US-EPR Technology Manual

Chapter 4.0

STEAM AND POWER CONVERSION SYSTEM

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4.0 STEAM AND POWER CONVERSION SYSTEM

Learning Objectives:

1. State the purposes, and describe the operation, of the following steam and power conversion systems:

    a. Main steam supply system,
    b. Condensate and feedwater system,
    c. Condenser circulating water system, and
    d. Emergency feedwater system.

2. Explain the purposes, and describe the operation, of the main steam relief trains.

3. Describe the major differences between the design of the US-EPR steam and power conversion system and those of currently operating PWRs.

4.1 General Description

The steam and power conversion system removes energy from the reactor coolant in the steam generators (SGs) and converts it into electric power in the turbine-generator. The steam and power conversion system is comprised of the following process systems and components:

- Turbine-generator (TG),
- Main steam supply system (MSSS),
- Main condensers,
- Main condenser evacuation system (MCES),
- Turbine gland sealing system (TGSS),
- Turbine bypass system (TBS),
- Condenser circulating water system (CWS),
- Condensate cleanup system,
- Condensate and feedwater system,
- Steam generator blowdown system (SGBS), and
- Emergency feedwater system (EFWS).

The following portions of the steam and power conversion system have safety-related functions:

- The main steam piping between each SG outlet nozzle and the fixed point restraint downstream of its respective main steam isolation valve (MSIV),
- The main feedwater piping between each SG inlet nozzle and the fixed restraints upstream of its respective feedwater isolation valves, and
- The EFWS.

Table 4-1 provides the major steam system parameters at rated thermal power, along with TG design data.

Steam generated in the four SGs is supplied by the MSSS to the high pressure (HP) turbine through stop and control valves which regulate steam flow. After expanding across the HP turbine blading, HP turbine exhaust steam is reheated in two moisture separator reheaters (MSRs). The MSRs supply the intermediate pressure (IP) turbine through stop and intercept valves. After expanding across the IP turbine blading, IP turbine exhaust steam flows to the three low pressure (LP) turbines.

The main condenser condenses the LP turbine exhaust and transfers the heat rejected in the cycle to the CWS. The CWS rejects heat to the normal heat sink. The main condenser operates at a vacuum maintained by the MCES.

Feedwater pumps return the condensate to the SGs through regenerative feedwater heaters that heat the condensate/feedwater with extraction steam from the turbine elements. A feedwater storage tank is integrated into the cycle to deaerate and heat the condensate. This tank also provides a buffer volume to accommodate minor system transients.

Water quality in the steam-water cycle is maintained by the SGBS and the condensate cleanup (polishing) system. Makeup water for the cycle is conditioned in a demineralizing system, stored in the demineralized water storage tank, and fed as required to the steam cycle.

The turbines are connected in tandem and operate at 1800 rpm. A three-phase synchronous electric generator is coupled directly to the turbine shaft. The generator has a hydrogen-cooled rotor and a water-cooled stator. It is equipped with a collector for the static excitation system directly coupled to the generator shaft.

4.2 Turbine-Generator

The turbine-generator package consists of an 1800-rpm, single-flow high pressure turbine and a single-flow intermediate pressure turbine in a common casing, and three double-flow low pressure elements in tandem. The generator has a hydrogen-cooled rotor and a stator cooled by de-ionized water. The generator is directly coupled to the turbine shaft. Moisture separation from and reheating of the steam is provided between the HP turbine and IP turbine by two combined MSR assemblies. The MSRs have two stages of reheating. The TG package is shown in Figure 4-1.

The TG performs no safety-related functions and therefore has no nuclear safety-related design bases. The TG's principal design capabilities include:

- The TG is designed for base load operation and has provisions for load follow operation.

- The TG is capable of a load step (increase or decrease) of 10% of rated load below the 50% power level, and a ramp rate (increase or decrease) of 5%/min when the power level is in the range of 50 to 100%, without necessitating a turbine trip.

- The TG is designed to trip automatically under abnormal conditions.

- The TG is designed to accept a sudden loss of full load without exceeding design overspeed.

The TG package equipment includes the HP turbine stop and control valves, the reheat stop and intercept valves, the MSRs and MSR drain tanks, steam lead piping, cold reheat piping, hot reheat piping, the TG control system, the static excitation system, and accessory equipment.

The TG design features a combined HP/IP cylinder module, in which the HP and IP steam flows are in opposite directions, in a single-shell casing. The HP and IP steam inlets are located at the center of the module, and the exhausts are at its two extremities. The HP section of the HP/IP module receives steam through four steam leads, one from each main steam control valve outlet. Normal operation utilizes full-arc admission. The steam is expanded axially across the stationary and rotating blades. Extraction steam from the HP turbine at two locations supplies the sixth and seventh stages of feedwater heating and the heating steam to the first-stage reheaters. HP turbine exhaust steam is collected in four cold reheat pipes. Most of the exhaust steam is routed to the MSR inlets, but some of it supplies the fifth stage of feedwater heating. After the HP turbine exhaust steam has undergone moisture removal and reheating in the MSRs, the steam is directed through four steam inlet pipes to the IP section of the HP/IP module, where it expands in stages of stationary and rotating blades. Extraction steam from the IP section supplies the third and fourth stages of feedwater heating.

Each of the three LP turbines receives steam exhausted from the IP outlets through two steam headers, one on each side of the turbine, fitted with expansion bellows. The LP turbines are identical, double-flow turbines. Each LP turbine has an inner structure and an outer casing. The inner structure supports the LP blade carriers and the LP bearings. The outer casing collects the steam exhausted from the last LP stages. The outer casing is installed independently of the inner casing and is welded to the condenser, which is directly anchored to the foundation slab. The outer casing moves freely with condenser thermal movements. A flexible sealing ring provided at each extremity maintains vacuum tightness between the outer casing and the inner LP turbine structure. Extraction steam from the LP turbines supplies the first and second stages of feedwater heating.

Four main stop and control valves admit steam to the HP turbine. The primary function of the main stop valves is to quickly isolate the steam flow to the turbine under emergency conditions. The primary function of the control valves is to control steam flow to the turbine in response to the turbine control system. Each control valve is operated by a single-acting, spring-closed servomotor and is opened by a high pressure, fire-resistant fluid supplied through a servo valve. The stop and control valves close in approximately 0.30 sec.

The reheat stop and intercept valves are arranged between the MSRs and the IP turbine inlets. The IP steam supply is controlled by four sets of two series-mounted valves. For each set, the stop valve fulfills the turbine protection function, and the intercept valve fulfills control and protection functions. The valves are butterfly-type valves. The reheat stop and intercept valves close in approximately 0.30 sec.

The generator is a four-pole machine directly driven by the turbine; it supplies the step-up transformer with high voltage electrical output. The field winding is directly cooled by hydrogen gas. The stator winding is directly cooled by an internal circulation of de-ionized water (stator cooling water). The generator static excitation system is controlled by an automatic voltage regulator. The generator rotor is made from a solid-alloy steel forging with high tensile strength. The slots for the field coils are milled in the central body of the rotor. The frame, which constitutes the outer envelope, is made of an assembly of heavy welded steel plates, forming a cylindrical shell. The machine is gas tight, and the hydrogen coolers are located in the frame itself. Hydrogen detectors are located around the generator hydrogen system to provide warning of a hydrogen leak.

