHSI pumps provide RCS makeup in the event of a spurious draining of the RCS or a SBLOCA during shutdown cooling operations. To compensate for the reduced pressure and makeup flow requirement for this operational condition, the large MHSI minimum flow line opens prior to injection to reduce the MHSI injection head. RCS pressure remains below approximately 580 psia during this event.

The SIS and its support and ancillary systems are designed, fabricated, erected, and tested to quality standards commensurate with the importance of the safety functions to be performed. Appropriate to its reactor core cooling function, the SIS is:

- Designed to codes consistent with the quality group classification assigned by RG 1.26;

- Protected from the effects of natural phenomena such as earthquakes, tornadoes, hurricanes, floods, and external missiles, and designed to function following such events (GDC 2);

- Designed to the Seismic Category I designation assigned by RG 1.29, so that it remains functional after a safe shutdown earthquake (SSE) (GDC 2);

- Designed to remain functional following the postulated hazards of fire and explosion, internal missiles, pipe whipping, and discharging fluids (GDC 3 and GDC 4);

- Provided with both onsite and offsite electric power systems, each of which can alone power the SIS to its full capacity (GDC 17);

- Capable, in combination with the extra borating system, of adding sufficient neutron poison to reliably control reactivity changes and maintain core cooling under postulated accident conditions, with an appropriate margin for stuck control rods (GDC 27);

- Designed to remain functional in the event of a single active component failure coincident with the loss of either the onsite or offsite power source (GDC 35);

- Designed to permit appropriate periodic pressure and functional testing to confirm the structural and leak-tight integrity of its components, the operability and performance of its active components, and the operability of the system as a whole; and

- Designed, principally through the features built into the in-containment refueling water storage tank, to reduce the containment pressure and temperature following a LOCA and to maintain them at acceptably low levels (GDC 38), and to provide long-term post-LOCA core cooling as required in 10 CFR 50.46(b)(5).

The SIS design and analysis incorporates resolution of the relevant safety issues specified in NUREG-0933. The SIS design incorporates operating-experience insights from applicable generic letters and bulletins.

The discharge head for the SIS accumulators and the discharge heads and delivery flow rates for the LHSI and MHSI pumps are listed in Tables 5-1, 5-2, and 5-3. The SIS provides core cooling capability for a wide spectrum of LOCAs, considering the hydraulic flow resistances of the SIS piping and valves and the available net positive suction heads. The volume of the IRWST, as listed in Table 5-4, provides sufficient borated water for long-term core cooling. In addition, the boron concentration in the IRWST, in combination with the EBS, provides sufficient negative reactivity to keep the core subcritical.

5.2.2 System Description

The SIS consists of four independent trains, designated as trains 1, 2, 3, and 4, with each train supplying one reactor coolant loop. The four trains are separated into four safety divisions and are functionally identical, as shown in Figures 5-3, 5-4, and 5-5. The IRWST arrangement is shown in Figure 5-6.

Each SIS train has separate MHSI and LHSI pump trains and an accumulator injection train. The MHSI and LHSI pump trains share an isolable suction line from the IRWST. The three-way valve in the suction line aligns the IRWST to both the MHSI and the LHSI pump suctions when in the open position. The LHSI pump train includes a heat exchanger and a suction line from the RCS hot leg for residual heat removal, which may be realigned for LHSI hot-leg injection. Each train’s discharge lines for the MHSI and LHSI pumps and the accumulator combine to share an injection nozzle on their associated RCS cold leg.

LHSI discharge cross-connecting lines between trains 1 and 2 and between trains 3 and 4, which are normally isolated by two motor-operated valves in series to maintain train separation, enhance system performance when SIS injection is demanded after an individual train has been removed from service for maintenance. Each cross-connect provides an alternate injection path for the train that remains in service. This configuration mitigates the effect of degraded safety injection due to steam entrainment during a LOCA, when the only available LHSI injection path (considering one train is unavailable due to single failure, another is unavailable due to maintenance, and a third train feeds the broken loop) is located adjacent to the broken loop. During such maintenance activities, both motor-operated valves of the cross-connecting line are secured open (breakers racked out) for protection against active single failures.

Component cooling water (CCW) is the cooling medium for the LHSI heat exchangers (all four trains), the MHSI pump motor coolers (all four trains), and the LHSI pump motor and seal coolers for trains 2 and 3. The safety chilled water system (SCWS) provides cooling water to the LHSI pump motor and seal coolers for trains 1 and 4. Essential service water serves as the final cooling medium, rejecting the heat transferred from the CCWS to the ultimate heat sink.

The four SIS trains are powered, respectively, by electrical divisions 1 through 4. Each electrical division has a separate and independent power supply housed and protected in the associated safeguard building. Each electrical division is also supplied by its assigned emergency diesel generator in the event of a loss of offsite power (LOOP).

Each MHSI train consists of a pump, an isolable supply branch from the shared IRWST suction line, and a discharge line that tees into its respective cold-leg LHSI injection line just upstream of the inboard LHSI-to-RCS isolation check valve. A line branching from the injection line, at a point upstream of the inboard MHSI-to-LHSI injection isolation valve, directs flow to the IRWST. This line branches into two flow paths, the smaller one for pump minimum flow protection and the larger one for reducing the MHSI discharge head. A line for filling the accumulator branches from the minimum flow protection line upstream of its maintenance isolation valve. A control valve, located between the tee to the mini-flow branch lines and the inboard MHSI-to-LHSI injection isolation valve, allows for manual throttling of the MHSI flow, if so required, during long-term post-accident management.

Each accumulator injection train has one accumulator, whose isolable injection line joins the respective cold-leg LHSI injection line just upstream of the inboard LHSI-to-RCS isolation check valve.

The LHSI train consists of an LHSI pump, an LHSI heat exchanger, an LHSI heat exchanger bypass line with flow control valve, a shared suction line from the IRWST with a motor-operated isolation valve, an LHSI heat exchanger discharge line with a temperature control valve, an RCS hot-leg suction line, a discharge cross-connect to another train, and various isolation and realignment valves as required to support operation, maintenance, shutdown, and accident mitigation. A minimum flow and test line branches from the cold-leg injection line upstream of the outboard LHSI-to-RCS isolation check valve. A control valve, located between the tee to the mini-flow line and the outboard LHSI-to-RCS isolation check valve, allows for manual throttling of the LHSI flow, if so required, during long-term post-accident management.

The SIS piping is protected from overpressure events by safety relief valves installed at the locations most susceptible to such events. The design overpressure transient is the spurious startup of an MHSI pump with the large head-reducing line isolated. The setpoints and capacities for these safety relief valves limit the protected piping to 110% of its design pressure.

5.2.3 Component Descriptions

5.2.3.1 Accumulators

Each accumulator is an austenitic stainless steel tank with a total volume of approximately 1950 ft^3 and is filled with approximately 1250 - 1400 ft^3 (approximately 10,000 gal) of borated water and approximately 550 - 700 ft^3 of pressurized nitrogen. The nominal operating pressure is 665 psig. The accumulators are designed so that the nitrogen pressure after injection is lower than the LHSI discharge pressure. Thus, they do not inject nitrogen into the RCS prior to the commencement of LHSI injection, even in the unlikely event of the loss of MHSI pumps. The relevant accumulator design and performance data are presented in Table 5-1.

5.2.3.2 SIS Pumps

The LHSI and MHSI pumps are horizontally mounted, centrifugal pumps with single mechanical seals. Their motors are cooled by the CCWS, with the exception of the LHSI pumps for trains 1 and 4, which are cooled by the SCWS. The nominal flow rate for an LHSI pump is approximately 2200 gpm at 480 ft of total developed head; for the MHSI pump it is approximately 600 gpm at 2260 ft of total developed head. The relevant LHSI and MHSI pump design and performance data are presented in Tables 5-2 and 5-3, respectively.

5.2.3.3 LHSI Heat Exchangers

In the U-tube-type, horizontally mounted LHSI heat exchangers, reactor coolant flows through the austenitic stainless steel tubes, and CCW flows through the ferritic shells. The relevant heat exchanger design and performance data are presented in Table 5-5. Conservative fouling factors are incorporated into the performance evaluation of the LHSI heat exchangers.

5.2.3.4 In-Containment Refueling Water Storage Tank

The IRWST is an open pool within a partly immersed building structure. It is located at the bottom of the containment between the reactor pit and the secondary shield wall, below the level of the heavy floor which supports the primary components. It is connected to various safety-relayed and nonsafety-related systems and serves as a water source, heat sink, and return reservoir. Select design data for the IRWST are shown in Table 5-4.

The IRWST supplies borated water to the SIS, the severe accident heat removal system (SAHRS), and the chemical and volume control system (CVCS). It also supplies the fuel pool cooling system (FPCS) via the CVCS suction line. The IRWST provides the necessary inventory of borated water for design-basis events. It contains a minimum of 66,886 ft^3 of borated water. The level, temperature, and homogeneous boron concentration of the contained volume are monitored. The water is used for both refueling and SIS operations and provides:

- Sufficient water during plant shutdown to fill the reactor cavity, the internal storage pool, the reactor building transfer pool, and the RCS;

- Sufficient water depth (static pressure head) at the suctions of the SIS, SAHRS, and CVCS pumps during normal and accident conditions (per RG 1.1); and

- A heat sink and water inventory for flooding the core melt in the spreading area during a beyond-design-basis event (severe accident).

The walls of the IRWST are lined with an austenitic stainless steel liner covering the immersed region of the building structure. The liner prevents leaks and the interaction of the boric acid with the concrete structure. Any leaks that do occur are collected, monitored, and quantified by the Nuclear Island drain and vent system.

The IRWST is provided with the following three filtering stages for the borated water return path to its integral sumps, as shown in Figure 5-7:

- The trash racks and weirs above the heavy floor openings to the IRWST are considered components of the IRWST. After a LOCA, the flow of coolant out of the RCS back to the IRWST passes through four openings in the heavy floor. The trash racks prevent large debris from entering the IRWST, while the weirs provide barriers that retain sediment and debris on the heavy floor.

- Retaining baskets in the IRWST below each heavy floor opening trap debris transported past the trash racks and weirs. Two of the retaining baskets also filter flow from the annular space in containment to the IRWST. The openings in the retaining baskets provide efficient retention of fibrous and particulate debris. A gap between the top of each basket and the heavy floor provides a flow path if the retaining basket is full or clogged.

- The SIS and SAHRS strainers are arranged above the respective SIS and SAHRS sumps. These strainers are designed as large cages with inclined sieves to facilitate debris detachment during backflushing. The opening size of the sieves limits the passage of debris during SIS and SAHRS recirculation flow to avoid pump malfunction and clogging of the smallest restriction in the core. The CVCS sump is also provided with a suction strainer.

The large dispersion area within the IRWST results in low flow velocities and promotes the settling of fine debris that passes through the retaining baskets.

The IRWST sump screen flow performance has been evaluated to verify that adequate long-term core cooling remains available in spite of impairment by accident-generated debris as well as debris in containment prior to the accident. The increased use of reflective metal insulation, which is not subject to transport to the SIS sumps, in the US-EPR design in place of most or all of the fibrous or micro-porous insulation assumed in the evaluation further reduces the potential for post-accident blockage of the sumps. The features of the IRWST screen design conform to RG 1.82 and address the issues of GSI-191. Technical Report ANP-10293, “U.S. EPR Design Features to Address GSI-191,” provides additional descriptions of the US-EPR design features that limit the impact of post-accident debris accumulation on SIS performance, summarizes the performance evaluations and component test program, and compares the design to the regulatory positions of RG 1.82 and the information requested by GL 2004-02.

The performance of the strainers is enhanced by cleanliness programs that limit debris in the containment. A COL applicant that references the US-EPR design certification will describe the containment cleanliness program which limits debris within containment. This program consists of controls on modifications to ensure that SIS performance complies with regulatory requirements, controls for foreign material exclusion, controls to assess and manage maintenance activities so that debris is not introduced into containment, and controls on the introduction of coatings into containment.

Coolant pH adjustment baskets containing granulated trisodium phosphate dodecahydrate (TSP-C) are strategically placed in the inlet flow paths to the IRWST within the boundary perimeter of the weirs at the four heavy floor openings of the reactor building. Flow through the baskets dissolves the TSP-C into the coolant that returns to the IRWST to passively neutralize entrained acids and to maintain the alkalinity of the coolant. The pH of the recirculated coolant is maintained above 7.0. The control of pH in the recirculated coolant reduces the potential for stress-corrosion cracking of austenitic stainless steel components, limits the generation of hydrogen attributable to the corrosion of containment metals, and minimizes the re-evolution of iodine in the post-LOCA containment solution, thereby maintaining the radioiodine in solution to reduce radioactive releases to the environment. The minimum amount of granulated TSP-C is 12,200 lbm.

The IRWST is connected to the molten core spreading area by pipes that are isolated during normal operation and accident conditions. If a severe accident occurs and molten material reaches the spreading area, an actuation device melts, flooding valves open, and IRWST water flows into the spreading area to support operation of the SAHRS. The IRWST is located at a higher elevation than the core spreading area to provide gravity flooding of the spreading area with the IRWST water inventory. The core spreading area and the SAHRS are described in Chapter 6.0.

5.2.4 System Operation

During normal at-power operation, the SIS is idle but configured for rapid automatic or on-demand response. The four cold-leg injection and IRWST suction flow paths are open, the hot-leg suctions or alternate injection paths are isolated, and CCWS and SCWS cooling for the SIS pumps and equipment areas is in service or available to start on receipt of a demand signal. The SIS is isolated from the RCS cold legs by its boundary check valves, which are back-seated by RCS pressure.

During shutdown cooling operations, MHSI trains are maintained in standby to make up for potential RCS leakage, with the CCWS available for pump and area cooling. The large minimum flow valves remain open to limit the MHSI injection pressure and flow rates to levels appropriate for the shutdown condition.

The most demanding SIS performance responses, which bound the responses required for other accidents, are the responses to the range of SBLOCAs and the response to the most limiting LBLOCA. For that reason, SIS performance has been evaluated for only these two most limiting events. These analyses show that the performance of the SIS limits the accident consequences to accommodate recovery, to protect the health and safety of the public, and to meet regulatory requirements.

5.2.4.1 Small-Break LOCA

The most limiting SBLOCA is a break with a cross-sectional area of up to approximately 0.5 ft^2 in a cold leg between the SIS injection location and the reactor pressure vessel, with a coincident LOOP. Such an event may not immediately challenge the SIS if the reactor coolant loss can be made up by injection from the CVCS. The loss of primary coolant eventually results in decreases in primary system pressure and pressurizer level, sequentially triggering a reactor and turbine trip and the closure of the main feedwater full-load isolation valves. Upon receipt of an SIS actuation signal, a partial cooldown of the secondary system, and thus the RCS, is initiated. During this sequence, the steam generators are fed by the emergency feedwater system, which is actuated by a protection system signal.

The SIS actuates on low pressurizer pressure, and the MHSI and LHSI pumps automatically start. During the partial cooldown, the RCS pressure decreases sufficiently to allow MHSI into the cold legs. The partial cooldown is performed by the available steam generators via steam relief to the atmosphere. The protection system automatically decreases the main steam relief train setpoints to a fixed pressure that is low enough to permit MHSI, but high enough to prevent core recriticality due to low RCS temperature. For the smallest of these breaks, the RCS leakage, still in liquid form, does not remove sufficient coolant mass to offset injection flow, and the RCS depressurization stops at the end of the partial cooldown. If the MHSI flow rate is insufficient to compensate for the break flow rate, the RCS inventory continues to decrease. The break flow rate decreases as the void fraction in the cold legs increases. When the break flow changes to single-phase steam, the ratio between steam production due to core decay heat and steam break venting changes, and the break size is the dominant parameter for the depressurization sequence.

For the smallest breaks, condensation in the steam generator tubes, in combination with direct steam venting from the break, eventually balances the production of steam in the core to the point that the RCS saturation pressure plateaus at a value slightly above the steam generator secondary-side pressure. For larger small breaks, steam venting is sufficient, regardless of the steam generator secondary-side temperature, to depressurize the RCS to the point where accumulator injection, and eventually LHSI, occurs.

5.2.4.2 Large-Break LOCA

The most limiting LBLOCA is a break in the cold-leg piping between the reactor coolant pump (RCP) and the reactor vessel for the RCS loop containing the pressurizer. The break is assumed to open instantaneously. For this break, rapid depressurization of the primary system occurs. The automatic partial cooldown is unnecessary due to the rapid depressurization caused by the break.

The SIS actuates on receipt of a low pressurizer pressure signal. The most limiting single failure for this event is the loss of one SIS train (i.e., loss of one MHSI pump and one LHSI pump). Because one other train is conservatively assumed to be unavailable due to maintenance or other activity, only two pump trains are available for the event. All four accumulators are assumed to be available, as accumulator maintenance is prohibited during power operation and the downstream accumulator isolation valves are secured open (breakers racked out) to protect against an active single failure.

When the RCS pressure falls below the accumulator pressure, fluid from the accumulators is injected into the cold legs. SIS pumps inject into the RCS when pump-start time delays have elapsed and the primary system pressure has fallen below the respective shutoff heads of the MHSI and LHSI pumps. While some of the SIS injection bypasses the core and goes directly out of the break, the vessel downcomer and lower plenum gradually refill. During this refill phase, heat is primarily transferred from the hotter fuel rods to cooler fuel rods and structures by radiative heat transfer.