Two cylindrical-shell, combined MSRs are installed in the steam paths between the HP and IP turbines. The MSRs dry and reheat the HP turbine exhaust steam. Cold reheat steam is piped into the bottoms of the MSRs. Moisture is removed in chevron-type moisture separators, drained to the moisture separator drain tanks, and then pumped to the deaerator/feedwater storage tank. The dry steam passes across two stages of reheaters, which are supplied with turbine extraction steam (first reheating stage) and main steam (second reheating stage). The steam is then routed to the hot reheat stop valves and intercept valves, which are located upstream of the IP turbine inlet nozzles. The first stage reheaters drain via drain tanks to the HP heaters, and the second stage reheaters drain via drain tanks to the high pressure drain coolers. Safety valves are provided on the MSRs for overpressure protection.

4.3 Main Steam Supply System

The main steam supply system conveys steam from the steam generators to the high pressure turbine. The MSSS also provides steam to the second-stage reheaters, deaerator pegging steam, and backup auxiliary steam.

4.3.1 Design Bases

The MSSS provides the following safety-related functions:

- Isolates the main steam lines in the event of excessive steam flow to prevent overcooling of the reactor coolant,
- During accident conditions, provides initial residual heat removal by venting steam to the atmosphere via the main steam safety valves (MSSVs) and the main steam relief trains (MSRTs), and
- In the event of a steam generator tube rupture (SGTR), retains activity by steam-side isolation.

The MSSS meets the following design-basis requirements and criteria:

- Safety-related portions of the MSSS are designed to withstand the effects of natural phenomena, such as earthquakes, tornadoes, hurricanes, floods, tsunamis and seiches, without losing the capability to perform their safety functions (GDC 2).

- Safety-related portions of the MSSS are designed to withstand the effects of external missiles and internally generated missiles, pipe whip, and jet impingement forces associated with pipe breaks (GDC 4).

- Safety-related portions of the MSSS are designed to meet fuel and reactor coolant pressure boundary (RCPB) design limits by providing a sufficient residual heat removal capacity, assuming that only onsite power or only offsite power is available (GDC 34).

- Safety-related portions of the MSSS are designed to provide the decay heat removal capability necessary for core cooling and safe shutdown during a station blackout (SBO – a beyond-design-basis accident) (10 CFR 50.63).

The MSSS is designed to meet the functional criteria of conveying steam from the SGs to the HP turbine and second-stage reheaters at the flow rates and steam conditions required by the turbine-generator supplier, providing the backup steam supply to the auxiliary steam system, and supplying deaerator pegging steam during startups and shutdowns.

4.3.2 System Description

A flow diagram of one main steam line of the MSSS (representative of all four steam lines) is provided in Figure 4-2. The system conveys steam from the SGs to the TG. The system consists of main steam piping, MSRTs, MSSVs, and main steam isolation valves (MSIVs). Table 4-2 provides design data for the MSSS.

Safety-related portions of the MSSS include the piping between each SG outlet nozzle and its respective main steam isolation valve, inclusive of the following components and associated branch piping:

- MSIVs,
- Main steam warming control valves (MSWCVs),
- Main steam warming isolation valves (MSWIVs),
- Main steam relief isolation valves (MSRIVs),
- Main steam relief control valves (MSRCVs), and
- MSSVs.

Each of the four SGs has an associated main steam line. Each main steam line connects to its SG outlet nozzle, exits the reactor building (RB) through a penetration and enters a division-related valve room. The divisionally separated main steam lines are located in a two-by-two arrangement in valve rooms on top of safeguard buildings 1 and 4 and on opposite sides of the RB.

Outside the valve rooms, the main steam lines are routed across a pipe bridge to the turbine building (TB), where they supply the HP turbine through four turbine stop valves. Drain pots are provided at the turbine inlets for condensate removal. Branch piping from each main steam line inside the TB supplies a common header with branches to the second-stage reheaters, the deaerator pegging steam header, the auxiliary steam system, and the turbine bypass valves.

Auxiliary steam from the MSSS is used to supply turbine gland steam during startups and shutdowns, and heating steam for the feedwater storage tank during startups. Pressure-reducing valves are provided as needed to reduce the header pressure to the pressure required for proper operation of the equipment. The normal supply of auxiliary steam is via extraction from the moisture separator reheaters.

4.3.3 Component Descriptions

4.3.3.1 Main Steam Safety Valves

Each main steam line has two spring-loaded safety valves, located upstream of the main steam isolation valve. The MSSVs and the MSRTs provide overpressure protection of the main steam piping and SGs. The normal relief capacity of each MSSV is 25% of the normal full-load steam line flow. The safety valves discharge to the atmosphere via directly connected vent stacks. Low-point drains in the vent stacks route any accumulated water to the Nuclear Island drain and vent system (NIDVS). Table 4-3 provides design data for the MSSVs.

4.3.3.2 Main Steam Relief Trains

Each main steam line has one MSRT located upstream of its MSIV. Each MSRT has a normally closed, fast-opening MSRIV upstream of a normally open MSRCV. The MSRIVs are designed in accordance with the ASME Code, Section III, Division 1, Subsection NC, including Article NC-7000.

The MSRTs are part of the SG secondary-side overpressure protection. The normal setpoint is 1370 psig. The MSRT setpoint and capacities are such that, with the consideration of a reactor trip, the MSRTs alone prevent system pressure from increasing above 110% of design pressure upon a full loss of load. The MSRTs discharge to the atmosphere via silencers and have low-point drains in the discharge piping to minimize condensate accumulation. Any accumulated water is routed to the NIDVS.

During mild pressure transients, the MSRIVs automatically open to prevent opening of the MSSVs. If the turbine bypass system is unavailable, the MSRIVs vent steam to the atmosphere to remove residual heat.

Each MSRIV is an angle globe valve with a motive-steam-operated piston actuator. The actuator is pilot operated for fast opening with high reliability. Each actuator has four pilot valves that are also actuated by the motive steam. These solenoid-driven pilot valves are arranged with two pilots in series in each of two redundant vent lines (manifolds). During normal operation, the MSRIV is kept closed by a spring located above the actuator piston, with balanced steam pressure above and below the actuator piston. Upon receipt of an actuation signal, the energized pilot solenoids open to admit steam into the pilot valves. This causes the pilot valves to open, venting steam from the upper chamber of the MSRIV actuator piston to the atmosphere. The steam pressure below the actuator piston exerts a force greater than the force applied above the piston, resulting in the valve opening.

When the valve actuation signal clears, the solenoid valves are closed (de-energized). This removes the steam pressure from the pilot valves, which causes the pilots to close, repressurizing the control volume above the actuator piston. With the steam pressure above and below the actuator piston again balanced and aided by the force applied by the spring above the actuator piston, the valve is closed. Figure 4-3 illustrates the MSRIV actuator.

The pilot valve arrangement prevents a failure of any pilot valve from causing either a spurious opening (two pilots in series) or a failure to open (two redundant control lines) of the MSRIV. Functional tests of pilot valves may be performed individually during normal operation without impairing power generation.

The motor-operated MSRCVs provide the safety-related function of controlling MSRT steam flow to prevent overcooling the reactor coolant. Closing the associated MSRCV mitigates the effects of a stuck-open MSRIV.

The MSRCVs are automatically maintained in standby positions, based on thermal power, as follows:

- From 0 to 20% thermal power – 40% open,
- From 20 to 50% thermal power – linear variation between 40 and 100% open, and
- For greater than 50% thermal power – 100% open.

These valve positions are selected to minimize overcooling of the reactor coolant in the event of a spurious opening of an MSRIV while ensuring sufficient relief capacity for overpressure events.

Major operational characteristics of the MSRTs are as follows:

Overpressure protection: When the overpressure setpoint (normally 1370 psig) is exceeded, as indicated by at least two of four pressure measurements on the associated steam line, the protection system opens the MSRIV. The safety automation system modulates the MSCRV to maintain the steam pressure at the relief setpoint.

Residual Heat Removal: During normal shutdowns and after accidents, the MSRTs remove residual heat from the reactor coolant system (RCS) via controlled steam release to the atmosphere, in the event that the turbine bypass system is unavailable. The MSRT capacity enables two of the four trains to provide sufficient heat removal to cool the primary from hot shutdown to residual heat removal system (RHRS) entry conditions within 36 hours.

Partial Cooldown: When a safety injection signal is actuated, a safety-related partial cooldown is initiated. This function lowers the MSRIV opening setpoint according to a predefined gradient, the MSRIVs open when the sepoint is exceeded, and the MSCRVs modulate as necessary to maintain steam pressure at the setpoint. The partial cooldown lowers the reactor coolant temperature at a rate of about 180°F/hr for 20 min. The partial cooldown ensures that the reactor coolant system pressure is reduced to a value low enough to permit medium head safety injection

(MHSI) in response to a potential in-progress small-break loss-of-coolant accident (SBLOCA).

Containment of Radioactivity: During an SGTR, as indicated by high level in the affected SG or by high radiation in the affected steam line, the relief setpoint for the affected SG's MSRIV is increased to 1435 psig. This action minimizes the potential for radioactive release from the affected SG. The MSRTs associated with the unaffected SGs remain available for decay heat removal.

4.3.3.3 Main Steam Isolation Valves

Each main steam line includes an MSIV, located in a valve room just outside the containment. The MSIVs provide the safety-related function of isolating the main steam lines in the event of excessive steam flow to prevent overcooling the reactor coolant.

In response to a main steam isolation signal, the MSIVs quickly and automatically close. Each MSIV is capable of closure in five seconds or less against a flow of approximately $5x10^6$ lbm/hr and a differential pressure of 1320 psid in either direction.

The MSIVs are gate valves with hydraulic-pneumatic actuators and constitute an ASME Code, Section III, Class 2 pressure boundary.

Each MSIV's hydraulic-pneumatic actuator is a piston actuator, with its upper chamber charged with high pressure nitrogen and its lower chamber connected to a hydraulic-oil system. The nitrogen stored in the closed upper chamber serves as a spring to close the valve without failure. The hydraulic oil supplied to the lower chamber opens the valve.

Each MSIV's actuator has its own hydraulic-oil system that pumps hydraulic oil from a tank to pressurize the actuator's lower chamber. Fast closure is performed by dumping the hydraulic oil back to the oil tank via two redundant lines. Figure 4-4 illustrates this subsystem; only one dump line is shown for clarity. Each dump line has a dump valve that is pilot-operated by two solenoid valves in series. The solenoids de-energize to trip (open). It is necessary to de-energize both pilots to open the dump valve and therefore close the MSIV. This arrangement prevents the failure of any one pilot valve from causing either spurious MSIV closure (two pilots in series) or failure to close (two redundant control lines).

Each dump line also has an exercise dump valve for testing (partial closure) or slow closure. Each exercise dump valve is operated by a solenoid pilot valve. For MSIV testing or slow closure, the main dump valve is in the quick-closure position, and the exercise pilot is energized to slowly drain hydraulic fluid to the tank.

Functional testing of pilot valves can be performed individually during normal operation without affecting power generation.

Each MSIV includes a bypass line for pressure equalization and warming. Each bypass line features both a motor-operated MSWIV and a downstream MSWCV. The isolation and control valves are normally closed and are part of the ASME Code, Section III pressure boundary. During startup, the control valves are positioned to regulate the warming rate.

4.3.3.4 Turbine Bypass Valves

The turbine bypass system discharges main steam from the steam generators directly to the main condenser in a controlled manner, bypassing the turbine. This process minimizes transient effects on the reactor coolant system during plant startups, hot shutdowns and cooldowns, and step reductions in generator load. The TBS is also referred to as the steam dump system.

The TBS performs no safety-related function and therefore has no nuclear safety-related design basis. Functionally, the TBS valves have sufficient combined capacity, in conjunction with a reactor trip, to prevent actuation of the MSRTs or MSSVs following a turbine trip or full load rejection. With one turbine bypass valve out of service, 50 percent of SG capacity can be dumped to the main condenser. The turbine bypass valves automatically open when steam generation exceeds the consumption limit of the turbine. Steam bypass to the main condenser is manually controlled during plant startups and also during normal cooldowns of the RCS from the hot shutdown condition to a point consistent with the initiation of the residual heat removal system.

All TBS piping and valves are located in the turbine building. The system includes a manifold connected to the main steam lines upstream of the turbine stop valves. Lines from the manifold supply six steam-regulating valves which dump to the condenser shells. The turbine bypass valves are designed to codes and standards consistent with the design of the main steam line piping in the turbine building. The turbine bypass valves and actuators are designed for turbine building environmental conditions and fail closed on the loss of electrical signal or actuating fluid.

Turbine bypass valves automatically modulate as necessary to control main steam pressure. During normal power operation, this function is realized by maintaining a floating main steam pressure setpoint above the measured main steam pressure value (Figure 4-5). As the measured pressure changes, the setpoint changes accordingly. However, a limitation is placed on the rate of change of the setpoint so that if the measured pressure increases at a rate greater than the limitation of the floating setpoint, the turbine bypass valves are opened. The turbine bypass valves close and are prevented from opening on high condenser backpressure or high hotwell level.

During plant heatup and cooldown operations, the operator adjusts a target pressure setpoint which is adapted with a limited temperature gradient. Based on the target pressure setpoint, the turbine bypass valves control main steam pressure and thus reactor coolant temperature. Locking logic is provided to interrupt the automatic heatup or cooldown process when RCS parameters deviate from their setpoint thresholds.

When a partial cooldown is initiated, the protection system sends an initiation signal for TBS operation via an isolated hardwired connection to the process automation system. The main steam pressure setpoint is gradually reduced at a specific rate; the partial-cooldown control has priority over all other setpoints and locking signals.

During the partial cooldown the setpoint for TBS operation is maintained slightly lower than the simultaneously controlled setpoint for the MSRTs. The turbine bypass valves thus effect the partial cooldown unless the TBS fails; in that case the safety-related MSRTs effect the cooldown.

Following a reactor trip, in order to avoid primary overcooling, the main steam pressure setpoint is immediately set to a fixed maximum pressure setpoint.

4.3.4 System Operation

4.3.4.1 Plant Startup

MSSS startup coincides with unit startup. Initially, reactor coolant pump (RCP) and core decay heat slowly warm up the MSSS piping and components in preparation for supplying steam to the turbine. Once no-load conditions (i.e., hot standby) are achieved and the reactor is critical, steam is admitted to the turbine, and the unit load is increased. During a plant startup, a large amount of condensate is generated in the main steam piping and is removed to prevent water hammer and turbine damage. Low point drains are opened prior to startup for condensate removal and are closed after the turbine is loaded.