When the lower plenum is refilled to the bottom of the fuel rod heated length, the refill phase ends and the reflood phase begins. The SIS-injected fluid accumulating in the downcomer provides the driving head to move coolant through the core. As the water/steam interface moves up the core height, steam is generated, and liquid is entrained in the steam. As this entrained liquid is carried into the SGs, it vaporizes because of the higher temperature in the SGs. This causes steam binding, which reduces the core reflooding rate. The fuel rods are cooled and quenched by radiation and convective heat transfer as the quench front moves up the core. Long-term recirculation cooling is maintained by the LHSI trains.

5.2.4.3 Manual Actions

The SIS injects automatically in response to a safety injection actuation signal and requires no operator intervention to accomplish its safety functions. The emergency coolant supply is initially enclosed within the containment and is constantly replenished by recirculated coolant flow during an accident; therefore, no operator action is required to continuously supply coolant or to remove decay heat during the injection phase.

To prevent boron precipitation and to mitigate steaming from the break, a manual switchover to hot-leg injection is required approximately one hour into the event. This action represents the response to the most severe of the postulated events, such as a LBLOCA.

For less severe events such as SBLOCAs, automatic action is adequate to manage the event. After completion of the initial automatic response, it may be beneficial to manage the event with deliberate operator action. For instance, while the protection system initiates a reactor trip and SIS actuation following an SBLOCA, it may be possible, depending on the scale of the event, to identify and isolate the failed component, thereby terminating the event and allowing safe shutdown without further challenges to the safety systems. Such actions are in accordance with approved procedures.

5.3 Residual Heat Removal System

The safety injection system/residual heat removal system removes residual heat from the core and the RCS during normal shutdowns and accident conditions. This section describes the residual heat removal function of the SIS/RHRS. The emergency core cooling function of the SIS/RHRS is discussed in section 5.2.

5.3.1 Design Bases

The heat removal function of the SIS/RHRS provides for the cooldown of the RCS during normal shutdown operations after secondary-side heat removal by the steam generators has been completed. The heat removal function maintains the reactor coolant temperature within allowable limits for refueling and maintenance activities, including mid-loop operation. The RHR function of the SIS/RHRS also provides a flow path to the chemical and volume control system for low pressure purification and mixing of the reactor coolant during shutdown operations. The SIS/RHRS also fills the reactor cavity and the SIS accumulators.

The US-EPR systems are designed to reduce RCS temperature from the at-power operating value (approximately 575°F) to approximately 131°F in 40 hours when the entire SIS/RHRS is operable, and to establish conditions that allow the removal of the reactor pressure vessel (RPV) head and the initiation of refueling operations within approximately 90 hours after initial reactor shutdown.

The US-EPR systems, with the SIS/RHRS providing its heat removal function, are capable of bringing the reactor to a cold shutdown condition using only safety-related equipment, with only offsite or only onsite power available, within a reasonable period of time following a shutdown, assuming the most limiting single failure (BTP 5-4).

The SIS/RHRS is designed, fabricated, erected and tested to quality standards commensurate with the importance of the safety-related functions to be performed (GDC 1, 10 CFR 50.55a(a)(1)), and remains functional after a safe shutdown earthquake, in accordance with RG 1.29 (GDC 2).

The low head safety injection pump suction piping from the RCS hot legs to the LHSI pumps is designed to be self venting to prevent the formation of loop seals (voids) within the piping. Similarly, the suction piping from the IRWST for both the LHSI and the MHSI pumps is designed to be self venting to preclude voids within the piping when the SIS/RHRS is aligned for the emergency core cooling function. Therefore, the entire shutdown cooling loops remain flooded when connected to the RCS, protecting the LHSI pumps from suction cavitation and the piping from water hammer (due to voiding) during shutdown cooling operations (GDC 4).

The RHR function of the SIS/RHRS is controlled from the main control room for all operating conditions (GDC 19). The SIS/RHRS can also be controlled from the remote shutdown station.

The RHRS is designed to transfer fission product decay heat and other residual heat from the reactor core at a rate such that acceptable fuel design limits and the design conditions of the reactor coolant pressure boundary (RCPB) are not exceeded.

The SIS/RHRS interfaces with the RCPB. This interface is considered part of the RCPB. The SIS/RHRS provides containment isolation when required.

5.3.2 System Description

Four physically separated and independently powered RHR trains comprise the RHRS. The instrumentation and controls used to manage the operation of the RHRS are separated and derive inputs from independent sources for process variables such as RCS pressure and temperature. The instrumentation and controls are independently powered from the same normal and emergency sources that power the associated motive equipment. Schematic piping and instrumentation diagrams for the four RHRS trains are shown in Figures 5-3 through 5-6.

The RHR function of the SIS/RHRS constitutes a single mode of operation with a temperature-controlled variable flow rate and operating temperatures and pressures that vary throughout its normal operating range.

The shutdown cooling loop of each RHRS train consists of an LHSI pump, an LHSI heat exchanger, an LHSI heat exchanger bypass line with a flow control valve, an LHSI heat exchanger discharge line with a temperature control valve, and a suction line from an RCS hot leg. Various isolation valves support maintenance or operational activities, including realignment for shutdown or accident mitigation.

Minimum flow and test lines, which are isolated during RHR operation, branch from the cold-leg injection line upstream of the outboard SIS/RHRS-to-RCS isolation valve. A CVCS letdown line, to accommodate expansion and shrinkage of the fluid in the corresponding RHRS train during shutdowns and startups, connects to the SIS/RHRS cold-leg injection and hot-leg suction lines between the RCPB isolation valves of each train.

The four RHRS trains are functionally identical except for additional CVCS letdown connections from the LHSI heat exchanger discharge and bypass lines of Trains 3 and 4.

For shutdown cooling operations, the LHSI pump of each RHRS train takes suction from the corresponding RCS hot leg, pumps the hot reactor coolant through the corresponding LHSI heat exchanger, where it is cooled by the corresponding CCWS train, and returns the reactor coolant to the RCS through the corresponding cold leg. Interlocks (permissive P14, refer to Chapter 8.0) prevent alignment of the RHRS to the RCS while RCS pressure and temperature are greater than approximately 464 psia and 350°F, respectively This feature protects the RHRS components from overpressure due to exposure to the RCS pressure during reactor operation (intersystem LOCA).

The initial stage of RCS cooldown is accomplished with SG cooling. Two trains of the RHRS are normally placed in service at an RCS pressure and temperature of approximately 390 psia and 250°F, respectively. The remaining two trains are placed in service after the RCS temperature has been further reduced to approximately 212°F. If main steam bypass is unavailable, the RHRS can be placed in service after RCS temperature is reduced to approximately 275°F.

For mid-loop operations, the RHRS is designed to maintain the RCS temperature below approximately 131°F with the CVCS automatically maintaining the RCS level.

Level sensors mounted on the RCS hot legs trip the LHSI pumps on low loop level, and the MHSI pumps automatically inject at a reduced discharge head in the event of an uncontrolled loss of coolant during mid-loop operations.

The redundancy of the RHRS design provides the capability to isolate affected sections of individual trains as required. Automatic isolation of the system, which could adversely impact the system's RCS cooling function, is not provided. Manual isolation capability is provided by series pairs of independently powered valves installed in each suction line.

During RHRS operation, the RCS is protected from overpressure by the pressurizer safety relief valves. A spring-loaded safety relief valve on the shutdown cooling suction piping of each RHRS train protects the system from overpressure when it is connected to the RCS. The setpoints and capacities for these safety relief valves limit the piping pressure to 110% of its design pressure. Fluid discharges through RHRS safety relief valves are collected and contained in the IRWST, such that flooding of any safety-related equipment does not occur, the capability of the emergency core cooling function of the SIS/RHRS needed to mitigate the consequences of a postulated LOCA is not reduced, and the water provided to the RCS to maintain the core in a safe condition is not discharged outside of the containment (BTP 5-4).

Physical separation for each of the trains is accomplished by locating the trains in separate safeguard buildings. Physical separation of the trains protects the system from an internal flooding hazard, which would be limited to a single division. The SIS/RHRS equipment inside the reactor building is located above the flooding level that results from a pipe failure.

5.3.2.1 Design Features Addressing Shutdown and Mid-Loop Operations

The design features of the US-EPR that support improved safety during shutdown and mid-loop operations, addressing NRC Generic Letter 88-17 and SECY 93-087, are as follows:

- Inherent redundancy in the design of the four-train RHRS, with each train having separate RCS connections,

- Automatic stop of the LHSI pumps operating in the RHR mode in the event of a low loop level or low ΔP_{sat} (difference between the RCS hot-leg temperature and the RCS hot-leg saturation temperature),

- Manual opening and closure of the RHR suction isolation valves (in addition to interlocks), which prevent unwanted RHRS alignments and allow isolation on irregular RCS pressure,

- Safety injection via MHSI with reduced discharge head during low loop level conditions, ensuring the availability of the LHSI pumps for the RHR function,

- Automatic isolation of the RHRS connections to the RCS in the event of a break outside of the containment, based on indications from the safeguard building sump level and pressure sensors,

- Spring-loaded safety relief valves, located on the RHRS hot-leg suction lines, which protect the SIS/RHRS against overpressurization when operating in the RHR mode,

- Redundant hot-leg level sensors that initiate RCS makeup on low RCS hot-leg level,

- During mid-loop operation, control of RCS loop level by the CVCS low pressure reducing valve to ensure that there is sufficient RCS water inventory for operation of the LHSI pumps in the RHR mode,

- A level sensor that continually monitors the reactor pressure vessel water level during outages, and

- Temperature sensors at the RCS hot legs which allow temperature monitoring of each hot leg with the plant in a reduced-inventory condition.

5.3.2.2 Design Features Addressing Intersystem LOCA

The design features of the SIS/RHRS that address the intersystem LOCA section of SECY 93-087 and SECY 90-016 are as follows:

- Codes and standards/seismic protection: The portions of the SIS/RHRS interfacing with the RCS and located outside the containment building (in the safeguard buildings) are classified as Quality Group B and Seismic Category I, so that the design, manufacture, installation, and inspection of this pressure boundary is in accordance with the ASME Boiler and Pressure Vessel Code, Section III, Class 2 Components.

- Increased design pressure: The portions of the SIS/RHRS from the RCS to the second reactor coolant pressure boundary isolation valves are designed to the RCS design pressure, and are classified as Quality Group A (ASME Boiler and Pressure Vessel Code, Section III, Class 1 Components) and Seismic Category I. This feature provides an additional barrier between the RCS and the lower pressure portions of the SIS/RHRS. The remaining portions of the SIS/RHRS are designed so that their ultimate rupture strength exceeds that of the full RCS operating pressure.

- Features preventing inadvertent opening of RCPB isolation valves: The first two RCPB isolation valves on each RHR hot-leg suction line are interlocked to prevent their opening at an RCS pressure and temperature above approximately 464 psia and 350°F, respectively. The positions of these valves are indicated in the control room. The first two RCPB isolation valves on each SIS/RHRS discharge line are check valves that allow only one-way flow.

- SIS/RHRS safety relief valves: The SIS/RHRS safety relief valve on each RHR hot-leg suction line is designed to provide overpressure protection for the system, particularly against overpressurization during operation in the RHR mode.

5.3.3 System Operation

Prior to a normal cooldown, the reactor is shut down by insertion of the rod cluster control assemblies. The cooldown of the RCS must not exceed 90°F/hr, while the cooldown of the pressurizer must not exceed 212°F/hr. In the early stages of the cooldown, all four reactor coolant pumps are in operation for mixing of the coolant in the RCS, the pressurizer level is automatically maintained by control of the CVCS letdown flow, the primary pressure is automatically adjusted by the main spray flow and the pressurizer heaters, and residual heat is removed by the steam generators. The steam generator levels are maintained by the main feedwater system.

Automatic cooldown of the RCS by the secondary systems from the hot standby mode to the RHRS initiation point is accomplished in parallel with the automatic RCS depressurization via the pressurizer. In this phase, reactor coolant makeup is performed by the CVCS, pressurizer level is automatically controlled in the CVCS letdown line, and steam generator levels are controlled by the startup and shutdown feedwater system.

Two RCPs are tripped when the RCS temperature decreases to 250°F, another RCP is tripped when the RCS temperature decreases to 158°F, and the last RCP is tripped when the RCS temperature decreases to 122°F (nominal analysis temperature values).

Two trains of the RHRS are normally placed in service when the RCS pressure and temperature decrease below approximately 390 psia and 250°F, respectively. The remaining two trains are placed in service after the RCS temperature has been further reduced to approximately 212°F.

The time required to cool the plant down to approximately 250°F is around 7.3 hours after reactor trip, while the time required to cool the RCS temperature down to approximately 131°F, using all four RHRS trains, is another 7.7 hours. The total time to cool the plant down to 131°F (for refueling) is approximately 15 hours after a reactor trip. This total time is much shorter than the 40 hours specified as a design basis.

5.4 Component Cooling Water System

The component cooling water system is a closed-loop cooling water system that, in conjunction with the essential service water system and the ultimate heat sink (UHS), removes heat generated from safety-related and nonsafety-related components. Heat transferred by these components to the CCWS is rejected to the ESWS via the component cooling water heat exchangers.

The four safety-related trains of the CCWS cool safety-related equipment, as required, during all phases of operation. Two nonsafety-related branches of the CCWS cool the common users located inside the fuel building, reactor building, radioactive waste processing building, and nuclear auxiliary building. The four independent safety-related trains provide sufficient capability that the loss of one train from a single component failure, with a second train out of service for maintenance, does not impair the ability of the CCWS to meet its safety-related functional requirements.

One additional nonsafety-related train comprises the dedicated CCWS that cools the severe accident heat removal system.

The CCWS fluid serves as a barrier that prevents radioactive fluid from leaking from the components it cools to the environment. It also serves as a barrier against the leakage of untreated service water into the containment or into reactor systems.

5.4.1 Design Bases

The CCWS safety-related trains are:

- Protected from the effects of natural phenomena such as earthquakes, tornadoes, hurricanes, floods, and external missiles, and designed to function following such events (GDC 2),

- Designed as Seismic Category I per RG 1.29 and therefore remain functional after a safe shutdown earthquake (GDC 2),

- Designed to remain functional in spite of the postulated hazards of internal missiles, pipe whipping, and discharging fluids (GDC 4),

- Designed to remain functional despite a single active component failure coincident with the loss of either the offsite or the onsite power source (GDC 44),

- Designed to permit isolation of lines that penetrate the primary containment to maximize containment isolation integrity (GDC 57), and

- Aligned to provide cooling to the thermal barriers of the reactor coolant pump seals during all plant operating modes when the RCPs are running.

The nonsafety-related dedicated CCWS train is available on demand, in the unlikely event of a severe accident, to cool the SAHRS.

5.4.2 System Description

The CCWS is a four-train system configured to allow sharing of operational and safety-related users among the trains during normal operation, while always maintaining train separation with rapid isolation capability of the nonsafety-related users in the event of an accident. The trains are configured in pairs; trains 1 and 2 comprise one pair, and trains 3 and 4 comprise the other pair. During normal operation, one or both trains in each associated pair can be in operation to cool the two common sets of users. Depending on the system user requirements, heat loads, and flow rates, and depending on the existing plant operating condition, the CCWS may have two, three, or all four trains in operation. System design parameters and flow requirements are listed in Tables 5-6 and 5-7.

Trains may be placed in service or shut down as necessary to maintain the CCWS heat exchanger outlet temperatures above the minimum required and below the maximum allowed values, and to maintain the individual CCWS pump steady-state operating flows between the minimum required and the maximum allowed values. Idle CCWS trains are available, isolated from the common headers, and ready to provide support of a safety injection system actuation if necessary. Maintenance on a CCWS train during power operation is possible.

During normal operation and design-basis events, the CCWS provides the cooling function for the safety injection system/residual heat removal system and for divisions 2 and 3 of the safety chilled water system. The CCWS also transfers decay heat from the fuel pool cooling system whenever fuel is stored in the spent fuel pool. The CCWS additionally cools the thermal barriers of the RCP seals during all plant operating modes when the RCPs are running. Upon receipt of a containment isolation signal, the CCWS responds to protect the integrity of the containment pressure boundary.

The CCWS flow rates are automatically controlled for those users which have been determined to have a limited operating temperature range for support of stable operation, while the flows to less temperature-sensitive users are fixed during all operating conditions. These fixed flow rates are adjusted once during plant commissioning with the system in its most demanding flow configuration (system flow balancing), and are reaffirmed regularly throughout the plant life by periodic surveillances, to ensure that there are adequate required user flows for all operating conditions. It is not expected that the CCWS flows will require adjustment after the initial flow balance has been established.

Leaks into or out of the CCWS are apparent from various indications and must be promptly isolated for repair or other corrective action. For instance, leakage of reactor coolant into the CCWS from an LHSI heat exchanger tube, an RCP seal thermal barrier, or other source is identified by increased activity in the CCWS fluid, as detected by a continuous monitor or routine sampling, and is also indicated by an unexpected increasing level in a surge tank. RCP thermal barrier leakage is also indicated by high outlet flow from the barrier or an elevated return temperature (or both). The operational CCWS-to-ESWS pressure gradient makes in-leakage of service water unlikely. Out-leakage from the system is indicated by an unexpected decrease in surge tank level, a noticeable increase in automatic makeup flow, visible leakage in an accessible area, or a change in reactor coolant chemistry identified during routine sampling. For significant out-leakage from the CCWS, a rapid decrease in the level in a particular surge tank would trigger automatic inhibition of transferring common user loads to that train on sufficiently low level, and subsequent isolation of the common header upon reaching the low level isolation setpoint. These actions conserve capacity to cool the safety-related SIS users directly associated with that CCWS train. The system configuration also enables all such leaks to be readily isolated to prevent the release of radioactive fluid or the excessive dilution or chemical contamination of reactor coolant.