Normally, the piping and components upstream of the MSIVs are warmed first, followed by the piping and components downstream of the MSIVs. However, if so desired, the process can begin with the MSIVs open, and the entire system is warmed simultaneously. In either case, the TG manufacturer's heatup limitations are observed.

For a warmup with the MSIVs initially closed, pressurization of the downstream piping can be initiated once an adequate SG pressure is attained. The MSWIVs are fully opened, and the warmup rate is manually adjusted by modulating the MSWCVs. Once the pressures on both sides of the MSIVs have equalized, the warmup lines are closed, and the MSIVs are opened. Once the MSIVs are open, further heatup is controlled by turbine bypass to the main condenser.

4.3.4.2 Normal Operation

During normal power operation, the electric generator is connected to the grid with core power and turbine load in equilibrium. The reactor and turbine control systems operate automatically, and the turbine bypass system is not in use. All four main steam lines direct steam from the SGs to the turbine. The states of major system components are as follows:

- The MSIVs are held open by the hydraulic oil pressure in their lower piston chambers. The solenoid-operated pilot valves are closed and energized.
- The MSRIVs are closed.
- The MSRCVs are open in their appropriate standby positions.
- The MSWIVs and MSWCVs are closed.

During normal power operation above 60% power, main steam flow is a function of turbine load; steam pressure is not controlled, but varies with turbine load. In the case of an imbalance between core power and turbine load, excess steam is dumped to the main condenser by the turbine bypass valves.

4.3.4.3 Plant Shutdown

MSSS shutdown coincides with unit shutdown. The unit load is reduced to no load, and the turbine and reactor are shut down. During shutdown, all four main steam lines are in operation, with steam generated in the SGs dumped either to the main condenser via the turbine bypass valves, or to the atmosphere via the MSRTs. Steam flow is a function of the rate of energy input from the RCPs and the core decay heat. The SG water inventories are maintained by the startup and shutdown feedwater system.

A cooldown from no load to the point of RHRS operation is performed by gradually reducing the main steam pressure. If the turbine bypass system is available, the process is automatic. If the MSRTs are used, the MSRIV setpoint is reduced manually by the operator in accordance with the primary-side cooldown curves.

Once the RHRS is operating, heat transfer from the reactor is via the RHRS. The turbine bypass system or MSRTs, feedwater system, and MSSS can be taken out of service, and the SGs can be isolated. If desired, the SGs may be placed in wet layup.

4.3.4.4 Emergency Operation

The following are MSSS component responses to abnormal or accident conditions:

- A main steam relief train relieves steam to the atmosphere in response to an overpressure condition in its associated main steam line. The MSRT's MSRIV opens when the pressure setpoint is exceeded, and the MSCRV modulates to maintain pressure at the setpoint.

- A main steam relief train isolates in response to an extremely low pressure in its associated main steam line. Both the MSRIV and the MSCRV receive closing orders. This function mitigates the secondary depressurization and primary overcooling resulting from an MSRT valve failing open.

- A safety injection actuation signal initiates a partial cooldown order to both the TBS and the MSRTs. The gradual secondary depressurization and corresponding primary cooldown drives primary pressure to a value low enough that MHSI is effective. The TBS pressure sepoint is lower than the MSRT pressure setpoint during the partial cooldown.

- All MSIVs automatically close in response to a main steam isolation signal (rapid pressure drop or low pressure in any SG) for the mitigation of a steam line break.

- The affected SG is isolated during an SGTR. The affected SG's MSIV is shut, its MSIV bypass line is isolated, and its MSRT relief setpoint is increased, in response to high SG level or high main steam activity.

4.4 Condensate and Feedwater System

The condensate and feedwater system provides feedwater to the steam generators at the required temperature, pressure, and flow rate. Condensate is pumped from the main condenser hotwell by the condensate pumps, directed through the low pressure feedwater heaters and the deaerator-feedwater storage tank to the main feedwater (MFW) pumps, and then pumped through the high pressure feedwater heaters to the SGs. The CFS includes a number of stages of regenerative feedwater heating and provisions for maintaining feedwater quality. It also includes extraction piping from the steam turbines, feedwater heater vents and drains, and drains from the moisture separator reheaters.

4.4.1 Design Bases

The CFS provides the following safety-related isolation functions:

- Containment isolation in the supply and return lines for the first-stage SG blowdown coolers;

- Isolation of main feedwater (shutting of the main feedwater isolation valve [MFWIV] and the full-load and low-load isolation valves) to one or more SGs as necessary to:

    - Shut off the feedwater supply in the case of a feedwater control malfunction to prevent an overcooling event due to SG overfeeding,
    - Reduce overcooling in the case of a main steam line break (MSLB),
    - Isolate the SG in the event of a feedwater line break (FWLB),
    - Prevent depressurization of the unaffected SGs in the case of a nonisolable FWLB inside containment, and
    - Prevent depressurization of the SGs in case of an isolable FWLB; and

- Isolation of the secondary side of the affected SG by shutting the MFWIV and the full-load and low-load isolation valves in order to:

    - Retain activity in the affected SG in the event of an SGTR, and
    - Shut off the feedwater supply in case of an MSLB or FWLB to prevent containment overpressurization.

The CFS satisfies the following design-basis requirements and criteria:

- Safety-related portions of the CFS are designed to withstand the effects of natural phenomena such as earthquakes, tornadoes, hurricanes, floods, tsunami, and seiches without loss of the capability to perform their safety functions (GDC 2).

- Safety-related portions of the CFS are designed to accommodate the effects of and to be compatible with the environmental conditions associated with normal operation, maintenance, testing, and postulated accidents, including loss-of-coolant accidents (LOCAs). These portions of the CFS are appropriately protected against the dynamic effects associated with possible fluid flow instabilities (e.g., water hammers) during normal plant operation as well as during upset or accident conditions (GDC 4).

- Safety-related portions of the CFS are designed to provide:
  - The capability to transfer heat loads from the reactor coolant system to the normal heat sink under normal operating conditions,
  - Redundancy of components so that under accident conditions, safety functions can be performed assuming a single active component failure, potentially coincident with the loss of offsite power, and
  - The capability to isolate components, subsystems, or piping as necessary to ensure that system safety functions can be performed.

The CFS performs the following plant operational functions:

- Transfers condensate from the condenser hotwell to the deaerator via the LP feedwater heaters,
- Supplies cooling water to the SG blowdown coolers,
- Maintains secondary-side water quality via the condensate polishing equipment,
- Delivers feedwater from the deaerator-feedwater storage tank to the SGs via the HP feedwater heaters,
- Controls SG water levels by means of control valves, and
- Recirculates feedwater for heating during a system startup.

4.4.2 System Description

Flow diagrams of the CFS are provided in Figures 4-6 and 4-7.

A multi-pressure condenser is provided, with each of the three condenser sections operating at a different pressure. Condensed steam from the two lower pressure sections is cascaded through loop seals to the highest pressure section for reheating and improved turbine performance. The condenser hotwell collects condensed turbine exhaust and various drains, including those from the feedwater heaters. Hotwell inventory is maintained by a water supply from the demineralized water distribution system (DWDS).

The condenser hotwell outlet supplies three 50%-capacity condensate pumps. Normally, two condensate pumps are in operation, with the third pump in standby. Downstream of the condensate pumps, the piping combines into a common header, which supplies a side-stream condensate polisher and includes a chemical injection and sampling point.

The condensate flows to the gland steam condenser in a bypass arrangement. A flow path to the condenser with a modulating control valve provides a minimum flow path for the gland steam condenser and condensate pumps.

Following the gland steam condenser, a condensate header supplies the SG blowdown coolers. The blowdown cooler supply line is routed from the condensate header, outdoors to the valve room located within a safeguard building, and then into the reactor building. The blowdown cooler return line is routed from the reactor building, through the valve room, outdoors to the turbine building, and back to the condensate header just upstream of the deaerator. The blowdown cooler supply and return lines have containment isolation valves.

The deaerator makeup valve station is located downstream of the blowdown cooler supply. To improve controllability over the expected operating range, the deaerator makeup valves are split ranged. The deaerator makeup valves control the deaerator–feedwater storage tank level by controlling condensate flow.

From the deaerator makeup valve station, condensate flows to the four stages of LP feedwater heaters, three strings for stages 1 and 2, and two strings for stages 3 and 4. Each string of LP heaters can be isolated and bypassed. Condensate exiting the fourth-stage heaters combines with the return flow from the blowdown coolers and flows to the deaerator–feedwater storage tank. The deaerator–feedwater storage tank inventory is maintained by a demineralized water supply from the DWDS.

The motor-driven main feedwater pumps and startup and shutdown feedwater pump are located in the turbine building below the deaerator–feedwater storage tank. Feedwater is pumped by four 33%-capacity MFW pumps and a single 5%-capacity startup and shutdown feedwater pump. Normally, three MFW pumps are in operation, with the fourth MFW pump and the startup and shutdown pump in standby. A separate line from the deaerator–feedwater storage tank supplies each feedwater pump.

Downstream of the feedwater pumps, the piping combines into a common header, which supplies the two strings of HP feedwater heaters and second-stage reheater drain coolers. Each string can be isolated and bypassed. A second, smaller common header which bypasses the HP heaters branches into four warming headers which supply the SGs.

Downstream of the HP heater strings, the MFW piping splits into individual feed lines, one for each of the four SGs. The feed lines are routed outdoors along a pipe bridge, through the safeguard buildings, and into the reactor building via the four containment penetrations. The feedwater valve stations are located inside compartments within valve rooms inside the safeguard buildings. The valves are split ranged to improve controllability over the entire operating range. Each valve station contains a main feedwater full-load control valve (MFWFLCV) with an upstream hydraulic-pneumatic main feedwater full-load isolation valve (MFWFLIV), and main feedwater low-load and very-low-load control valves (MFWLLCV and MFWVLLCV) with a common upstream motor-operated main feedwater low-load isolation valve (MFWLLIV).

Each feed line also has a motor-operated main feedwater isolation valve (MFWIV) in one of the safeguard buildings just outside the reactor building. Downstream of the MFWIV, a damped check valve in each feed line inside the reactor building provides additional containment isolation. Piping from the valve stations to the SGs is routed upward without loops to preclude steam plugging during transients.

4.4.3 Component Descriptions

Design data for feedwater piping and valves are provided in Table 4-4.

4.4.3.1 Main Feedwater Full-Load Isolation Valves

Each MFWFLCV features an upstream isolation valve that quickly and automatically closes when feedwater isolation is necessary. The main feedwater full-load isolation valves are gate valves with hydraulic-pneumatic actuators.

The hydraulic-pneumatic actuator is a piston actuator, with its upper chamber charged with high pressure nitrogen and its lower chamber connected to a hydraulic-oil system. The nitrogen stored in the closed upper chamber serves as a spring to close the valve without failure. The hydraulic oil supplied to the lower chamber opens the valve. The upper chamber is manually connected to a nitrogen gas cylinder to restore nominal pressure as needed. Each actuator has its own hydraulic-oil system, which supplies hydraulic oil from a tank to the actuator’s lower chamber.

Fast closure is performed by dumping the hydraulic oil back to the oil tank via two redundant lines. Each dump line has a dump valve pilot operated by a solenoid valve, which operates on the energize-to-trip principle. This arrangement prevents the failure of any pilot valve from causing its associated MFWFLIV to fail to close (two redundant control lines).

4.4.3.2 Main Feedwater Low-Load Isolation Valves

A common valve quickly and automatically isolates both the low-load and the very-low-load feedwater lines to an SG when feedwater isolation is necessary. The main feedwater low-load isolation valve is a motor-operated gate valve.

4.4.3.3 Main Feedwater Control Valves

All feedwater control valves are motor-operated gate valves. The MFWVLLCVs are designed to regulate flow from 0 to 5% load, the MFWLLCVs are designed to regulate flow from 5 to 20% load, and the MFWFLCVs are designed to regulate flow from 20 to 100% load.

4.4.3.4 Containment Isolation Valves

The containment isolation valves in each CFS feed line include a motor-operated MFWIV and a damped check valve inside the reactor building. The check valve is dampened to reduce the potential for water hammer during an FWLB.

The containment isolation valves in the condensate SG blowdown cooler supply and return lines include a motor-operated isolation valve in the supply line located just outside the reactor building, a check valve in the supply line inside the reactor building, a motor-operated isolation valve in the return line located just outside the reactor building, and a second motor-operated isolation valve in the return line located inside the reactor building.

4.4.3.5 Main Condenser

The main condenser is a multi-pressure, three-shell unit. Each shell is located beneath its respective LP turbine. The tubes in each shell are perpendicular to the turbine-generator longitudinal axis. The three condenser shells are designated as the LP shell, the IP shell, and the HP shell. Each shell has two or more tube bundles. Circulating water flows in series through the three single-pass shells.

The condenser shells are located below the turbine building operating floor and are supported above the turbine building foundation. Each LP turbine outer casing (exhaust hood) is rigidly welded to the condenser neck of its respective shell.

Condenser materials depend on the circulating water characteristics. For example, titanium tubes and tubesheet overlay are used for condensers cooled by seawater, while stainless steel tubes and tubesheet overlay are used for freshwater applications. The COL applicant that references the US-EPR design certification will describe the site-specific main condenser materials.

During normal plant operation, the main condenser is operated under a vacuum. Steam exhausted from the low pressure turbines expands down into the main condenser shells across the main condenser tubes and condenses. The condensate collects in the hotwell. The main condenser also serves as a collection point for steam, demineralized water, equipment drains, and extracted water and vented air from other systems.

The condenser vacuum is maintained by the main condenser evacuation system. A steam and air mixture is extracted from the condenser shells by one of two 100%-capacity vacuum pumps. The vacuum pump discharges through a separator/silencer to the air vent system, where the radiological activity of the exhausted air is monitored.

4.4.3.6 Feedwater Pumps

There are four 33%-capacity horizontal MFW pumps driven by constant-speed electric motors. Each pump unit consists of an integral, low speed, single-stage booster pump and a high speed, multistage main pump. Both the booster pump and the main pump are driven by the same motor, with gearing providing the speed differences.

The single 5%-capacity startup and shutdown feedwater pump is a horizontal multistage pump driven by a constant-speed electric motor.

4.4.3.7 Feedwater Heaters

All feedwater heaters are shell-and-tube heat exchangers with carbon steel shells and stainless steel tubes.

4.4.3.8 Deaerator-Feedwater Storage Tank

The deaerator–feedwater storage tank is a direct contact heat exchanger with an integral spray-type deaerator. The feedwater storage tank volume acts as a buffer for the feedwater supplies to the SGs.