The four separate, independently powered, safety-related cooling trains of the CCWS, combined with high standards for system design, installation and maintenance, provide assurance that the system will fulfill its safety-related functions under the most demanding postulated conditions in spite of its most limiting credible single failure.

Each physically separated CCWS safety-related train (Figure 5-8) includes:

- A main system pump fitted with a recirculation line and a pump motor cooling line,

- A heat exchanger, cooled by the ESWS, with a parallel flow bypass line with control valve to maintain the CCW minimum temperature during cold weather and low-load operation,

- A concrete, steel-lined surge tank, with sufficient capacity to compensate for CCWS normal leaks or component draining, connected to the pump suction line,

- A sampling line with continuous radiation monitor and a chemical additive supply line, and

- Isolation valves to separate the train from the common load set.

Each CCWS safety-related train supplies cooling to its respective CCWS and medium head safety injection pumps and motors and associated LHSI heat exchanger. CCWS trains 2 and 3 cool their respective LHSI pumps and motors. The LHSI pumps and motors of trains 1 and 4 are cooled by the SCWS.

The SCWS chillers for divisions 2 and 3 are supplied by CCWS trains 1 or 2, and 3 or 4, respectively. This alignment enables continuous availability of the safety chillers during testing or maintenance activity and allows for equitable distribution of operating time for each of the CCWS safety-related trains.

The nonsafety-related operational loads are supplied by two separate isolable headers designated as common 1 and common 2. Common 1 may be supplied by either of safety-related trains 1 or 2, and common 2 may be supplied by either of safety-related trains 3 or 4. Each common header branches into subheaders further designated as “a” and “b” (i.e., common 1.a, 1.b and common 2.a, 2.b). Headers 1.a and 2.a, which cool FPCS trains 1 and 2, respectively, are separate from the other operational loads to provide continued cooling of the spent fuel when the other operational loads are isolated. Headers 1.b and 2.b cool the remaining operational CCWS loads. Each of the common “b” headers is isolable from each of the associated safety-related trains by fast-acting hydraulic valves installed in the supply and return lines of each train.

Either of CCWS common headers 1.b or 2.b can provide cooling to the RCP thermal barriers. The CCWS supply to the RCP thermal barriers is able to withstand a single, active failure or a moderate-energy crack because of the thermal barrier cross tie that enables cooling from either common header, thus allowing a cooling supply from any of the four CCWS trains. To meet the single-failure criterion for the RCP thermal barrier cooling function, the thermal barrier load is required to be cooled by a CCWS common header which is capable of being connected to either of two operable CCWS trains. If a CCWS train is out of service, the operators have 72 hours to align RCP thermal barrier cooling to the CCWS common header that has two available CCWS supply trains. In the event of an RCP thermal barrier fault such as a tube rupture, the faulted RCP thermal barrier is isolated via inlet and outlet isolation valves in the RCS. A fault of a single RCP thermal barrier does not isolate the entire common header supply to the remaining operable thermal barriers. To maintain strict CCWS train separation for thermal barrier cooling, an interlocking function is required. The supply and return containment isolation valves in the RCP thermal barrier cooling path of common 1.b cannot be opened unless the corresponding valves of common 2.b are closed, and vice-versa.

The nonsafety-related CCWS loads in the nuclear auxiliary building and in the radioactive waste building can be quickly isolated from the rest of the CCWS by fast-closing hydraulic valves, as required.

The design of the CCWS minimizes and withstands adverse transients (i.e., water hammer) and meets functional performance requirements for all operating modes, including postulated design-basis accidents, consistent with the guidance for water hammer prevention and mitigation found in NUREG-0927. The CCWS design minimizes the potential for dynamic flow instabilities by avoiding high line velocities and by specifying valve opening and closing speeds that are low enough to prevent damaging pressure increases.

Consideration has been made to avoid voiding, which can occur following pump shutdown or during standby conditions, by placing the pumps and CCWS users at elevations below the water levels of the surge tanks. Means are provided for slow and controlled filling of those portions of the CCWS where voiding could occur after pump shutdown or during standby conditions.

One nonsafety-related train comprises the dedicated CCWS. This train cools the SAHRS, is supplied demineralized makeup water by the dedicated CCWS injection pump, is cooled by its assigned dedicated ESWS train, and is provided backup power from its assigned station blackout diesel generator (SBODG). The dedicated CCWS train consists of one main pump, one dedicated ESWS-cooled heat exchanger, one surge tank connected to the pump suction line to keep the system filled and to maintain adequate head to prevent in-leakage of radioactive fluids from the SAHRS heat exchanger, a connection to the demineralized water distribution system (DWDS) with an injection pump for inventory makeup, a chemical additive supply connection, and associated piping, fittings, and valves. The dedicated CCWS surge tank is charged with nitrogen, which allows compressible compensation for fluid expansion and contraction and helps to ensure that any potential coolant leakage is into rather than out of the SAHRS.

All components and piping are carbon steel, except the demineralized feedwater line, which is stainless steel, and the CCWS heat exchanger tubes and dedicated CCWS train heat exchanger tubes, which are fabricated of a suitable corrosion-resistant metal.

5.4.3 Component Descriptions

5.4.3.1 CCWS Pumps

All CCWS pumps (the four safety-related pumps and the dedicated CCWS pump) are centrifugal-type pumps. Each pump motor is cooled by an air/water cooler supplied by the CCWS itself. The pump and motor of each set are horizontally mounted on a common base plate. The pump and motor bearings are oil lubricated and air cooled. A motor heater is provided for each motor and is energized when the pump is not in operation to prevent the formation of condensation.

During normal operating conditions, at least two of the four safety-related pumps are operating. The dedicated CCWS pump is in standby.

5.4.3.2 CCWS Heat Exchangers

All (safety-related and dedicated-train) CCWS heat exchangerss are horizontal tube-and-shell-type heat exchangers. CCW is circulated on the shell sides, and the ESWS supplies cooling water to the tube sides.

5.4.3.3 CCWS Surge Tanks

The CCWS surge tanks for the safety-related trains are concrete structures with steel liners. Each tank is connected to the suction side of its respective train's CCWS pump. Each surge tank has sufficient storage capacity to compensate for normal system leaks or component draining. Makeup water is supplied from the DWDS. An additional makeup source of water to each surge tank originates from the seismically qualified portion of the fire water distribution system inside the Nuclear Island.

The dedicated CCWS surge tank is connected to the dedicated CCWS pump suction line. The surge tank makeup is provided from the DWDS. Nitrogen overpressure is provided to prevent a leak of radioactive fluids into the dedicated CCWS train from the SAHRS. The surge tank is provided with overpressure protection.

5.4.3.4 Major CCWS Valves

Common Header Switchover Valves: These valves are fast-acting, hydraulically operated valves. The valves provide the physical train separation for the support of the common cooling loads. They are used to transfer cooling of the common users during normal plant operation or in the event of a failure during a design-basis event. The valves are interlocked so that two trains may not be simultaneously connected to the same common header. The stroke times of these fast-acting valves are sufficient to minimize the interruption of cooling to the CCWS loads.

LHSI Heat Exchanger Isolation Valves: These valves are motor-operated valves. The valves are normally closed to prevent dilution of the LHSI fluid and may be opened when necessary to provide adequate flow paths in support of long-term pump operation. Each valve automatically opens when the associated train of the LHSI system is placed into service.

LHSI Pump Seal Fluid Cooler Isolation Valves: These valves are motor-operated valves. The valves are normally closed to prevent dilution of the LHSI fluid. Each valve automatically opens when the associated train of the LHSI system is placed into service.

Containment Isolation Valves: The CCWS containment isolation valves are motor-operated valves. The normally open valves provide the means for containment isolation to maintain the integrity of the containment penetrations and thus to prevent the release of potentially radioactive material during a design-basis accident. The containment isolation valves for nonsafety-related loads are automatically closed by a containment isolation actuation signal. The containment isolation valves for the RCP thermal barrier coolers are not closed by a containment isolation signal, but they may be manually closed from the control room if required.

5.4.4 System Operation

5.4.4.1 Normal Operation

At-Power Operation: During normal operations, one or two trains can be in operation in each pair of associated trains (trains 1 and 2 constitute one pair, trains 3 and 4 constitute another); each pair cools one of two common sets of heat loads (common 1 and common 2). Each of the common headers may be split so that one of the two associated trains is supplying the common “a” header, and the other is supplying the common “b” header, to enhance the cooling efficacy of the cooling chain.

Common 1.a provides cooling to the first FPCS train, and common 2.a provides cooling to the second FPCS train. These are separated from the other operational loads (supplied by common 1.b and 2.b) so that the CCWS maintains cooling of the FPCS during maintenance or plant outages.

For each of the common headers (common 1 and common 2), the associated safety-related trains are isolated from each other by appropriate positioning of the four common header switchover valves, which are located on the supply and return sides of each common subheader (1.a, 1.b, 2.a, 2.b).

The following criteria drive the selection of two, three, or four operating trains:

- The CCW temperature at the outlet of the CCWS heat exchangers must be above the minimum required and below the maximum allowed.

- The CCWS pump steady-state operating flows must be between the minimum required and the maximum allowed.

To make sure that each CCWS pump operates within its allowable range, system operating configurations are limited. The allowed load combinations for an individual train are as follows:

- Only its associated SIS loads (train-related LHSI heat exchanger and LHSI and MHSI pumps),
- Common 1.a (2.a) (FPCS loads) and its associated LHSI loads,
- Only common 1.b (2.b) (main common load group),
- Common 1.b (2.b) and its associated LHSI users,
- Common 1.a and 1.b (2.a and 2.b), and
- Common 1.a and 1.b (2.a and 2.b) and its associated LHSI loads with less than the maximum flow rate through the CVCS and FPCS heat exchangers.

For pump protection, the following combinations of loads for an operating train are not permitted:

- A train cannot be isolated from the common headers and also from the LHSI heat exchanger.
- A train cannot supply only common 1.a (2.a).
- A train cannot supply common 1.a and 1.b (2.a and 2.b) and its associated LHSI loads with the maximum flow rate through the CVCS and FPCS heat exchangers.

Forbidden configurations lead to operations with abnormal flow rates and are subject to automatic system protection.

CCWS leakage (e.g., from valve packing and pump seals) is compensated by the makeup of demineralized water to the CCWS surge tanks. This makeup is controlled by the automatic positioning of the DWDS supply isolation valves.

Depending on the ESW temperature, the CCW temperature could be too low. The CCWS heat exchanger bypass control valve in each train is positioned in order to maintain a CCWS heat exchanger outlet temperature greater than the minimum allowable.

Shutdown Cooling by Two CCWS trains - RCS Temperature < 250°F: Two LHSI trains are operating in the RHR mode and are transferring residual heat from the RCS to the UHS. The associated CCWS trains cool the LHSI heat exchangers. The other two trains cool common 1 (train 1 or 2) and common 2 (train 3 or 4).

During the plant cooldown and before depressurization of the RCS, it is necessary to purify the RCS fluid. The two CVCS charging pumps are running and the two CVCS HP coolers are supplied by the CCWS.

Shutdown Cooling by Four CCWS trains - RCS Temperature < 212°F: The two CCWS trains which had been cooling the common headers are now aligned to their corresponding RHRS trains. Within these two trains, heat removal from the LHSI heat exchangers is controlled by throttling the LHSI heat exchanger bypass flows to limit the CCWS heat exchanger outlet temperatures to the maximum allowable.

The FPCS heat exchangers are cooled by common 1 and common 2. Flow through one heat exchanger can be secured to increase the efficiency of the aligned CCWS train.

Refueling: At the beginning of the core unloading process, the CCWS is cooling the fuel in the reactor vessel and cooling the FPCS also, at the minimum flow value. At the end of the core unloading process, the CCWS is only cooling offloaded fuel in the spent fuel pool (SFP), with cooling provided to both FPCS heat exchangers at the maximum rate. As core unloading proceeds, the CCWS flow rates to the FPCS heat exchangers are increased, and the flow rates to the LHSI heat exchangers are reduced. Cooling of the common headers is maintained during core unloading.

5.4.4.2 Emergency Operation

For the accident analysis it is assumed that one CCWS train is unavailable due to maintenance or other activity and that a second train fails to perform its function, leaving only two trains available for the event. Upon the receipt of safety injection system and containment isolation stage 1 actuations, the protection system starts the CCWS pumps and opens the low head safety injection isolation valves (admitting CCWS flow to the LHSI heat exchangers in all trains and to the LHSI pump coolers in trains 2 and 3) of the trains not initially in operation. The nonsafety-related common users outside the reactor building, as well as the containment ventilation loads and the RCDT cooler inside the reactor building, are isolated. A subsequent containment isolation stage 2 signal isolates the RCP and CVCS loads inside the reactor building, except for the RCP seal thermal barrier coolers.

For the analysis, the accident is assumed to occur with a coincident loss of offsite power. The loss of one train is assumed to occur due to a single failure, the most limiting of which is the loss of one electrical division. This loss also results in the incidental loss of the associated SIS and ESWS trains. Throughout accident mitigation and recovery, one of the remaining available CCWS trains cools its associated LHSI heat exchanger, and the other provides additional cooling to the remaining safety loads, with both CCWS trains cooled by their associated ESWS trains.

During severe accidents, containment heat is removed by the dedicated cooling chain, consisting of the SAHRS, the dedicated CCWS train, and the dedicated ESWS train. This dedicated CCWS train is normally in standby and is manually started if needed. If the dedicated CCWS or ESWS division is lost, the SAHRS cooling chain is lost. The dedicated cooling chain is started in response to events that are beyond the design basis.

5.5 Essential Service Water System

The function of the essential service water system is to remove heat from plant components which require cooling during normal operation, for the safe shutdown of the reactor, and following a design-basis accident. The system provides cooling water from the essential service water cooling tower basins to the component cooling water system heat exchangers, the emergency diesel generator (EDG) heat exchangers, and the ESW pump room coolers. The function of the ESW cooling towers is to dissipate heat rejected from the ESWS during all plant modes of operation.

5.5.1 Design Bases

The ESWS satisfies the following design bases:

- ESWS structures, systems and components which provide essential cooling for safety-related equipment are designed to withstand the effects of natural phenomena such as earthquakes, tornadoes, hurricanes, floods, and external missiles without the loss of capability to perform their safety-related functions (GDC 2). The seismic design of this system meets the guidance of RG 1.29.

- Safety-related portions of the ESWS are designed to accommodate the effects of and to be compatible with the environmental conditions associated with normal operation, maintenance, testing, and postulated accidents. These system portions are appropriately protected against dynamic effects, including the effects of missiles, pipe whipping, and discharging fluids, that may result from equipment failures and from external events (GDC 4).

- The ESWS provides heat removal from the CCWS heat exchangers, EDG heat exchangers, and ESW pump room coolers during normal operation and accident conditions, and transfers that energy to the UHS (GDC 44).

The ESWS provides sufficient cooling water for removing heat from essential plant equipment and transferring energy to the cooling towers over the full range of normal reactor operation. The ESWS flow capacity and supply capability are designed so that the temperatures in essential plant equipment remain within their specified limits.

The ESWS operates in conjunction with the CCWS and other reactor auxiliary components to provide a means to cool the reactor core and reactor coolant system to achieve a safe shutdown. The safety-related ESWS divisions provide continued heat transfer from the fuel pool cooling system via the CCWS as long as any spent fuel assemblies are in the spent fuel storage pool located outside containment.

5.5.2 System Description

The ESWS consists of four separate, redundant, safety-related divisions, and one dedicated, nonsafety-related division.

The ESWS cools the CCWS, which acts as an intermediate loop isolating the ESWS from the RCS. The CCWS is monitored to detect radioactive contamination into and leakage out of the system.

The ESW pumps take suction from the UHS cooling tower basins and provide cooling water to the CCWS heat exchangers, EDG heat exchangers, and ESW pump room coolers. The heated water is then returned to the UHS cooling towers. The system is shown in Figure 5-9.

Each safety-related ESWS division consists of one ESW pump, a debris filter, piping, valves, controls, and instrumentation.

Provisions are made to ensure a continuous flow of cooling water under normal and accident operating conditions. The four safety-related divisions of the ESWS are powered by Class 1E electrical buses backed by the EDGs.

The nonsafety-related, dedicated division contains a dedicated ESW pump, a debris filter, piping, valves, controls, and instrumentation. The nonsafety-related ESWS division pumps cooling water from the division 4 UHS cooling tower basin to the dedicated CCWS heat exchanger and back to the division four UHS cooling tower during severe accidents. The dedicated ESW pump is powered by a Class 1E electrical bus, which can be supplied by an emergency diesel generator or by a station blackout diesel generator.

5.5.3 Component Descriptions

5.5.3.1 Safety-Related ESW Pumps

Each of the four safety-related cooling divisions contains one 100%-capacity pump. During normal operating conditions, two of the four divisions are operating. The required flow rate of each ESWS pump is defined by the energy to be removed from the system loads. Design parameters are listed in Table 5-8.

The pump motors are air cooled. Motor heat loads are rejected to an air recirculation system installed for each division. In addition, an anti-condensation heater for each motor is switched on as soon as the pump is stopped.

5.5.3.2 Dedicated ESW Pump

The 100%-capacity dedicated ESW pump is normally in standby mode. This nonsafety-related pump is manually started only in response to certain postulated severe-accident conditions; it is not credited in the response to any design-basis accident.

The required flow rate of the dedicated ESW pump is defined by the energy to be removed from the dedicated CCWS heat exchanger. Design parameters are listed in Table 5-9.

The pump motor is air cooled. In addition, an anti-condensation heater for the motor is switched on as soon as the pump is stopped.

5.5.3.3 Debris Filters

The debris filters for all (safety-related and dedicated) divisions remove all debris particles from the cooling water that would obstruct the system-supplied heat exchangers.