4.4.4 System Operation

4.4.4.1 Plant Startup

The emergency feedwater (EFW) pumps are normally used for SG filling. However, if so desired, the startup and shutdown feedwater pump can be used to fill the SGs, with feedwater flows controlled by the MFWVLLCVs.

Before startup of the CFS, the feedwater lines are warmed by aligning valves so that flow is from the deaerator–feedwater storage tank, through the startup and shutdown feedwater pump, to the feedwater valve stations, and back through the HP feedwater heaters to the deaerator– feedwater storage tank. During the warming process, the recirculation valve maintains minimum flow through the startup and shutdown feedwater pump.

The condensate portion of the system is started before the SG blowdown or startup and shutdown feedwater portions of the system. The condenser need not be evacuated. However, the condenser circulating water pumps are operating to remove heat from the condenser.

Using one condensate pump during recirculation, the system is vented and pressurized in stages. Turbine sealing may begin once condensate flow is established through the gland steam condenser. Similarly, SG blowdown begins once condensate flow is established through the blowdown cooler. Once water is admitted to the deaerator–feedwater storage tank, the low range makeup valve automatically maintains deaerator–feedwater storage tank level.

At very low loads the startup and shutdown feedwater pump provides feedwater to the SGs, and the MFWVLLCVs automatically modulate to maintain SG water levels. At approximately 5% load, one of the MFW pumps is started, as required to maintain SG water level. As load is increased, the second and third MFW pumps are started. The feedwater pumps are started in a staged manner to reduce the possibility of overfeed in the event of controls malfunctioning. At approximately 50% load, a second condensate pump is started to maintain flow. The condensate pump recirculation valve gradually modulates closed as the unit load is increased.

As load is increased, flow control is automatically transferred from the MFWVLLCVs to the MFWLLCVs, and eventually from the MFWLLCVs to the MFWFLCVs.

4.4.4.2 Normal Operation

During normal plant operation, two condensate pumps take suction on the condenser hotwell and discharge through the gland steam condenser, LP feedwater heaters, and blowdown coolers into the deaerator–feedwater storage tank. The standby condensate pump is normally set to automatically start on failure of an operating pump.

During normal operation, all three MFW pumps take suction on the deaerator–feedwater storage tank and discharge through the HP feedweater heaters and second-stage reheater drain coolers into the SGs. The standby MFW pump is normally set to automatically start on the failure of an operating pump. The startup and shutdown feedwater pump is normally set to start on the failure of all MFW pumps.

4.4.4.3 Plant Shutdown

As unit load is decreased, the condensate pump recirculation valve gradually modulates open. At approximately 50% load, one condensate pump is shut down. A single condensate pump is kept in service so long as there is a demand for gland steam cooling or SG blowdown cooling.

As unit load is decreased, the MFW pump recirculation valves gradually modulate open. Flow control automatically transfers from the MFWFLCVs to the MFWLLCVs, and then from the MFWLLCVs to the MFWVLLCVs. At approximately 65% load, one MFW pump is shut down. Subsequently, the second and third MFW pumps are shut down. The startup and shutdown feedwater pump is started before the last MFW pump is stopped, and it remains in service until core cooling is provided by the RHRS. As during a startup, the feedwater pumps are shut down in a staged manner to reduce the possibility of overfeed in the event of controls malfunctioning.

4.4.4.4 Emergency Operation

Large Main Feedwater Line Break inside Containment between Check Valve and Steam Generator: A break in this location results in the reduction of the pressure and inventory of the affected steam generator. The inventories of the unaffected steam generators also decrease due to the loss of feedwater out the break, but to a lesser extent. The reduced steam generator water inventories reduce secondary-side heat removal and cause an increase in reactor coolant temperature. A reactor trip results from the degraded reactor coolant conditions or degraded SG inventories.

The reactor trip causes the closure of all MFWFLCVs and MFWFLIVs, thereby reducing the feedwater loss. However, the affected steam generator continues to depressurize, and the inventories in all steam generators continue to drop. Feedwater flow to the affected steam generator is automatically terminated on either high–high steam generator pressure drop or low-low steam generator pressure. Feedwater flow to the affected steam generator is terminated by the automatic closure of the associated MFWLLCV, MFWVLLCV, MFWLLIV, and MFWIV. The low-load flow paths for the unaffected steam generators remain open. If a steam generator’s water level should continue to drop, its EFW pump automatically starts to maintain inventory.

Large Main Feedwater Line Break Upstream of Check Valve: A feed line break upstream of the check valve causes the check valve to close, thereby preventing the depressurization of the affected steam generator. The feedwater flow to all steam generators is reduced due to feed flow losses out the break. The resulting reduced steam generator water inventories reduce secondary-side heat removal and cause an increase in reactor coolant temperature. A reactor trip results from the degraded reactor coolant conditions or degraded SG inventories.

The reactor trip causes closure of all MFWFLCVs and MFWFLIVs. However, the inventories in all steam generators continue to drop until the EFW pumps automatically start to maintain levels.

Main Steam Line Break: An MSLB causes all steam generators to begin depressurizing. Depending on the break location, a reactor trip results from high containment pressure or from one of the following signals, each of which also causes main steam isolation:

- High steam generator pressure drop, or
- Low steam generator pressure.

The reactor trip causes closure of all MFWFLCVs and MFWFLIVs. If the break is downstream of the MSIVs, the depressurization stops. If the break is upstream of an MSIV, the affected steam generator continues to depressurize.

To prevent overfilling a steam generator, feedwater flow is terminated by automatic closure of its MFWLLCV, MFWVLLCV, MFWLLIV, and MFWIV on any of the following conditions:

- High–high steam generator pressure drop,
- Low–low steam generator pressure, or
- High steam generator level with time delay after reactor trip.

Steam Generator Tube Rupture: To prevent the release of contaminated fluid from the affected SG, the SG is isolated by a steam generator isolation signal, generated by a partial cooldown signal coincident with one of the following signals:

- High steam generator water level, or
- High main steam line activity.

Steam generator isolation causes all six feedwater control and isolation valves for the affected SG to close.

4.5 Condenser Circulating Water System

The condenser circulating water system supplies cooling water from the normal heat sink to the main condenser. After removing heat from the condenser, the circulating water is returned to the normal heat sink.

4.5.1 Design Bases

The CWS performs no safety-related function and therefore has no nuclear safety-related design basis. The CWS meets the functional criteria of supplying cooling water from the normal heat sink to the main condenser, discharging heated water from the main condenser to the normal heat sink, and cooling the discharged heated water in the normal heat sink to an acceptable temperature.

4.5.2 System Description

The CWS is a nonsafety-related interface system that provides a continuous supply of cooling water to the main condenser and rejects heat to the environment via the normal heat sink. The CWS consists of circulating water pumps, mechanical draft cooling towers, and associated piping, valves and instrumentation, as shown in Figures 4-8 and 4-9. The design of the CWS outside of the turbine building is site specific. A COL applicant that references the US-EPR design certification will provide the description of the site-specific portions of the CWS.

The CWS has mechanical draft cooling towers, each with a basin and circulating water sump. Each sump houses a circulating water pump. The sumps are designed to provide sufficient submergence of the pump suctions. Trash racks or suction screens are provided to prevent the ingestion of debris. The circulating water pumps are constant-speed, vertical-shaft-type pumps. The pumps are designed to operate under normal plant operating load conditions. Each pump has its suction located in its own pump bay. The pumps are designed to permit reverse flow.