The debris filters are automatic-backwash-type filters. With increasing fouling of a filter, the differential pressure across the filter segments increases until it reaches a preset operational point. The pressure relief backwash process of the filter is initiated by either the differential pressure signal, a timer after the start of the ESW pump, or manual action.

The discharge and disposal of the collected debris is treated in accordance with federal and state regulations relevant to the plant location.

5.5.4 System Operation

5.5.4.1 Normal Operation

ESWS operation is vital for all phases of plant operation and is designed to provide cooling water during both power operation and shutdowns of the plant. During normal plant operation, at least two divisions are operating; the remaining divisions are in standby. The running pumps are changed periodically, thus changing the operational divisions.

The four divisions are filled and vented prior to operation. Under normal system operating conditions on a per division basis, the ESW pump is in operation, the debris filter is functioning, and all the valves in the main line are open. If the differential pressure across the debris filter reaches the predefined setpoint, automatic filter cleaning initiates.

Each standby division is aligned for normal operation (manual valves in the main line are open), and the division is filled and vented. Automatic backwash for the debris filter is in standby. The pump can be started manually from the main control room or automatically. The stopping of a particular division is performed manually.

Four ESWS divisions are normally running to achieve cold shutdown in the minimum time. Only two operating divisions are required to achieve cold shutdown.

During refueling, when the core is almost discharged to the fuel building, two or three ESWS divisions are in operation. During this phase, maintenance can be performed on one division. When the core is totally offloaded to the fuel building, only two ESWS divisions are required to be in operation.

The dedicated ESWS division is not in use during normal plant operation. The ESW side of the dedicated CCWS heat exchanger is isolated from the rest of the system. The ESWS inlet and outlet isolation valves are closed, and this piping section is filled with demineralized water to prevent corrosion.

5.5.4.2 Emergency Operation

During accident conditions the safety-related trains supply cooling flows to support operation of the CCWS trains and EDGs needed to mitigate the accident. In the event of a LOCA during power operations, the protection system initiates safety injection actuation and containment isolation phase 1 signals. In response, the previously idle ESW pumps automatically start. The ESWS has sufficient capability to perform its safety-related functions assuming a single active failure of one train and with a second train out of service for maintenance.

The dedicated ESWS division is manually activated in the case of a severe accident. Required actions include closing the ESW isolation valve downstream of the train 4 CCWS heat exchanger, manually opening the dedicated ESWS isolation valves upstream and downstream of the dedicated CCWS heat exchanger, and manually starting the dedicated ESW pump.

5.6 Emergency Feedwater System

The EFWS is a safety-related system that is expected to operate only during anticipated transient or accident conditions. The US-EPR is equipped with a dedicated startup and shutdown feedwater pump that supplies feedwater to the steam generators for startup and shutdown operations. Operation of the startup and shutdown feedwater pump reduces the number of operating cycles for the EFWS and increases the reliability of the entire feedwater system.

The EFWS has four separate and independent trains, each consisting of a water storage pool, pump, control valves, isolation valves, and interconnecting piping so that water from the storage pools can be pumped into the SGs, one division per SG. The storage pool for each train is a lined concrete structure inside one of the safeguard buildings. A cross-connecting header ties to the suction lines of all EFWS pumps. Similarly, a cross-connecting header ties to all EFWS pump discharge paths, allowing any EFWS pump to supply any SG. Normally, the isolation valves between the individual trains and the cross-connect headers are closed, and operator action is required to change the flow paths. All four EFWS trains are powered from separate Class 1E buses, each backed by an EDG.

The EFWS design differs slightly from the totally independent four-train safety concept (i.e., with each train dedicated to a specific RCS loop or SG). Although the EFWS is capable of adequately supplying feedwater to the SGs in the event of a single failure of one EFWS train with a second train out of service for maintenance, valves on the discharge header can be manipulated to redirect EFW flow from an affected SG to an intact SG. In addition, the valves on the suction piping can be aligned to allow any pump to take suction on the storage pools of other divisions.

The EFWS is a steam and power conversion system that is more completely discussed in Chapter 4.0.

5.7 Extra Borating System

The extra borating system injects borated water into the reactor coolant system to maintain the core subcritical for safe shutdown.

5.7.1 Design Bases

The EBS is designed to inject a concentrated boron solution into the RCS against any credible RCS pressure. The EBS injects borated water into the RCS at a rate sufficient to maintain subcriticality during the cooldown from any operational or anticipated transient, and is required to maintain subcriticality after a steam generator tube rupture. The EBS also provides reactivity control to support the capability to take the reactor from normal operating conditions to cold shutdown using only safety-related systems, in accordance with Branch Technical Position 5-4.

- A portion of the EBS is part of the reactor coolant pressure boundary. The system is normally isolated from the RCS to maintain the integrity of the RCPB in the event of a leak in the EBS piping (GDC 14).

- The EBS provides containment isolation for EBS piping that penetrates containment (GDC 55).

- EBS components are designed to quality standards commensurate with their importance to safety (GDC 1). As such, the EBS is protected from the effects of natural phenomena, such as earthquakes, tornadoes, hurricanes, floods, and external missiles, and it is designed to function following such events (GDC 2). It is designed to remain functional following the postulated hazards of fire and explosion (GDC 3), and is designed to withstand internal missiles, pipe whipping, and discharging fluids (GDC 4).

- The EBS is capable of adding sufficient neutron poison to reliably control reactivity changes and to maintain the capability to cool the core under the postulated conditions resulting from an SGTR (GDC 27).

5.7.2 System Description

The EBS is composed of two trains, designated as trains 1 and 4 to reflect their divisional assignments. Each train consists of a borated water storage tank, a full-capacity positive displacement pump, and a test line (all of which are located in the fuel building), and an injection line that feeds two RCS cold legs via the safety injection nozzles. Key design and operating parameters for the EBS are listed in Table 5-10, and the general configuration of the EBS (one train) is shown schematically in Figure 5-10.

The EBS pumps are air-cooled, positive-displacement piston pumps. Power is supplied to the pumps from the 480-Vac electrical distribution buses, and emergency diesel generators provide backup power.

The EBS tanks are located above the pumps to maintain adequate net positive suction head. The two EBS tanks are interconnected through a normally open flow path that allows either EBS pump to draw from both tanks.

A test line with a multi-stage flow restrictor in each EBS train allows it to be tested at its required injection pressure by recirculating the borated water in the EBS tank.

This feature also allows mixing and heating of the EBS inventory using pump energy, thereby eliminating any requirement for heaters or mixers in the tanks. Flow and pressure indications confirm proper pump operation. If EBS injection is required during the periodic test, the test line motor-operated valves are closed, and the outboard containment isolation valves are opened.

Each EBS train's injection line branches into two lines just downstream of its reactor building penetration. Each branch line connects to a safety injection system line upstream of the SIS check valve, which in turn connects to an RCS cold leg. Each line is isolated with a normally closed motor-operated valve. The EBS piping between the containment isolation valves and the outboard RCS isolation valves is protected by relief valves against overpressure due to thermal expansion.

The EBS is designed to prevent boric acid crystallization during standby without heat tracing. The temperature inside the fuel building, where the tanks and main pipe lines are located, is maintained above 68°F by the fuel building ventilation system. For piping outside the temperature-controlled rooms, a normally closed suction connection from the in-containment refueling water storage tank (IRWST) allows those pipes to be filled with less borated water to prevent crystallization.

The EBS lines outside the temperature-controlled rooms are also thermally insulated. After an initiation of the EBS, the insulation delays crystallization of the boric acid remaining in the lines to allow time for the lines to be purged with IRWST water, or to take other measures to prevent crystallization.

A normally closed suction connection from the volume control tank allows the EBS to be used for hydrostatic testing of the RCS. A normally closed connection from the train 1 EBS pump discharge line to the CVCS seal injection header provides the injection path for these tests.

5.7.3 System Operation

In the event of an SGTR, or for any instance where shutdown is required and boration from another source (such as the IRWST, CVCS, or the reactor boron and water makeup system) is not available, EBS injection is required and is manually initiated by the operator in the main control room. Manual operation is not required to mitigate a design-basis event for the first 30 minutes after event initiation. If a containment isolation signal that automatically closes the EBS containment isolation valves occurs, the signal immediately resets to allow the valves to be reopened so that EBS injection may proceed. Once injection begins, the EBS operates until the operator manually stops the EBS injection when EBS tank levels indicate that the minimum required volume has been injected. Level indications and alarms alert the operator if the EBS tank inventories are nearing depletion, so that the pumps are stopped prior to loss of suction.

The minimum required EBS injection flow rate is sufficient to compensate for the positive reactivity addition due to RCS cooldown and xenon decay, and to maintain a sufficient shutdown margin. The maximum allowable EBS injection flow rate, which is less than the average rate of reactor coolant contraction due to the cooldown that occurs during the response to a postulated SGTR, prevents the pressure control instability that would result from overfilling the RCS.

During normal operations, the EBS is in standby and has no function other than periodic mixing of the borated water in the EBS tanks and periodic system testing. The concentrated boric acid solution in the tanks is initially prepared in the mixing tank of the reactor boron and water makeup system and transferred to the EBS tanks. The EBS tank levels and temperatures are continuously monitored to verify system readiness.

5.8 Fuel Pool Cooling and Purification System

The fuel pool cooling and purification system is designed to maintain the spent fuel pool water temperature and water level within prescribed limits by removing the decay heat generated by the stored spent fuel assemblies, and to remove impurities from the fuel building pool and the reactor building pool to maintain water clarity and to limit the specific radioactivity in the water.

The FPCPS consists of the following separate and independent subsystems:

- Fuel pool cooling system, and
- Fuel pool purification system (FPPS).

5.8.1 Design Bases

The FPCPS provides the following safety-related functions:

- Removal of decay heat from the SFP,
- Containment isolation of the reactor pool purification supply and return lines,
- Preclusion, by design, of draindown of the spent fuel pool below the required level for shielding of the spent fuel and FPCS operation,
- SFP makeup (i.e., Seismic Category I water source, pump, and piping) to compensate for normal SFP evaporation for up to seven days, and
- Isolation of nonsafety-related FPPS piping from the reactor building transfer compartment, reactor cavity, fuel building transfer compartment, and cask loading pit.

The design-basis requirements and design criteria are as follows:

- The FPCPS provides containment isolation for the reactor building pool purification supply and return lines (GDC 56).

- The FPCS components are located inside the fuel building structure, which is designed to withstand the effects of natural phenomena, such as earthquakes, tornadoes, and hurricanes (GDC 2).

- The safety-related portions of the FPCPS are protected from the dynamic effects associated with pipe whip, internal missiles, and discharged fluids, and they accommodate the expected environmental conditions such that the system is capable of performing its intended safety functions (GDC 4).

- The seismic design of the FPCPS components meets the guidance of RG 1.29. The FPCS cooling trains are safety-related and Seismic Category I. The quality group classification and seismic categories of system components meet the requirements of RGs 1.26 and 1.29.

- The FPCS provides adequate cooling to the spent fuel for all heat loads, including full-core offloads, by maintaining a maximum SFP temperature of 140°F. In addition, the system design conforms to RG 1.13, position C.9.

- The FPCS provides SFP makeup to maintain a steady SFP water level that meets cooling and shielding requirements. In addition, the system design conforms to RG 1.13, position C.8.

- The FPCS maintains required pool water levels and uniform water temperatures during operating and accident conditions, and conforms to RG 1.13, position C.6.

- The safety functions of the FPCS can be performed assuming a single active failure of a safety-related component or subsystem, or failures of nonsafety-related components or subsystems.

- The FPCPS design includes the capability to prevent the reduction in fuel storage coolant inventory under accident conditions and the capability and capacity to remove corrosion products, radioactive materials, and impurities from the pool water and to reduce occupational exposure to radiation.

- In accordance with the requirements of 10 CFR 20.1101(b), engineering controls are provided to keep radiation doses associated with the FPCPS to as-low-as-reasonably-achievable (ALARA) levels.

5.8.2 System Description

Operation of the FPCPS involves the following:

- Fuel building and reactor building pools,
- Fuel pool cooling system,
- SFP makeup capability, and
- Fuel pool purification system.

5.8.2.1 Fuel Building and Reactor Building Pools

The fuel building pool includes the following three compartments:

- The fuel building transfer compartment is used for the transfer of used or new fuel between the fuel building and the reactor building. This compartment is filled from the in-containment refueling water storage tank before refueling.

- The cask loading pit is filled with water when spent fuel transfer from the SFP is required. The water needed to fill this compartment is stored in the fuel building transfer compartment.

- The SFP is dedicated to the storage and cooling of the spent fuel.

The reactor building pool includes the following four compartments:

- The reactor building transfer compartment is connected to the fuel building transfer compartment by a transfer tube, and is used for the transfer of used or new fuel between the fuel building and the reactor building.

- The instrumentation lance compartment is used to store instrumentation (e.g., core outlet thermocouples and incore detectors). This compartment remains flooded during all modes of plant operation.

- The internals compartment is filled with water from the IRWST, and is used to store the reactor upper internals during refueling outages.

- The reactor cavity is filled with water from the IRWST during refueling operations.

The initial filling, inventory maintenance, and refilling of the fuel building and reactor building pools is performed by the reactor boron and makeup water system. Demineralized water is normally used to compensate for normal evaporation in the pools. The boron concentration of the pool water is maintained the same as that of the water in the IRWST.

5.8.2.2 Fuel Pool Cooling System

The FPCS, shown in Figure 5-11, consists of two separate cooling trains located on opposite sides of the SFP for the removal of decay heat generated by irradiated fuel stored in the SFP. Each train consists of two pumps in parallel, one heat exchanger, supply and return piping, and associated valves. The pumps can be operated individually or simultaneously, as needed. The heat exchanger is cooled by the component cooling water system. The cooling water flow to the heat exchanger can be adjusted from the main control room with CCWS motor-operated control valves. Each FPCS train includes a motor-operated isolation valve downstream of the heat exchanger.

The FPCS is designed to maintain the SFP temperature below 120°F during refueling periods to facilitate operations in the SFP area, with a maximum temperature of 140°F if a single failure occurs.

5.8.2.3 Spent Fuel Pool Makeup Capability

Normal makeup water to the Seismic Category I SFP is supplied by the demineralized water distribution system.

Additionally, a safety-related source of SFP makeup water, containing approximately 29,000 gallons, is maintained in the cask loading pit or the fuel building transfer compartment (or both). The cask loading pit and transfer compartment are both Seismic Category I structures adjacent to the SFP. A Quality Group C and Seismic Category I pump that can take suction from either source, and associated discharge piping to the SFP, are provided. The SFP makeup pump is shown in Figure 5-12. The SFP makeup pump is provided with Class 1E electrical power and is operated from the main control room.

The safety-related makeup capability is provided with sufficient inventory and capacity to compensate for normal evaporative losses from the SFP for up to 7 days with the FPCS in operation and to maintain the SFP temperature at 140°F. SFP leakage associated with a dropped fuel assembly is not considered, as an assembly drop will not result in perforation of the SFP liner.

Other independent on-site Seismic Category I water supplies are available to provide backup SFP makeup capability, including the IRWST with at least 500,000 gallons available during plant operation. The piping and pump used to deliver the backup water supply to the SFP are not designed as Seismic Category I.

5.8.2.4 Fuel Pool Purification System

The FPPS, portions of which are shown in Figures 5-12 and 5-13, provides purification of the fuel building and reactor building pool compartments and is used to transfer water between the pool compartments or between a compartment and the IRWST. The FPPS includes two pumps installed in parallel. One pump is generally used for fuel building pool purification; the second pump is used for reactor building pool purification. However, either pump can be aligned to either pool via an appropriate suction-header alignment. A motor-operated control valve downstream of each purification pump is used to set the required flow for the desired system configuration.

The water discharged from a purification pump is pumped through a pre-filter, a mixed-bed ion exchanger, a resin trap, and a post-filter before the purified water is returned to the respective pool. The mixed-bed ion-exchanger resin removes ionic corrosion impurities and fission products, and the filters remove particulate matter. Spent resin from the ion exchangers is sent to the resin waste tank of the coolant purification system (CPS).

The FPPS suction and return lines that terminate at the fuel building pool water surfaces are designed to prevent siphoning from the pool. Otherwise, the suction piping from either pool originates at the bottom of the pool. Valves are provided on each line to allow isolation of any leakage. The valves and the piping from the pools to the isolation valves are safety related and Seismic Category I. Strainers are provided to preclude particles from damaging the pumps and from creating radioactive hot spots in the piping system. The return piping to all pool compartments enters the pools from the top.

The SFP and reactor cavity include skimming equipment to remove particles from the surfaces of the pools. The SFP skimming equipment includes a pump and filter; the pump takes suction from a skimmer box mounted on the pool wall and returns the filtered water to the pool. The reactor cavity skimming equipment includes a floating skimmer box that is connected by a hose to the skimmer pump suction pipe. The skimmer pump discharge piping is connected to the reactor building purification supply pipe. The water collected in the skimmer is filtered by the FPPS ion exchange and filters.

The purification supply piping from each pool compartment and the purification pumps are also used for transferring water between pool compartments or between a compartment and the IRWST. Water can be circulated through the purification ion exchanger and filters as needed, before transfer to the desired pool compartment.

Boron addition to the SFP is normally provided by the reactor boron and makeup water system. Makeup and boron-addition operations are performed manually.

5.8.3 Component Descriptions

This section provides general descriptions of the major components of the FPCPS. Key component design data for these components are listed in Table 5-11.

The four FPCS pumps are centrifugal-type pumps.