The cooling tower makeup system is site specific and will be designed to provide adequate makeup flow to the cooling tower basins. Additionally, the cooling tower blowdown system is site specific; along with the makeup system, it will be designed to maintain the concentration of dissolved solids in the CWS within acceptable limits.

Water treatment for the CWS is based on site makeup water chemistry, blowdown requirements, environmental regulations, and system materials. A COL applicant that references the US-EPR design certification will provide the specific chemicals used to support the chemical treatment system, as determined by the site-specific water conditions.

The CWS is designed to withstand the maximum operating discharge pressure of the circulating water pumps. The CWS includes condenser water boxes and tube bundles, butterfly valves, and expansion joints. A COL applicant that references the US-EPR design certification will provide the site-specific CWS piping design pressure.

A butterfly valve is installed downstream of each circulating water pump. Isolation valves are installed at the inlets to the low pressure condenser water box and at the outlets from the high pressure condenser water box. Each cooling tower riser also has a butterfly valve that serves to isolate the cooling tower cell during maintenance activities. The butterfly valves contained in the CWS are designed to operate under normal plant operating load conditions. Valve opening and closing times are chosen to reduce water hammer effects.

A vacuum breaker is installed at the outlet water box of the condenser. During transient operating conditions or shutdowns of circulating water pumps, the valve opens, and atmospheric air flows into the circulating water piping to prevent water hammer.

Deposits that form on condenser tubes are removed by the condenser tube cleaning system (CTCS). Continuous cleaning of internal tube surfaces is accomplished by a constant circulation of sponge-rubber balls having a diameter slightly larger than the condenser tube diameter, and a density when wet similar to that of the circulating water. These balls are injected into the condenser cooling water inlet through two or more ball injection nozzles. The flow of water carries them into the water boxes, through the tubes, and into the ball strainer at the condenser circulating water outlet. They are drawn from the ball strainer by the ball circulation pump and pumped through the ball collector back to the cooling water inlet.

4.5.3 System Operation

During normal plant operation, circulating water is routed from the individual cooling tower basins into the respective circulating water sumps. The circulating water pumps discharge the circulating water into a common header, and from there into two separate supply lines to the condenser water boxes. Circulating water passes through the water boxes sequentially. Downstream of the condenser water boxes in the outdoor area, the circulating water is routed back to the cooling towers through two separate return lines.

As unit load is decreased, and at lower-than-design wet bulb temperatures, individual cooling tower fans can be switched off. Additionally, individual circulating water pumps can be turned off, and their associated butterfly valves can be closed. One circulating water pump and cooling tower must remain in operation as long as there is demand for heat removal from the condensers.

4.6 Emergency Feedwater System

The emergency feedwater system supplies water to the steam generators to restore and maintain water levels and to remove decay heat following the loss of normal feedwater during design-basis transient and accident conditions. The EFWS-supplied feedwater removes energy from the reactor coolant in the SGs and then is discharged as steam to the condenser via the turbine bypass valves or to the atmosphere via the MSRTs.

4.6.1 Design Bases

The EFWS provides the following safety-related functions:

- Provides sufficient flow to the SGs to recover and maintain SG water inventories and to remove residual heat from the RCS via the SGs and MSRTs to assist in the cooldown and depressurization of the RCS to RHRS initiation conditions under design-basis transient and accident conditions,

- Isolates EFWS flow to the affected SG following a main steam line break to prevent overcooling the RCS and adding the associated positive reactivity to the core,

- Isolates EFWS flow to an SG with a tube rupture in response to a high SG water level condition to prevent SG overfill and to mitigate the potential radiological consequences of an SGTR, and

- Provides sufficient water inventories in the storage pools to support cooldown requirements.

The EFWS satisfies the following design-basis requirements and criteria:

- Safety-related portions of the EFWS are designed to withstand the effects of natural phenomena such as earthquakes, tornadoes, hurricanes, floods, and external missiles, and are designed to function following such events (GDC 2).

- Safety-related portions of the EFWS are designed to withstand the effects of the postulated hazards of internal missiles, pipe whipping, and discharging fluids (GDC 4).

- Safety-related portions of the EFWS are capable of bringing the primary plant temperature to the RHRS initiation point following four hours at hot standby, with control by the operators in the control room using only safety-grade equipment and assuming a single active failure (NUREG 0800, BTP 5-4 and GDC 19).

- Safety-related portions of the EFWS have sufficient flow capacity that the system can remove residual heat resulting from the entire range of reactor operation and cool the plant to the RHRS initiation temperature assuming a single active failure with the loss of offsite power (GDC 34 and GDC 44).

- Safety-related portions of the EFWS are capable of automatic initiation under conditions indicative of an anticipated transient without scram (ATWS) (10 CFR 50.62).

- The EFWS is capable of providing sufficient decay heat removal during a station blackout (10 CFR 50.63). This is a nonsafety-related function.

The EFWS is a safety-related system and is not required to operate during normal plant operation. As described above, during normal power operation the heat removal function is performed by the CFS, with feedwater flow provided by the MFW pumps or by the startup and shutdown feedwater pump.

4.6.2 System Description

A flow diagram of the EFWS is shown in Figure 4-10. The EFWS has four separate trains, each consisting of a water storage pool, pump, control valves, isolation valves, piping, and instrumentation. A supply header allows the cross-connection of the storage pools to the pump suctions, and another header allows the cross-connection of the pump discharges to the SGs. Each train's pump suction connection to the suction cross-connect header has a manual isolation valve that is normally maintained in the closed position, while each train's pump discharge connection to the discharge cross-connect header is isolated by a motor-operated valve, which can be operated from the control room to change the pump's discharge alignment.

One EFWS train is located in the lower levels of each of the safeguard buildings; the buildings provide separation and physical protection from external and internal hazards. The storage pools are stainless-steel-lined concrete structures which are integral to the associated safeguard building structures.

The DWDS is used to initially fill the EFWS storage pools and can be aligned from the main control room to provide makeup to the storage pools. Makeup to the storage pools can also be provided from the fire water system and from other available water sources.

The EFWS has the capability to perform its required safety-related functions following design-basis transients or accidents assuming a single active failure in one EFWS train and with a pump out of service for preventive maintenance in a second train. The system capacity is sufficient to remove decay heat and effect a cooldown of the RCS following a reactor trip from full power.

The EFWS design flow requirement is 400 gpm (at 122°F) per train to a minimum of two SGs following a main feedwater line break when pumping against the MSRT setpoint pressure. This requirement is met assuming a single active failure and an EFW pump out of service for maintenance.

Each EFWS train is powered from a separate emergency bus, each backed by an emergency diesel generator (EDG), with trains 1 and 4 also capable of being powered from the diverse station blackout diesel generators (SBODGs).

4.6.3 Component Descriptions

EFWS component data are provided in Table 4-5.

4.6.3.1 EFW Pumps

The four EFW pumps are centrifugal, multistage, barrel-type pumps. The pump casings have top-mounted suction and discharge flanges. The pump and motor of each unit are horizontally mounted on a common base plate. The pump and motor bearings are oil lubricated, and the thrust bearings are air cooled. The pump has a single cartridge-type mechanical seal that does not require external seal water.

The pump bearing temperatures are monitored by sensors located on the outer ring of the rolling elements. Pump vibration is monitored by vibration sensors located on the pump bearing housings.