The FPCS heat exchangers are of the plate-type design and are cooled by the CCWS. The heat exchangers consist of a series of corrugated stainless steel plates. The gasketed plates are compressed together on a rigid frame to create an arrangement of parallel flow channels. FPCS water flows in the odd-numbered plates, while CCW flows in the even-numbered plates in the counter-current direction. The heat exchangers have flanged piping connections. The CCWS pressure is greater than that of the FPCS, which precludes radioactive SFP water from entering the CCWS in case of leakage.

The fuel building and reactor building purification pumps are centrifugal canned-motor pumps.

The FPPS mixed-bed ion exchanger is a stainless steel pressure vessel containing ion-exchange resin. Fresh resin is loaded manually, and spent resin is remotely removed to prevent high radiation exposure. Cartridge-type pre- and post-filters and a resin trap are provided for the mixed-bed ion exchanger.

5.8.4 System Operation

5.8.4.1 Fuel Pool Cooling System Operation

Operation of the FPCS is required whenever spent fuel assemblies are stored in the SFP. During normal plant operation, one FPCS train operates continuously. The second FPCS train is maintained in the standby condition as a backup to the train in operation.

During refueling operations, including a full-core offload, the SFP temperature is maintained below120°F. Both FPCS trains are used as necessary. The CCW flow rates to the heat exchangers are adjusted depending on the pool water heat load.

Makeup water to the SFP is normally supplied from the demineralized water distribution system. The makeup water supply compensates for normal evaporative losses from the SFP. The makeup water flow rate to the pool is locally controlled by a manually operated valve.

Samples of the SFP water can be taken from the sample lines downstream of the heat exchangers.

5.8.4.2 Fuel Pool Purification System Operation

Normal operation of the FPPS is manually controlled and intermittent. The FPPS maintains water clarity and limits ionic corrosion and fission product concentrations in the fuel building and reactor building pools. The system is generally aligned for the fuel building purification pump to discharge through the filters and mixed-bed ion exchanger. However, both purification pumps can be operated to obtain maximum system capability. Samples may be taken periodically to determine the quality of the water.

If purification of the reactor building instrumentation lance compartment or the IRWST is needed during plant operation, the valve alignment can be performed from the control room to direct the water to either of the purification pumps along with the filters and ion exchanger.

During an outage when the reactor building pool is filled, it is possible to purify one or several compartments of the reactor building pool at the same time. The reactor cavity is generally purified via the residual heat removal system by the CPS. However, if needed during fuel movement, the CPS path from the RHRS is temporarily isolated, and the reactor building purification pump supplies the CPS filters and ion exchanger for purification of the reactor cavity and reactor building transfer compartment.

During refueling outages, the fuel building purification pump and the FPPS filters and ion exchanger are generally used for purification of the fuel building pool, including the fuel building transfer compartment, to control water clarity and to maintain the required water chemistry. A CPS filter can also be aligned in parallel with one of the FPPS filters, if needed, during fuel movement.

Water transfers can be made between reactor building pool compartments, fuel building pool compartments, and the IRWST using different supply and return piping and valve alignments. The SFP and instrumentation lance compartments are always filled with water.

The SFP surface skimmer system is manually aligned and operated, as required, to clean the SFP water surface. The reactor cavity skimmer is generally operated during reactor building pool purification.

Filling of the mixed-bed ion exchanger is performed manually through resin feed nozzles. Demineralized water is added until the cation- and anion-exchange resins are covered. The resin is then mixed by injecting nitrogen into the bottom of the ion exchanger. Upon high differential pressure or indication by manual sampling that the ion-exchange resins are spent, the spent resin in the mixed-bed ion exchanger is transferred remotely to the resin waste tank.

The cartridge filters and skimming filters are changed remotely with a filter-changing machine to limit radiation exposure.

Table 5-1 Accumulator Design and Operating Parameters

Parameter	Value
Number of units	4 (one per train)
Material	Austenitic stainless steel
Design pressure	800 psig
Normal operating pressure	667.2 psig
Maximum operating pressure	696.2 psig
Minimum operating pressure	638.2 psig
Design temperature	140°F
Nominal operating temperature	90.5°F
Maximum operating temperature	122.0°F
Minimum operating temperature	59.0°F
Maximum liquid volume	1412.6 ft^3
Minimum liquid volume	1236.0 ft^3
Maximum nitrogen volume	706.3 ft^3
Minimum nitrogen volume	529.7 ft^3
Total accumulator volume	1942.3 ft^3
Minimum boron enrichment	37% of ^{10}B
Maximum boron concentration	1900 ppm
Minimum boron concentration	1700 ppm
Overall accumulator height	353.6 in
Accumulator pipe internal diameter	11.75 in
Accumulator discharge line piping wall thickness	0.5 in
Minimum accumulator fL/D + K (for flow area = 0.3941 ft2 and f = 0.014)	3.71

Table 5-2 Low Head Safety Injection Pump Design and Operating Parameters

Parameter	Value
Number	4
Type/arrangement	Centrifugal/horizontal
Design pressure/temperature	1160 psig/360°F
Normal flowrate (approximate)	2200 gpm
Normal flow head (approximate)	480 ft
Minimum flowrate (approximate)	530 gpm
Flow head at minimum flowrate (approximate)	750 ft
NPSH required at maximum flowrate (approximate)	8.2 ft
Nominal motor power (approximate)	340 kW

LHSI Pump Characteristics		
Pump flow (gpm)	**TDH (ft)**	**NPSHR (ft)**
0.0	787.4	N/A
440	771.0	N/A
880	721.8	3.3
1320	656.2	3.9
1760	574.1	4.6
2200	475.7	5.2
2640	360.9	6.2

Table 5-3 Medium Head Safety Injection Pump Design and Operating Parameters

Parameter	Value
Number	4
Type/arrangement	Centrifugal/horizontal
Design pressure/temperature	1525 psig/250°F
Normal flowrate (approximate)	600 gpm
Normal flow head (approximate)	2260 ft
Minimum flowrate (approximate)	165 gpm
Flow head at minimum flowrate (approximate)	3200 ft
NPSH required at maximum flowrate (approximate)	10 ft
Nominal motor power (approximate)	455 kW

MHSI Pump Characteristics

Pump flow (gpm)	TDH (ft)	NPSHR (ft)
0.0	3280.8	N/A
220	3116.8	8.9
440	2706.7	6.2
660	2050.5	6.6
880	1148.3	7.9

Table 5-4 IRWST Design Parameters
Sheet 1 of 2

Parameter	Value
IRWST	
Design pressure	75 psig
Design temperature	320°F
Minimum operating temperature	59°F
Maximum operating temperature	122°F
Minimum volume	66,886 ft^3 (500,342 gallons)
Maximum volume	70,010 ft^3 (523,703 gallons)
Minimum boron enrichment	37% of B-10
Minimum boron concentration	1700 ppm
Maximum boron concentration	1900 ppm
SIS Sump Screen Filters	
Number	4
Material	Austenitic stainless steel
Design pressure	75 psig
Design temperature	320°F
Opening size	0.08 x 0.08 in
Diameter of wire	0.03 in
Total screen area (approx.)	753 ft^2
SIS Vortex Suppressors	
Number	4
Material	Austenitic stainless steel
Design pressure	75 psig
Design temperature	320°F
Liner	
Material for fluid wetted parts	Austenitic stainless steel
Liner plate thickness	
Wall	0.39 in
Bottom	0.39 in
Ceiling	0.39 in
Area	
Wall	6350.7 ft^2
Bottom	5866.3 ft^2
Ceiling	1829.9 ft^2

Table 5-4 IRWST Design Parameters
Sheet 2 of 2

Sump	484.4 ft^2
Water depth (approximate)	12.3 ft
IRWST Retaining Baskets	
Double Compartment Retaining Baskets	
Number	2
Material	Austenitic stainless steel
Design Pressure	75 psig
Design Temperature	320°F
Opening size	0.08 x 0.08 in
Diameter of Wire	0.03 in
Total screen area large compartment (approx. min.)	721 ft^2
Total screen area small compartment (approx. min.)	269 ft^2
Total Volume large compartment (approx. min.)	1589 ft^3
Total Volume small compartment (approx. min.)	530 ft^3
Single Compartment Retaining Baskets	
Number	2
Material	Austenitic stainless steel
Design Pressure	75 psig
Design Temperature	320°F
Opening size	0.08 x 0.08 in
Diameter of Wire	0.03 in
Total screen area (approx. min.)	721 ft^2
Total Volume (approx. min.)	1589 ft^3
IRWST Trash Racks	
Number	4
Material	Austenitic stainless steel
Design Pressure	75 psig
Design Temperature	320°F
Opening size (approx.)	4.0 in x 4.0 in

Table 5-5 LHSI Heat Exchanger Design and Operating Parameters

Parameter	Value
Type	U-Tube, horizontally mounted
Number of units	4
Type of fluid (tube side)	Primary coolant
Type of fluid (shell side)	Cooling water from CCWS
Material (tube side)	Austenitic stainless steel
Material (shell side)	Ferritic steel
Design pressure (tube side)	1160 psig
Design pressure (shell side)	175 psig
Design temperature (tube side)	360°F
Design temperature (shell side)	225°F
CCWS maximum inlet temperature (normal cooldown)	100.4°F
CCWS maximum inlet temperature (design basis accident)	113°F
LHSI flowrate – injection mode LBLOCA (including minimum flow)	392.4 lb_m/s
LHSI flowrate – RHR operation (minimum flow line closed)	330.7 lb_m/s
CCWS flowrate Trains 1 and 4 (shell side)	828.9 lb_m/s
CCWS flowrate Trains 2 and 3 (shell side)	608.5 lb_m/s
Heat transfer coefficient (UA value)	3.5361 x 10^6 BTU/(hr °F)

Table 5-6 CCWS Design Parameters

Description	Technical Data
Component Cooling Water Pump (KAA10/20/30/40 AP001	
Number	4
Type	Centrifugal Pump
Flow rate max.	17,768 gpm
Pump head min (at max flow rate)	199.7 ft
Dedicated Component Cooling Water Pump (KAA80 AP001)	
Number	1
Type	Centrifugal Pump
Flow Rate	2678 gpm
Pump Head	180 ft
Component Cooling Water Surge Tank KAA10/20/30/40 BB001)	
Number	4
Volume	950 ft^3
Dedicated Component Cooling Water Surge Tank (KAA80 BB001)	
Number	1
Volume	75 ft^3
Component Cooling Water HX (KAA10/20/30/40 AC001)	
Number	4
Heat Load (DBA)	291.3×10^6 Btu/hr

Table 5-7 CCWS User Requirements
Sheet 1 of 3

Component	KKS	Heat Load (10^6 BTU/hr)	Required Flow (10^6 lb/hr)	Comments
Fuel Pool Cooling System				
Fuel Pool Cooling Heat Exchanger	30FAK10/20 AC001	29	0.8818	Normal Operations
		47.8	2.645	Normal Refueling
		33.78	2.645	Refueling (full off-load)
Reactor Coolant System				
RCP Lower Bearing Oil Cooler	JEB10/20/30/40 AC001	0.0819	0.0088	Cooling Isolated with Containment Isolation (CI) Stage 1 Signal
RCP Motor Air Cooler	JEB10/20/30/40 AC002/003	1.075	0.0529	
RCP Upper Bearing Oil Cooler	JEB10/20/30/40 AC004	1.305	0.1323	
RCP Thermal Barrier	N/A	0.3915	0.0198	Not Isolated with CI-1 or CI-2
Safety Injection and Residual Heat Removal System				
MHSI Pump Motor Cooler	JND10/20/30/40 AP001	0.239	0.0265	
LHSI Heat Exchanger	JNG10/20/30/40 AC001	152.8	2.984	Normal cooldown when CCW train is only connected to the train SIS users
		36.54	2.1906	Normal cooldown when CCW train is also connected to the CCW common header
		241	2.1906	DBA
LHSI Pump Motor Cooler	JNG20/30 AP001	0.1262	0.0141	
LHSI Sealing Fluid Cooler	JNG20/30 AP001	0.0341	0.0062	Flow isolated when LHSI pump is out of service for dilution prevention
Severe Accident Heat Removal System				
SAHRS Heat Exchanger	JMQ40 AC001	47.77	1.106	Cooled by dedicated CCWS
SAHRS Pump Seal Watercooler	JMQ40 AC003	0.0593	0.0053	Cooled by dedicated CCWS

Table 5-7 CCWS User Requirements
Sheet 2 of 3

Component	KKS	Heat Load (10^6 BTU/hr)	Required Flow (10^6 lb/hr)	Comments
SAHRS Pump Motor Cooler	JMQ40 AC002	0.089	0.0079	Cooled by dedicated CCWS
SAHRS Pump Bearing Cooler	JMQ40 AC004	0.0223	0.002	Cooled by Dedicated CCWS
Volume Control System				
CVCS HP Cooler	KBA11/12 AC001	30.71	0.873	Plant Heatup
		14.3	0.2968	Normal Load
		6.9	0.1228	Plant Cooldown
Charging Pump Motor Cooler	KBA31/32 AP001	0.1706	0.0198	
Charging Pump Oil Cooler	KBA31/32 AP001	0.1706	0.0025	
Charging Pump Seal Water Cooler	KBA31/32 AP001	0.1706	0.0033	
Coolant Treatment System				
After Cooler	KBF25 AC001	0.6824	0.0381	Cooling Isolated with Safety Injection (SI) Signal
Condensate Cooler	KBF20 AC006	0.9315	0.0262	
Condenser	KBF20 AC003	0.6824	0.019	
Gas Cooler	KBF20 AC004	0.0358	0.002	
Gas Cooler	KBF40 AC004	0.0481	0.0027	
Reflux Cooler	KBF40 AC003	0.9622	0.0262	
Seal Water Cooler	KBF35 AC001	0.1297	0.0071	
Coolant Degasification System				
CDS Condenser	KBG10 AC002	8.131	0.4524	Cooling Isolated with SI Signal
CDS Gas Cooler	KBG10 AC003	0.6244	0.0349	
Containment Ventilation System				
Containment HVAC Cooler 1/2/3/4	KLA61/63 AC001/003	1.365	0.1437	Cooling Isolated with CI Stage 1 Signal
Solid Waste System				
Condenser	KPC30/40/50 AC001	0.0341	0.0024	Cooling Isolated with SI Signal
Vacuum Unit	KPC60 AC001	0.0239	0.0048	

Table 5-7 CCWS User Requirements
Sheet 3 of 3

Component	KKS	Heat Load (10^6 BTU/hr)	Required Flow (10^6 lb/hr)	Comments
Liquid Waste Processing System				
Distillate Cooler	KPF11 AC004	0.3583	0.0167	Cooling Isolated with SI Signal
Gas Cooler	KPF11 AC003	1.365	0.0397	
Injection Water Cooler	KPF11 AC006	0.0409	0.0024	
Seal Water Cooler	KPF11 AC007	0.1297	0.0071	
Nuclear Island Drain and Vent System				
Reactor Coolant Drain Cooler	KTA10 AC001	1.996	0.1124	Cooling Isolated with CI Stage 1 Signal
Nuclear Sampling System				
Nuclear Sampling (RCS/HL3)	KUA10 AC001	0.3958	0.0147	
Nuclear Sampling (RCS/HL3)	KUA20 AC001	0.3958	0.0147	
Nuclear Sampling (RCS/PZR)	KUA30 AC001	0.3958	0.0147	
Steam Generator Blowdown System				
SGBS Second Stage Cooler	LCQ51 AC003/004	10.03	0.1932	Cooling Isolated with SI Signal; Heat Exchangers are in series and the heat transfer listed is the combined load.
Safety Chilled Water System				
Safety Chiller	QKA20/30 AC002	4.123	0.373	
Operational Chilled Water System				
OCWS (QNA)	QNA21/22/23/24 AC002	11.84	0.986	Cooling Isolated with SI Signal
OCWS (QNB)	QNB62/63 AC002	1.269	0.119	
Sampling System for Condensate Systems				
SG Secondary Sampling (SG1)	QUC11 AC001	0.2593	0.0097	
SG Secondary Sampling (SG2)	QUC12 AC002	0.2593	0.0097	
SG Secondary Sampling (SG3)	QUC13 AC003	0.2593	0.0097	
SG Secondary Sampling (SG4)	QUC14 AC004	0.2593	0.0097	

Table 5-8 Essential Service Water Design Parameters

Essential Service Water Pump 30PEB10/20/30/40 AP001	
Description	Technical Data
Number	4
Type	Wet Pit Vertical Turbine
Normal Flow Rate	19,340 gpm
Required Pump Head at Normal Flow Rate	185 ft/H_2O
Required Minimum Water Level in the Basin	95 inches (from suction inlet)
Design Cold (UHS Outlet) Water Temperature, °F, (Max, DBA)	95
Max Cooling Tower Basin Temperature Limit during Normal Plant Operation to Verify UHS Performance in a DBA, °F, (Max)	90

Table 5-9 Dedicated Essential Service Water Design Parameters

Dedicated Essential Service Water Pump 30PEB80 AP001	
Description	Technical Data
Number	1
Type	Wet Pit Vertical Turbine
Normal Flow Rate	2737 gpm
Required Pump Head at Normal Flow Rate	150 ft/H_2O
Required Minimum Water Level in the Basin	46 inches (from suction inlet)

Table 5-10 Extra Borating System Design and Operating Parameters

Parameter	Value
Pump design pressure	3770 psig
Pump design temperature	212°F
Nominal flow rate	52 gpm / pump
Minimum required flow rate	49 gpm
Maximum allowable flow rate	110.8 gpm
Tank design pressure	15 psig
Tank design temperature	140°F
Minimum boron enrichment	37% B-10
Boron concentration in tank	7000 to 7300 ppm
Tank gross volume (Tank 1 / Tank 4)	1274 ft^3 / 1253 ft^3
Tank minimum required volume (based on analysis)	1994 ft^3
Pump discharge relief valve setpoint / capacity	3625 psig / 52 gpm
Penetration and injection piping relief valve setpoint / capacity	3395 psig / 1 gpm

Table 5-11 Fuel Pool Cooling and Purification System Component Design Data
Sheet 1 of 2

Fuel Pool Cooling Pump		
Quantity	4	
Nominal Flow	1.76 x 10^6 lb/hr (one pump per train) 2.12 x 10^6 lb/hr (two pumps per train)	
Design Pressure	120 psig	
Design Temperature	230°F	
Material	Austenitic stainless steel	
Fuel Pool Cooling Heat Exchangers		
Quantity	2	
Type	Plate	
Fluid Circulated	SFP Water	CCWS
Nominal Flow – One Pump	1.76 x 10^6 lb/hr	2.645 x 10^6 lb/hr
Nominal Flow– Two Pumps	2.12 x 10^6 lb/hr	
Inlet Temperature (Typical)	120°F to 140°F	100.4°F
Outlet Temperature (Typical)	condition dependent	condition dependent
Design Pressure	120 psig	175 psig
Design Temperature	180°F	180°F
Material	Austenitic stainless steel	
Spent Fuel Pool Makeup Pumps		
Quantity	1	
Nominal Flow	Approximately 25 gpm	
Design Pressure	25 psig	
Design Temperature	140°F	
Material	Austenitic stainless steel	
Fuel & Reactor Building Purification Pumps		
Quantity	2	
Nominal Flow	400 gpm	
Design Pressure	175 psig	
Design Temperature	140°F	
Material	Austenitic stainless steel	

Table 5-11 Fuel Pool Cooling and Purification System Component Design Data
Sheet 2 of 2

FPPS Mixed Bed Ion Exchanger	
Resin Volume	106 ft^3
Design Pressure	175 psig
Design Temperature	140°F
Sieve Tray Gap Width	0.008 in
Material	Austenitic stainless steel
Resin Trap for Mixed Bed Ion Exchanger	
Type	Sieve basket
Mesh Size	200 micron
Design Pressure	175 psig
Design Temperature	140°F
Material	Austenitic stainless steel
Cartridge Pre-filter	
Type	Cartridge type filter
Retention Rate	10 micron
Design Pressure	175 psig
Design Temperature	140°F
Material	Austenitic stainless steel
Cartridge Post Filter	
Type	Cartridge type filter
Retention Rate	1 micron
Design Pressure	175 psig
Design Temperature	140°F
Material	Austenitic stainless steel

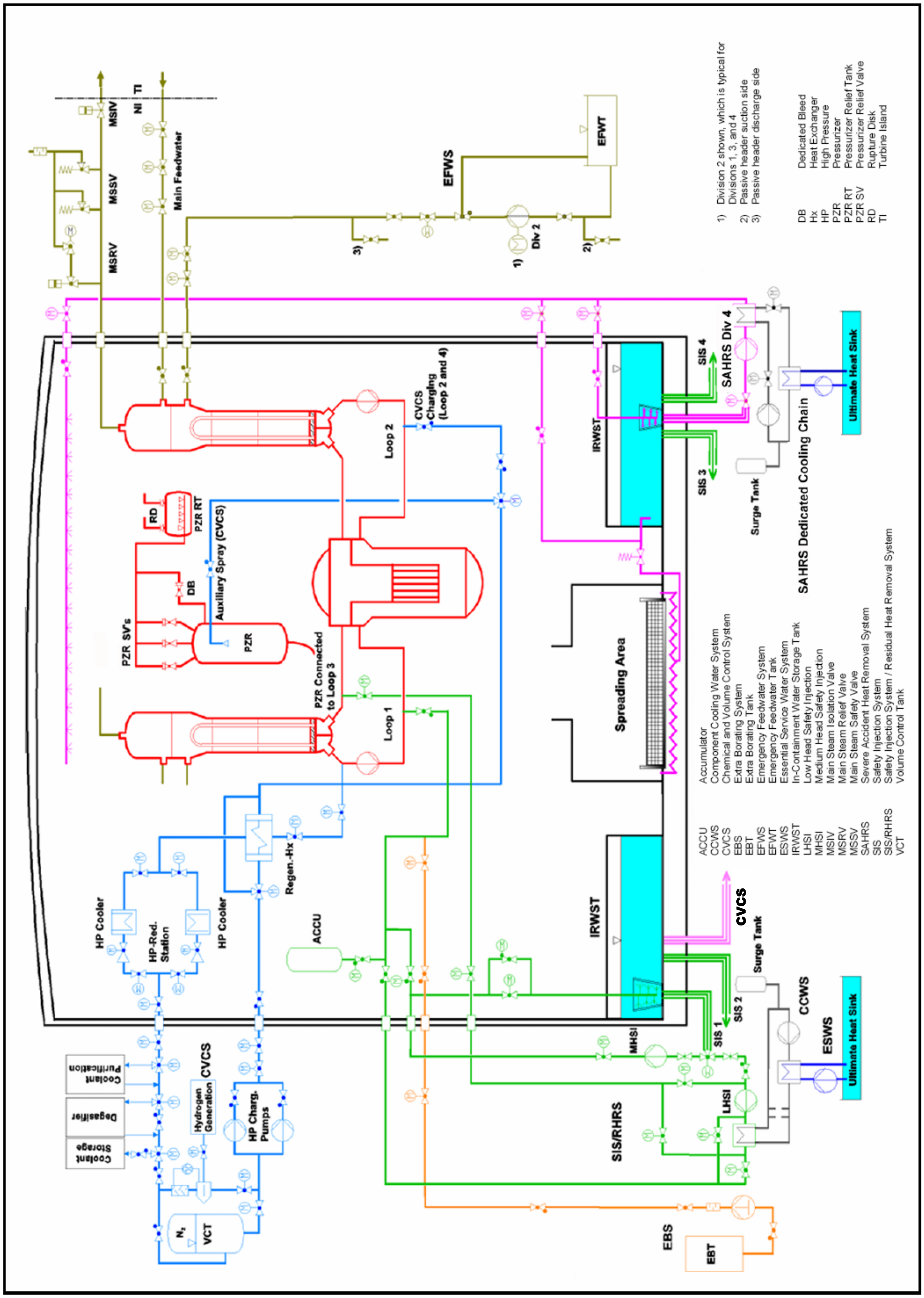

Figure 5-1 Major US-EPR Fluid Systems

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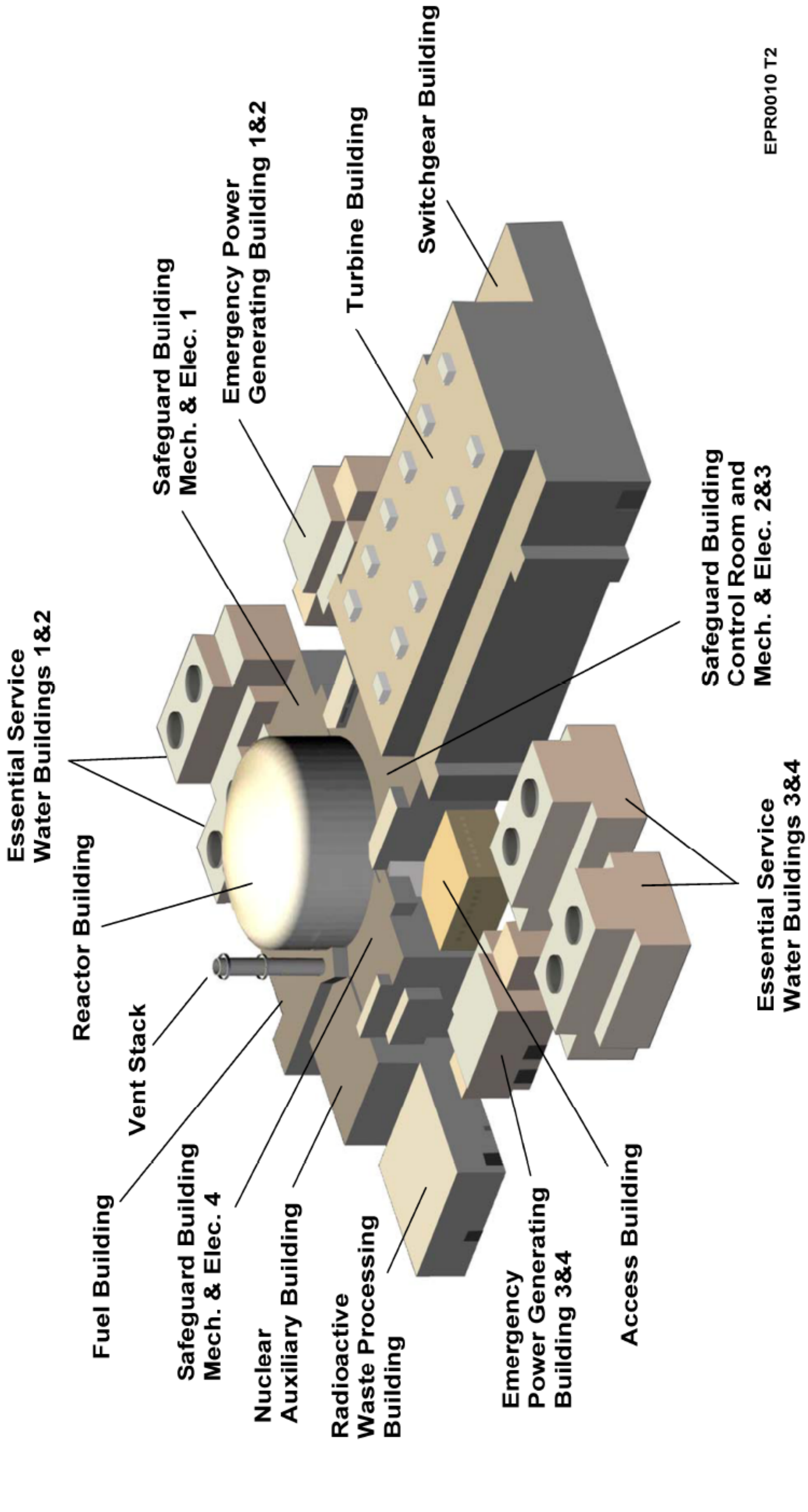

Figure 5-2 Plant Configuration

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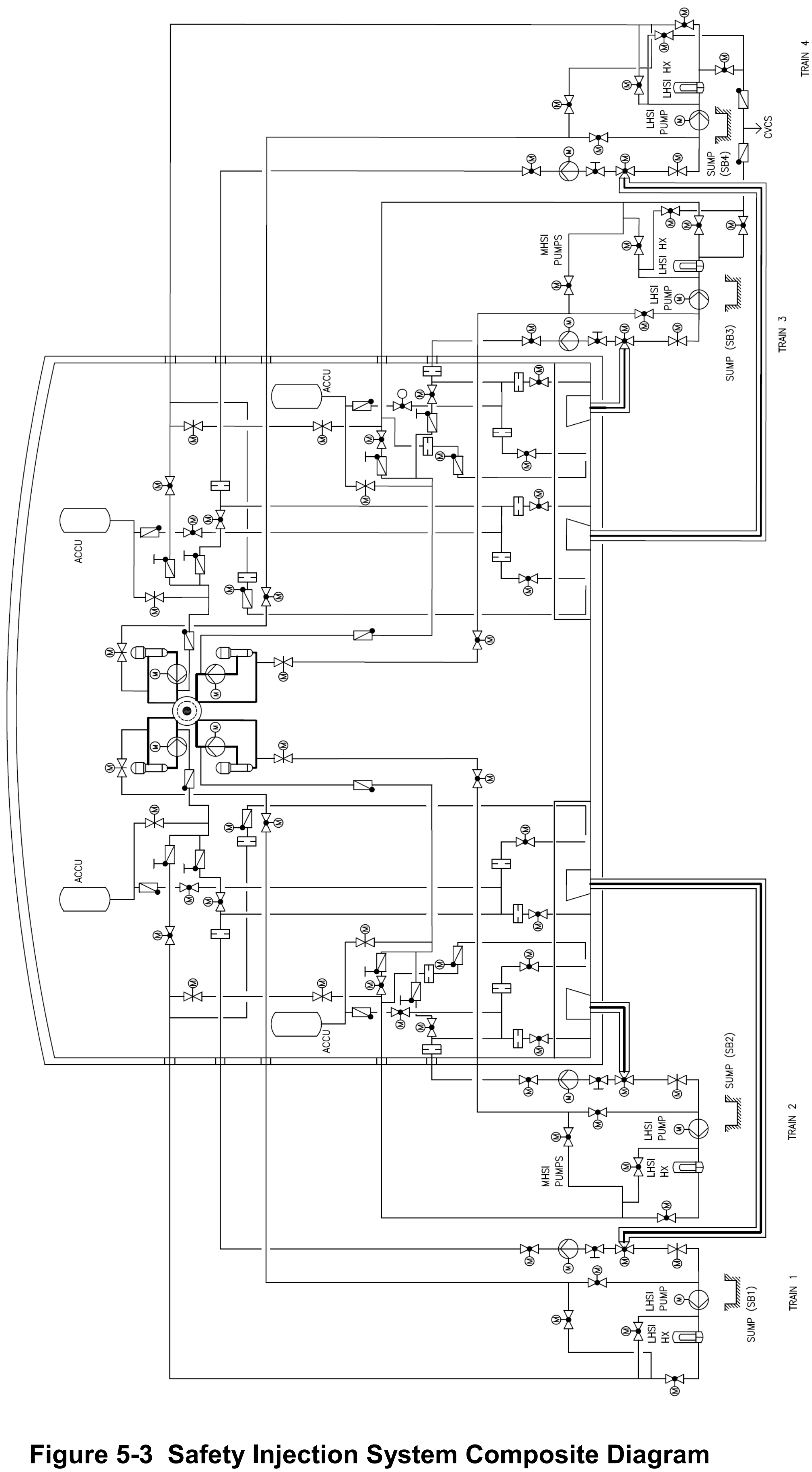

Figure 5-3 Safety Injection System Composite Diagram

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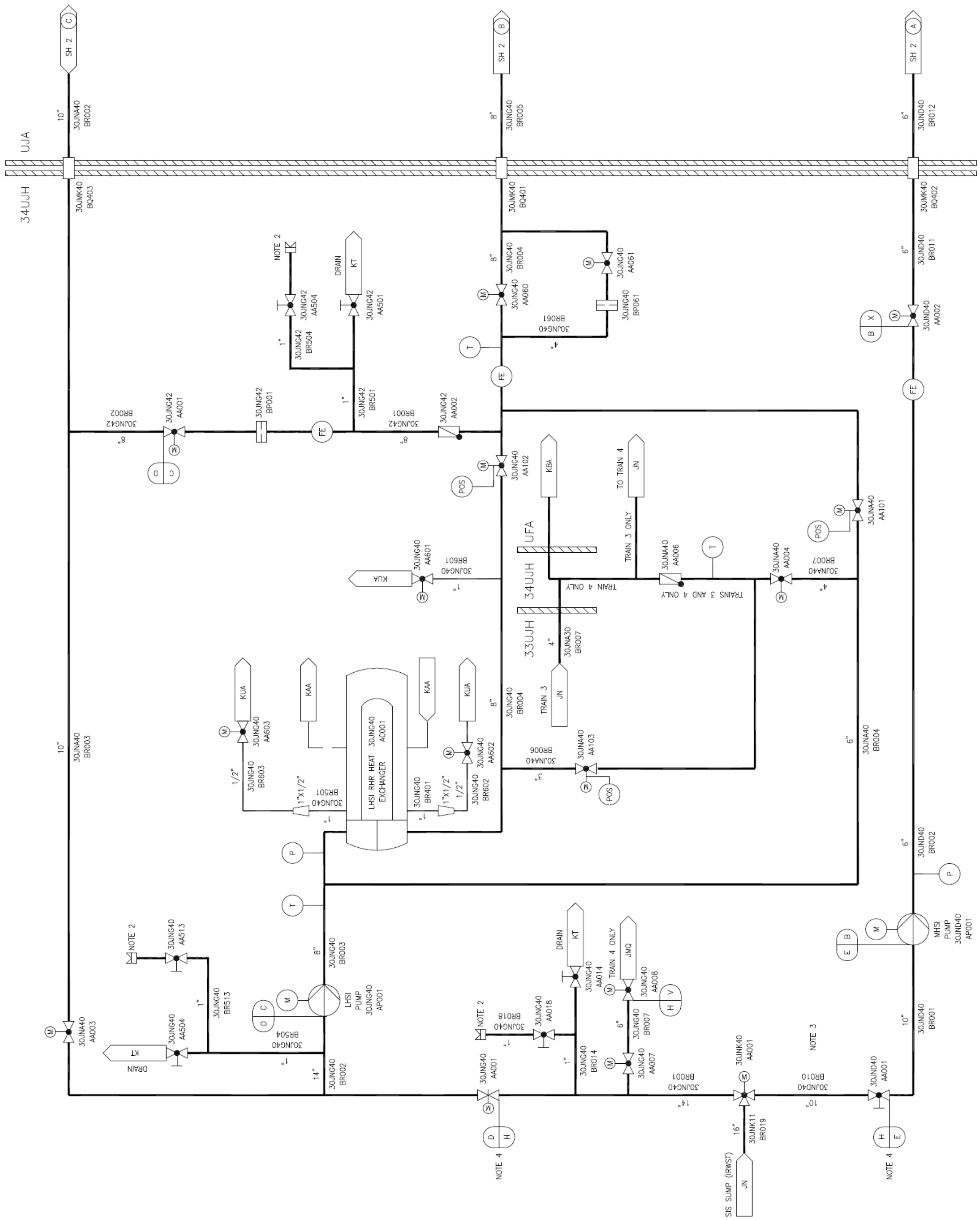

Figure 5-4 SIS/RHRS Train (Sheet 1)

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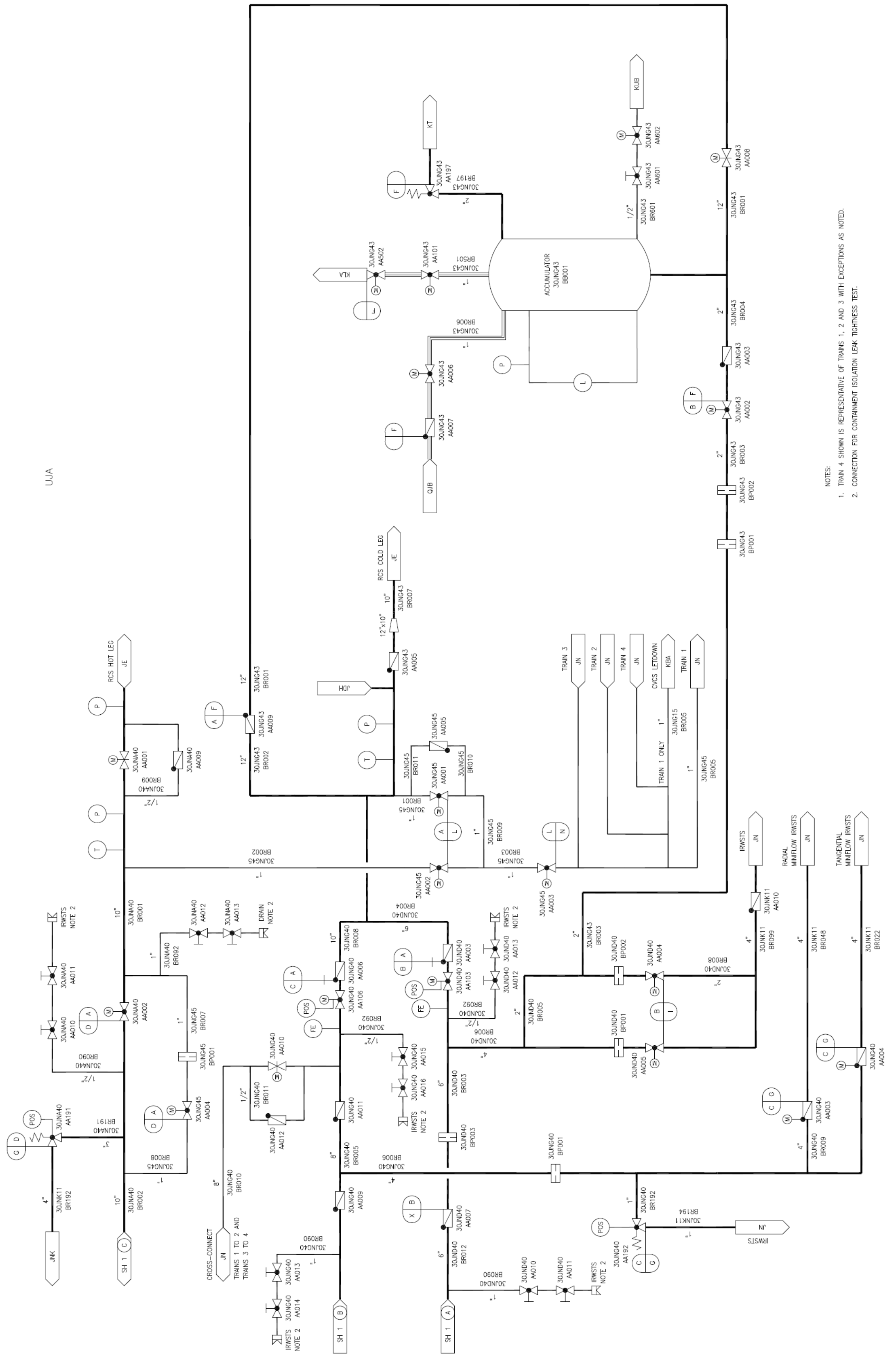

Figure 5-5 SIS/RHRS Train (Sheet 2)

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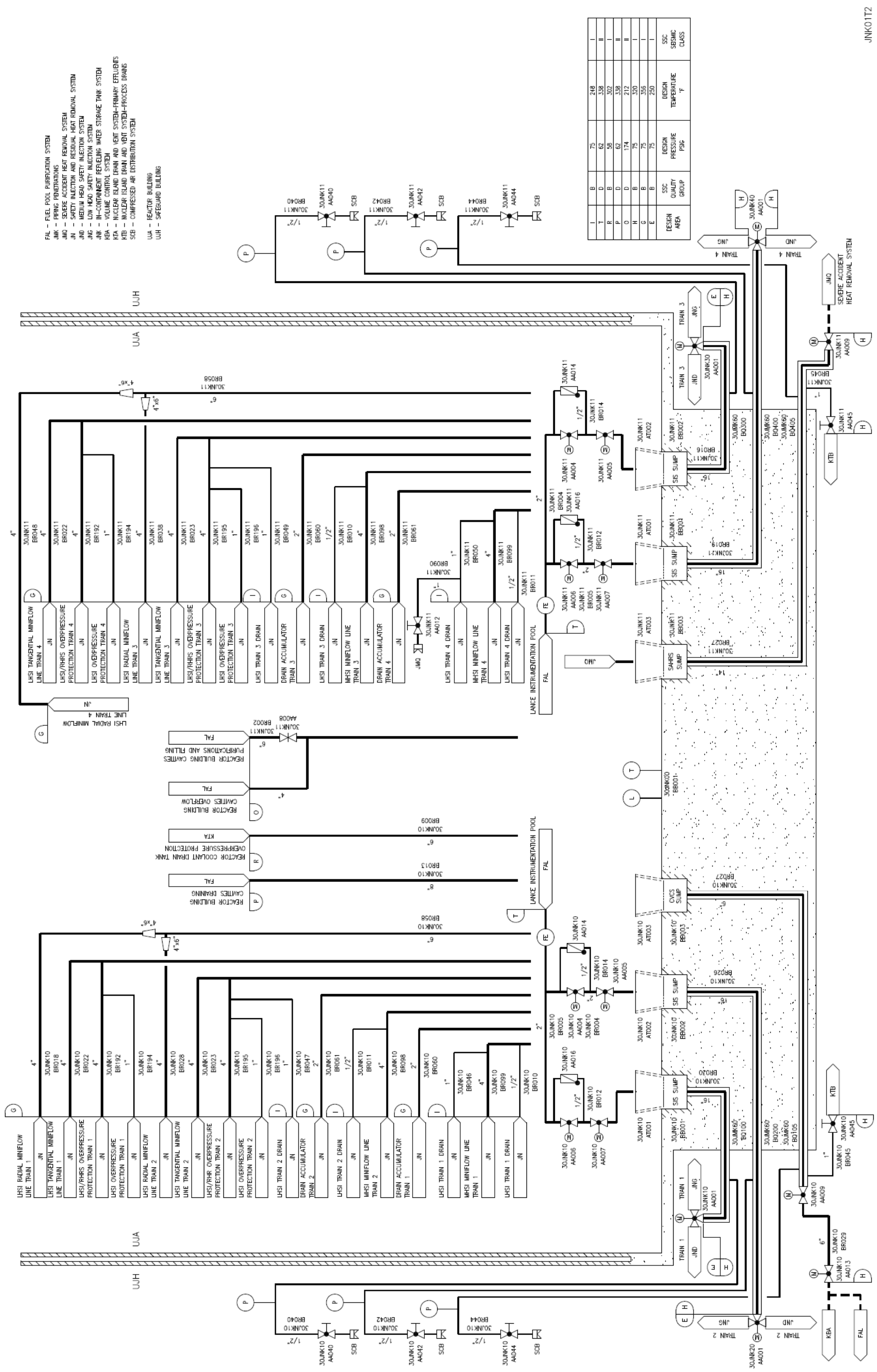

Figure 5-6 IRWST Layout

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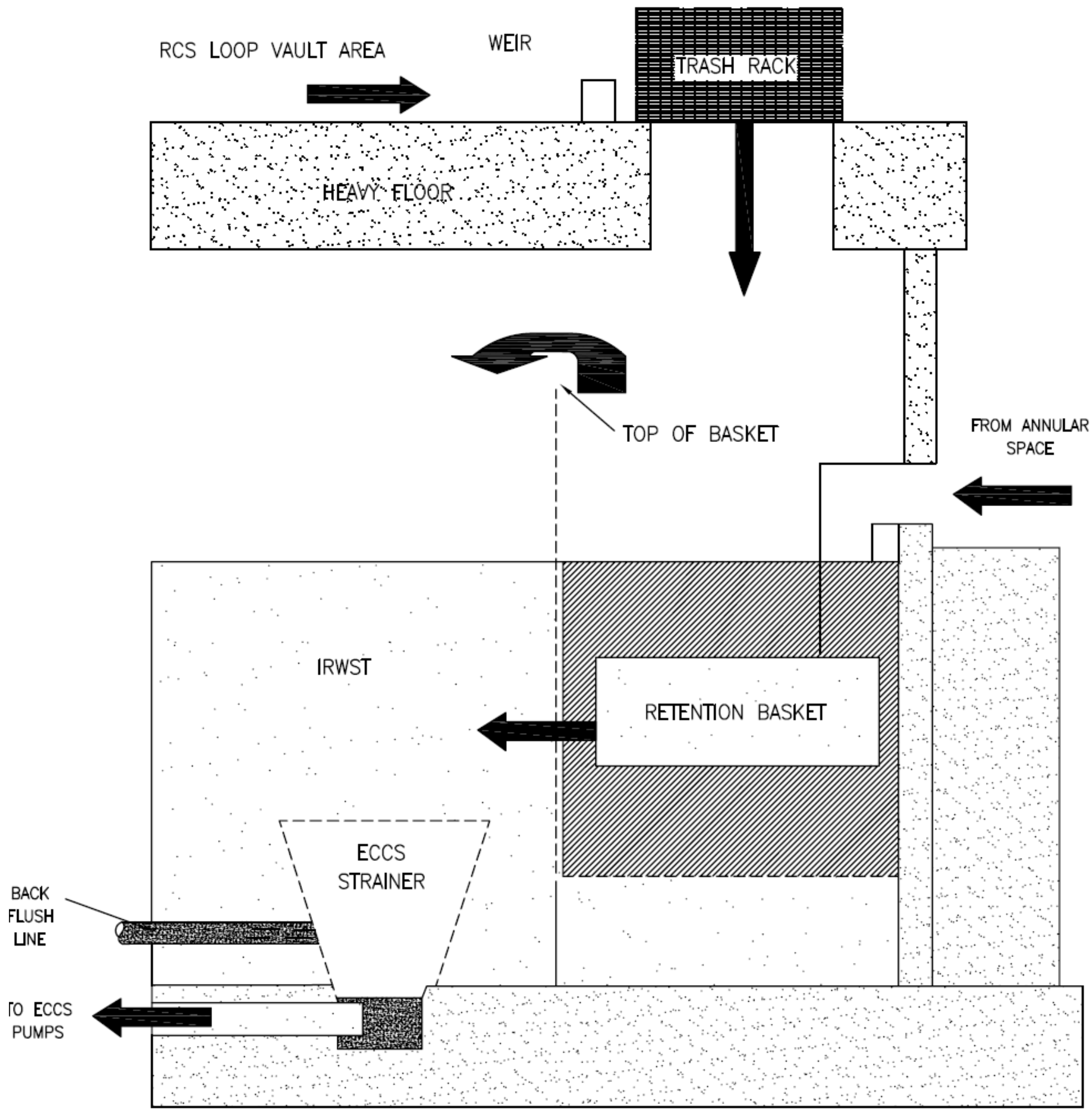

Figure 5-7 Sump Debris Entrainment Prevention Features

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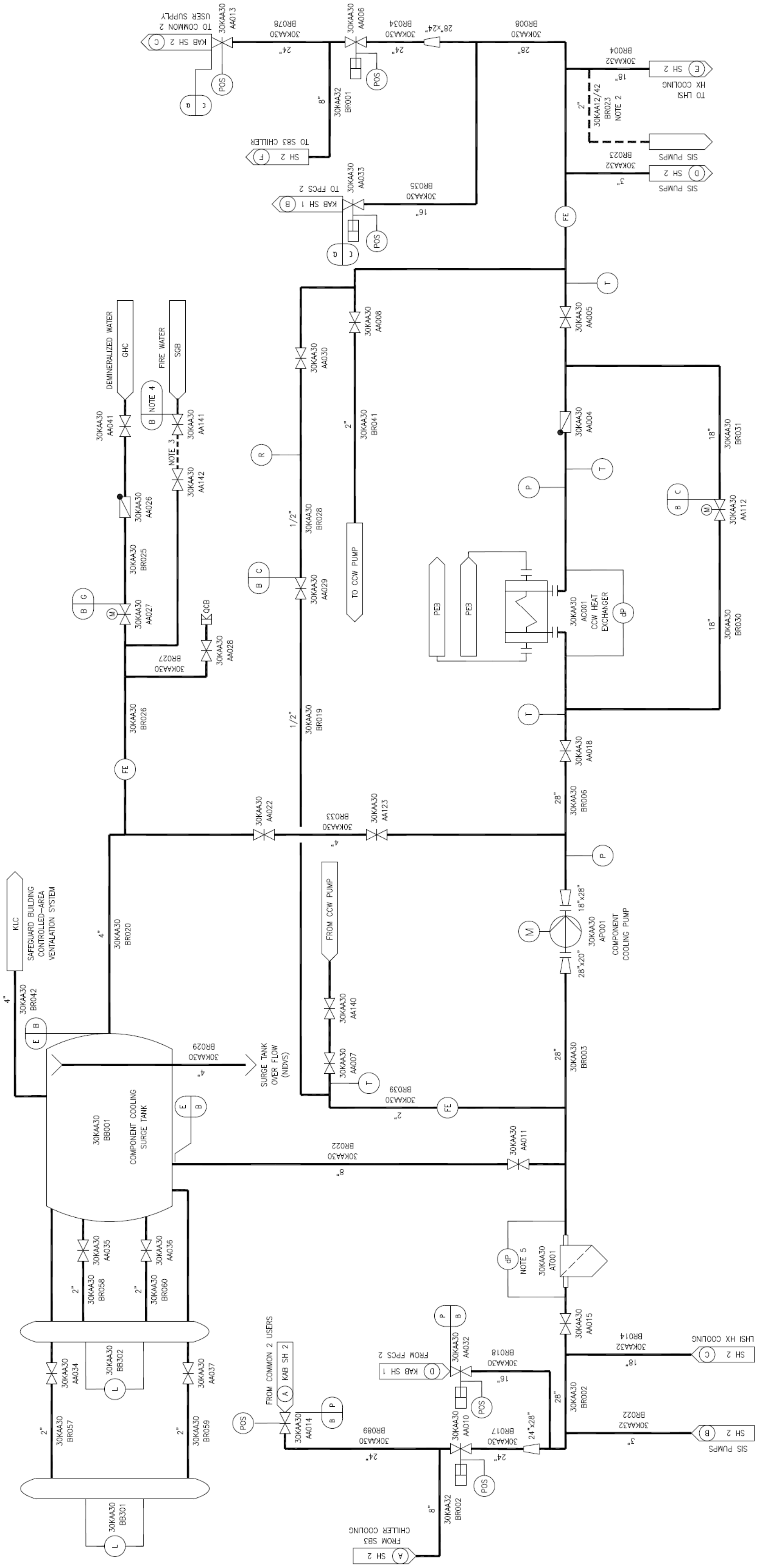

Figure 5-8 Component Cooling Water System Train

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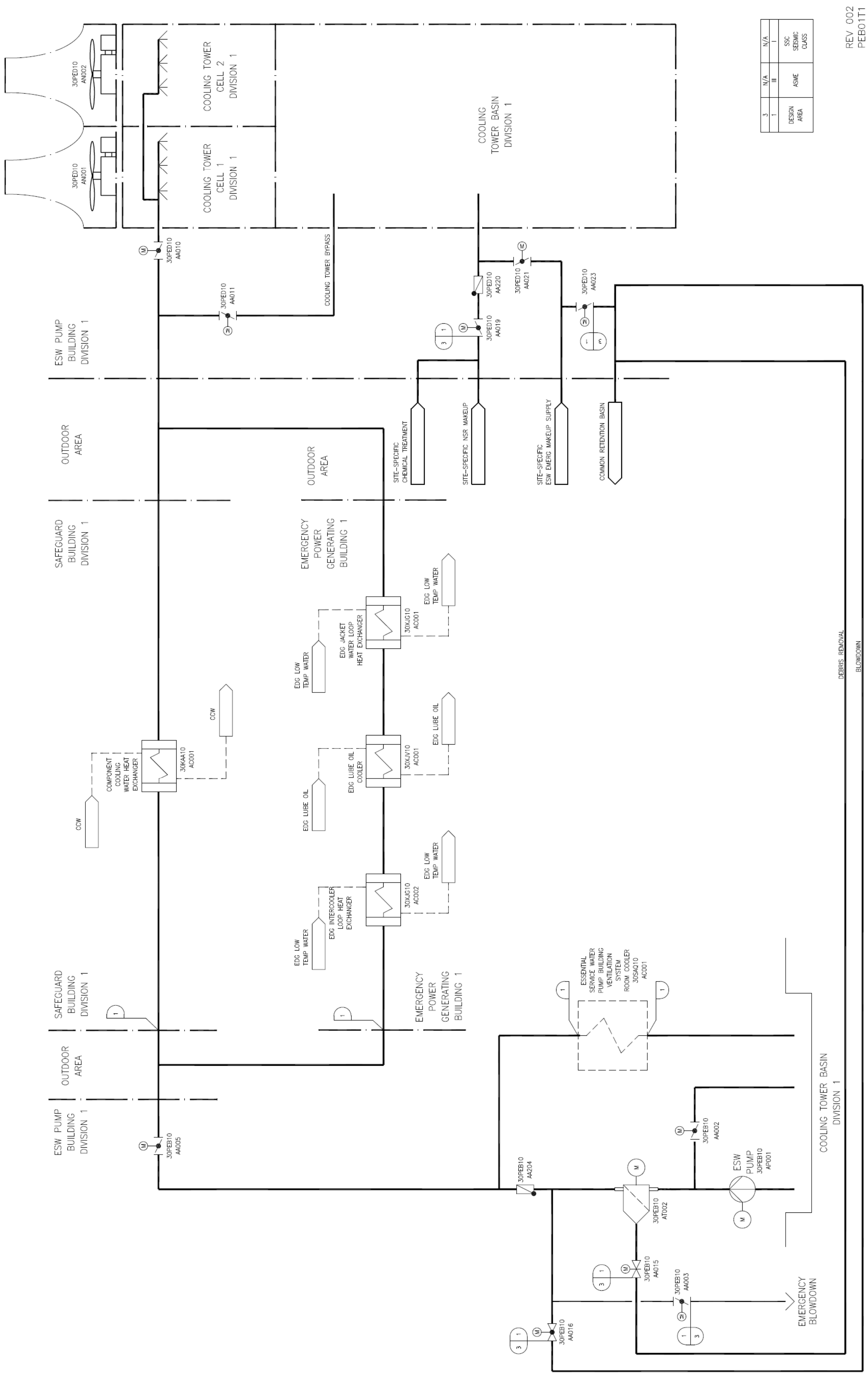

Figure 5-9 Essential Service Water System Train

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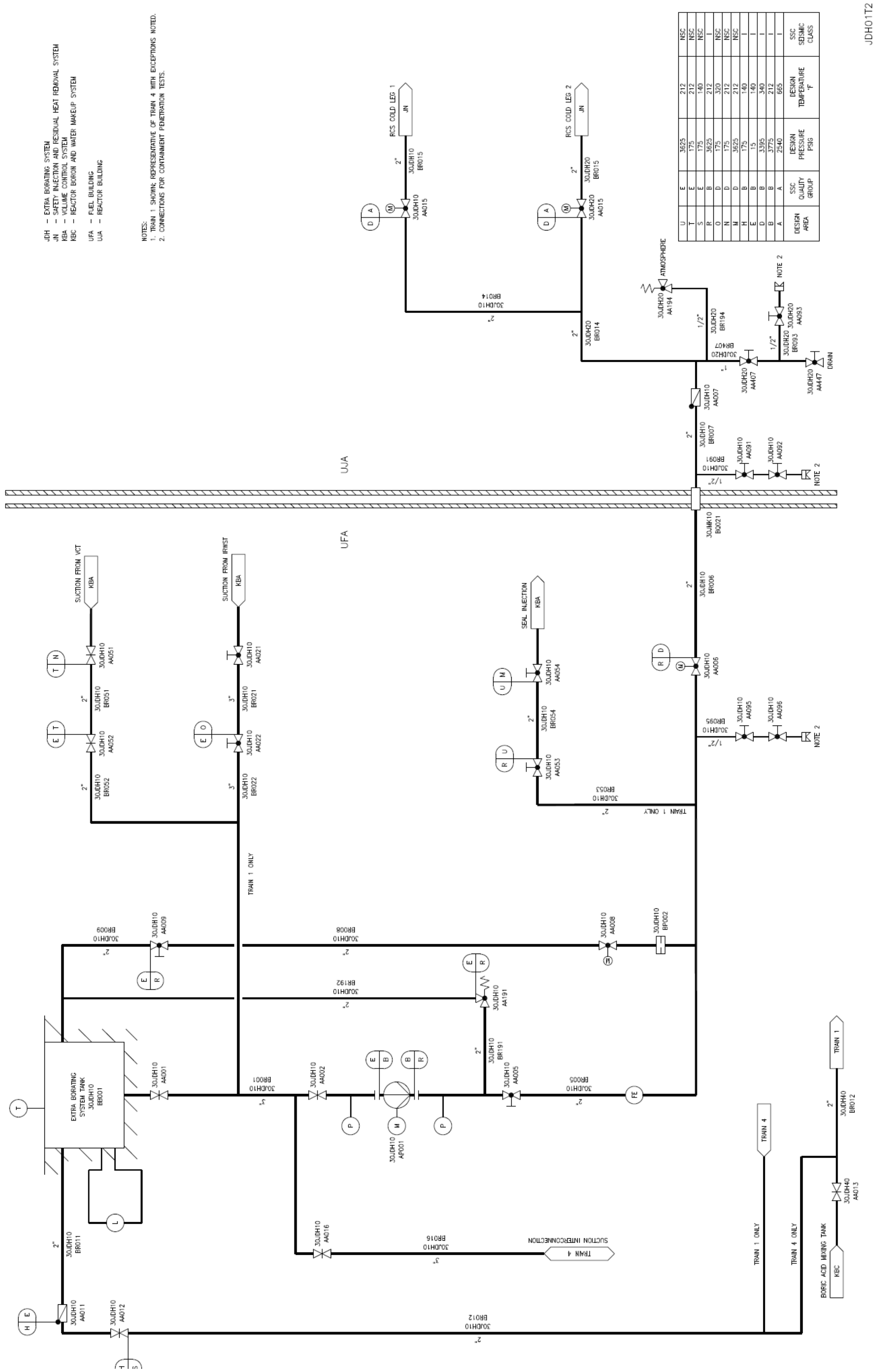

Figure 5-10 Extra Borating System Train

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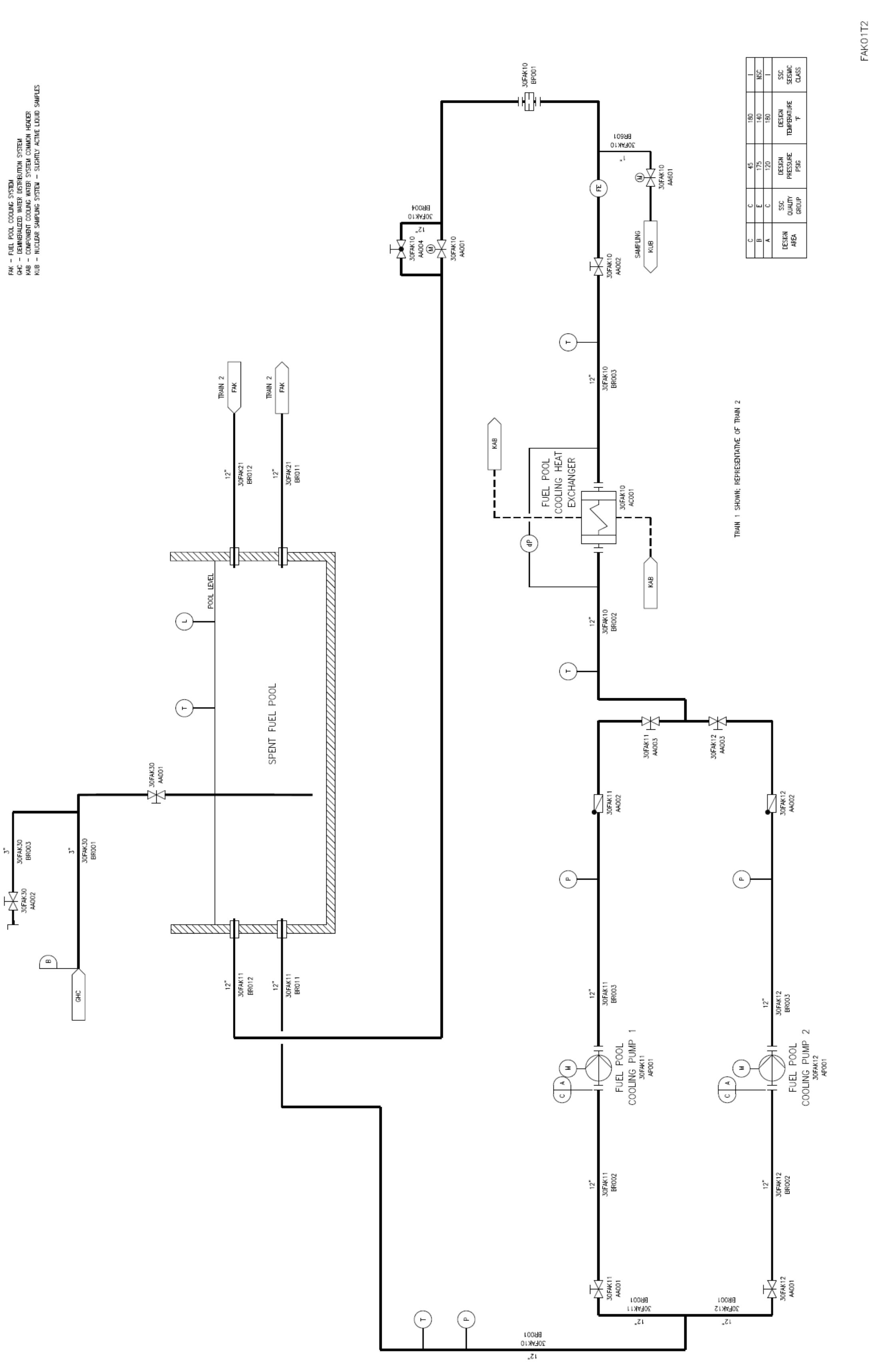

Figure 5-11 Fuel Pool Cooling System

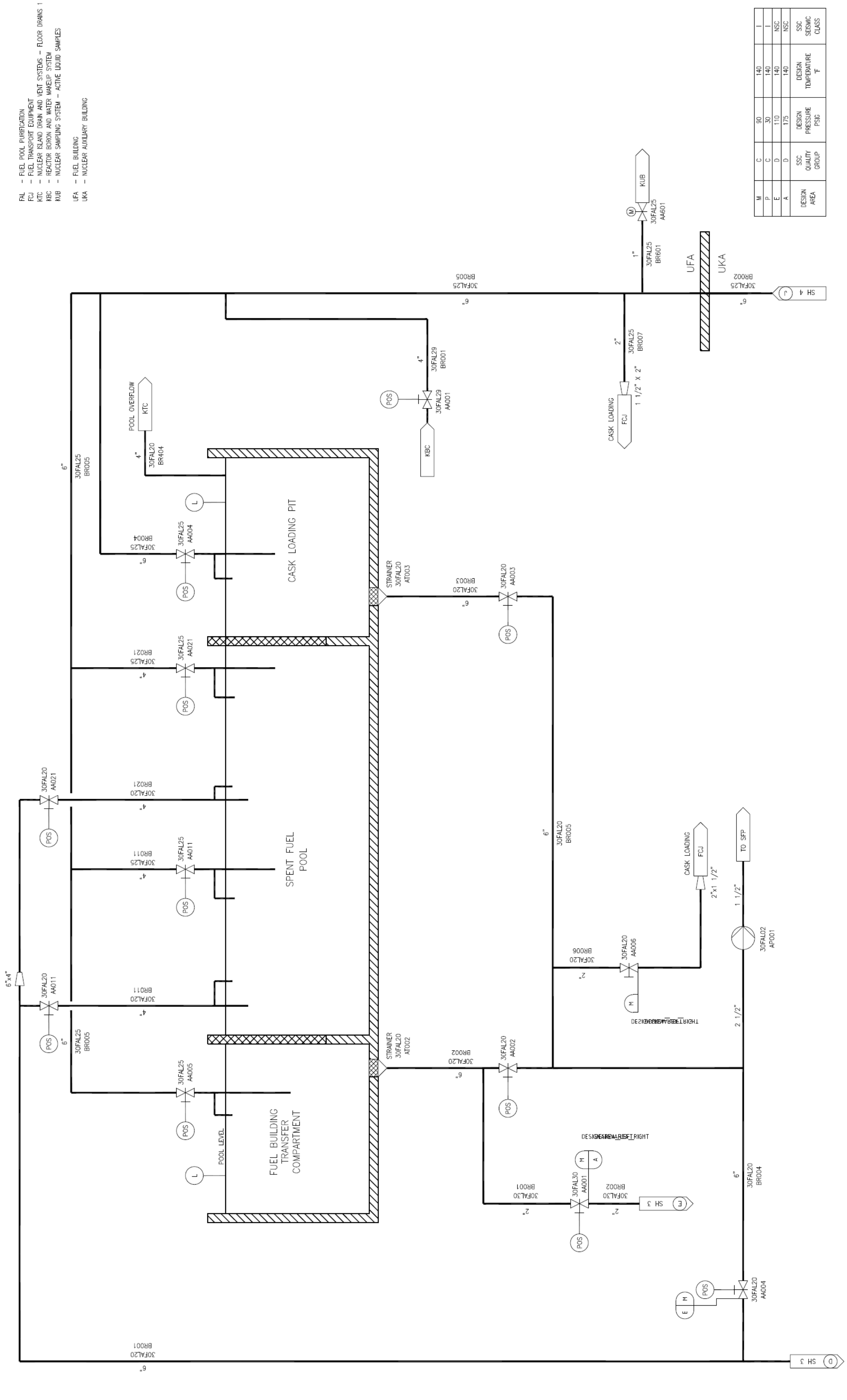

Figure 5-12 Fuel Pool Purification System (Sheet 1)

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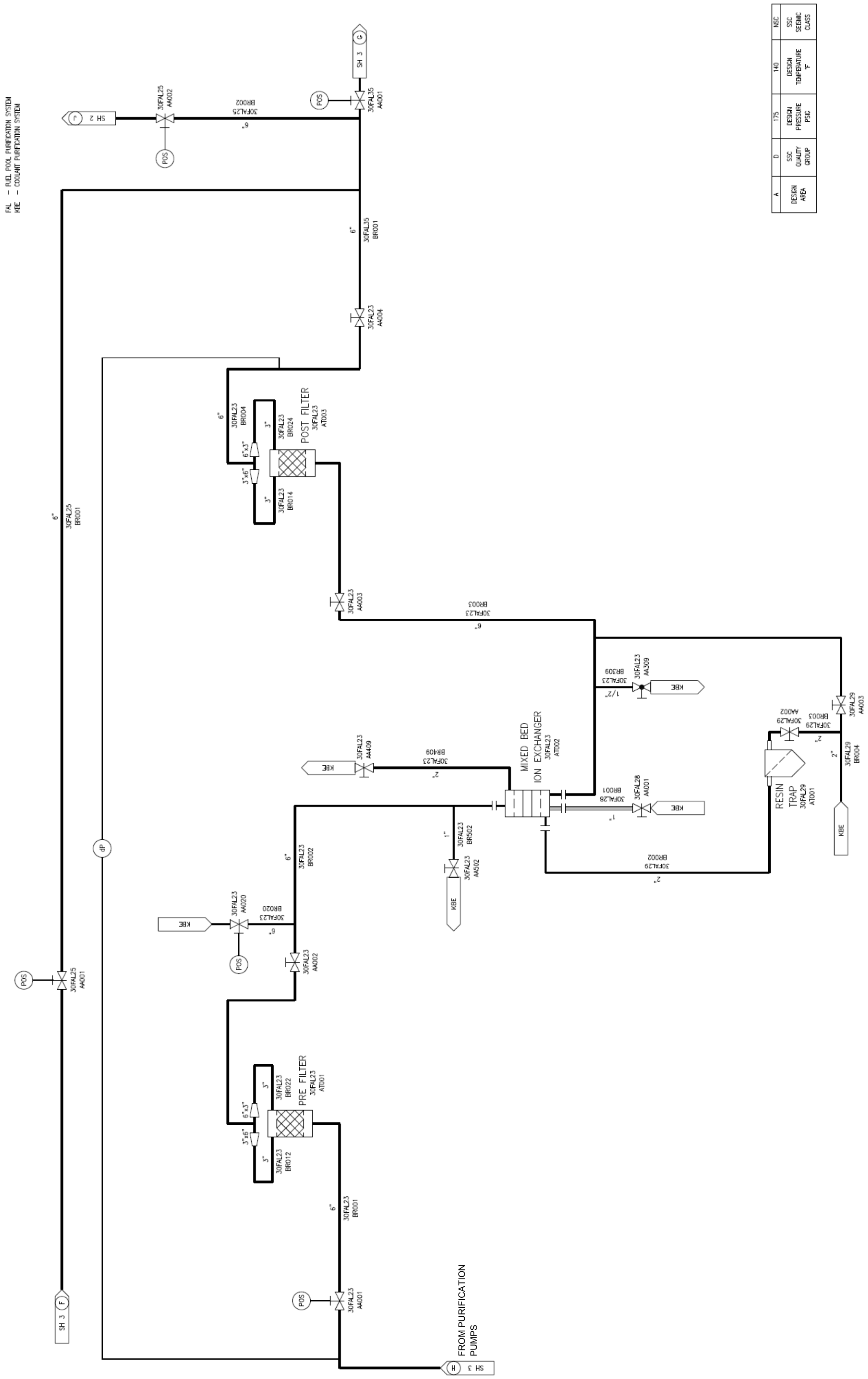

Figure 5-13 Fuel Pool Purification System (Sheet 2)

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