The EFW pumps are driven directly by ac motors through flexible couplings. The motor bearings and winding temperatures are monitored, as is motor-bearing vibration.

Each pump’s minimum flow requirement is ensured by the minimum flow check valve on the pump discharge.

Two check valves are located in each pump’s discharge piping to prevent steam from reaching the pump suction. Temperature instrumentation is provided upstream of the in-containment check valve to detect any heatup resulting from leakage past the check valve. Alarms are provided in the main control room to alert the operators that backleakage has occurred. Plant procedures require prompt operator action to address the potential for unacceptable EFW pump suction conditions. System maintenance and operating procedures will include specific guidance and precautions to preclude the occurrence of steam binding of the EFW pumps.

4.6.3.2 EFW Storage Pools

The EFW storage pools are located in the safeguard buildings. The storage pools are made of concrete and have stainless steel liners. The usable volumes of the pools are approximately 110,000 gal for trains 1 and 4 and 95,600 gal for trains 2 and 3.

Each storage pool includes a top-mounted manway, an overflow pipe, and a vent line. If required for maintenance, an EFW pool can be drained to the plant drainage system. Pool contents are recirculated and sampled prior to pool draining. Draining is accomplished by manual valve alignment and starting of the drain pump.

Wide range and narrow range storage pool level indications are provided in the main control room, and local manometers are provided in the EFW pump rooms. Storage pool temperatures are also indicated in the control room.

4.6.3.3 Major EFWS Valves

EFW Flow Control Valves: Each valve (one per train) is a motor-operated control valve that limits EFW pump flow to a depressurized SG and prevents pump runout. The valve includes an adjustable mechanical stop that is set to limit the maximum flow. Each valve is positioned on its mechanical stop when the associated pump is in standby during normal plant operation. During EFW pump operation, the valve is automatically positioned to provide the design flow of 400 gpm.

EFW Steam Generator Level Control Valves: Each valve (one per train) is a motor-operated control valve that is in the open position (standby) during normal plant operation and receives an open signal upon an EFW actuation on low SG level or a loss of offsite power (LOOP) coincident with a safety injection signal. The valve closes automatically on high SG level to prevent SG overfill following an SGTR. These valves maintain the SGs at the setpoint level by adjusting the EFW pump flow rates. Any of the valves can be manually closed from the control room to isolate EFW flow to an overfilling SG.

EFW Steam Generator Isolation Valves: Each valve (one per train) is a motor-operated gate valve that is open during normal plant operation and receives a closure signal on high SG level following an SGTR to prevent SG overfill and to provide the outside-containment isolation boundary. Any of the valves can be manually closed from the control room to isolate EFW flow to an affected SG.

EFW Minimum Flow Check Valves: Each valve (one per train) seats to prevent backflow through the associated EFW pump and opens when the pump is running. If flow to the SG is below the minimum required pump flow, the bypass flow path is opened to provide the minimum EFW pump flow back to the storage pool. This minimum recirculation path automatically closes when the SG injection flow increases above the minimum required pump flow.

The check valve's minimum flow path capability is sized to provide the required minimum pump flow of approximately 88 gpm. This value is based on preliminary vendor information, which will be refined during the pump procurement process and confirmed by vendor-performed analysis and/or testing. The objective will be to establish a minimum recirculation flow that provides stable flow conditions with respect to rotor and hydraulic stability, as well as acceptable thermal conditions as required by IE Bulletin 88-04. The concern identified in IE Bulletin 88-04 that is related to the potential dead heading of one or more pumps that have a minimum flow line common to two or more pumps does not apply to the US-EPR design since each pump has a separate and independent minimum flow recirculation line.

EFW Isolation Check Valves: Each valve (one per train) provides the inside-containment isolation boundary and prevents the backflow of contaminated liquid outside the containment following an SGTR.

EFW Supply Header and Discharge Header Cross-Connect Isolation Valves: Each train's supply header cross-connect isolation valve and discharge header cross-connect isolation valve are maintained closed during normal plant operation and can be opened, as necessary, to change component alignments. The discharge header isolation valves are motor operated and also have manual hand wheels; they can be operated from the control room or locally.

4.6.3.4 EFWS Piping

The EFWS piping is routed to minimize the potential for destructive water hammer during system startups. The EFWS piping connects directly to the SGs; it is thus not directly impacted by pressure transients in the main feedwater piping. In each train the EFWS piping continuously rises from the containment penetration to the connection with the SG. Each EFWS injection path also includes a check valve within the containment. Within the SG, the EFW flow is routed through a split ring header. EFWS flow exits the ring header via vertical tubes, so that the ring header is maintained full of water.

Piping in the EFWS is required to be maintained full of water. Procedures are required to assure that the piping is properly filled, vented, and maintained filled.

4.6.4 System Operation

4.6.4.1 Normal Plant Operation

During normal plant operation, the heat removal function is performed by the CFS. The EFWS is maintained in a standby condition ready for actuation. The EFWS is aligned as follows:

- The EFW pumps are available in standby, ready to start.
- The SG level control valves are open.
- The flow control valves are positioned at their mechanical stops.
- The SG isolation valves are open.
- The discharge header cross-connect isolation valves are closed.
- The pool supply header cross-connect isolation valves are closed.

- The storage pools are full of water.
- The pump room chilled water/air heat exchanger fans are switched off.

4.6.4.2 Abnormal Operating Conditions

Loss of Normal Feedwater: The loss of normal feedwater flow from both the MFW pumps and the startup and shutdown feedwater pump results in the automatic actuation of the EFWS when any SG reaches a sufficiently low level. A minimum of two EFWS trains are available to restore and maintain SG water inventories during a subsequent RCS cooldown to RHRS entry conditions.

Short-Term Loss of Offsite Power: The loss of the nonemergency ac power supplies results in the loss of the CFS pumps. As the main steam system pressure increases following the ensuing reactor trip, the MSRIVs automatically open and relieve to the atmosphere. The EDGs start on the loss of normal power and supply power to the EFW pumps, which actuate on low SG level.

Check Valve Leakage: The potential for steam leakage from the SGs to the EFW pumps during standby conditions is limited by the presence of two check valves in each train. Should leakage occur, temperature instrumentation detects the resulting high temperature condition and provides an alarm in the control room to alert the operators to close the affected train's SG isolation valve and to promptly perform any other required actions to return the affected train to service.

4.6.4.3 Accident Conditions

Small-Break Loss-of-Coolant Accident: An SBLOCA results in a loss of reactor coolant inventory which cannot be compensated for by the chemical and volume control system (CVCS). The loss of primary coolant results in decreasing reactor coolant pressure and pressurizer level. The EFWS is automatically started if the SG low level setpoint is reached. On a safety injection signal, a partial cooldown is initiated to enable MHSI flow.

A minimum of two EFWS trains are available to restore and maintain SG water inventories during the RCS cooldown to RHRS entry conditions.

Steam Generator Tube Rupture: An SGTR results in a leak of primary coolant into the affected SG. The EFWS is utilized to assist in the RCS cooldown as necessary. In addition, EFWS flow to the affected SG can be isolated manually after 30 minutes or by the automatic closure of the associated SG isolation valve and level control valve on high SG level. The associated EFW pump is shut down manually. A minimum of two EFWS trains are normally available to restore and maintain SG water inventories during the subsequent RCS cooldown to RHRS entry conditions.

In the unlikely event of an SGTR in one SG coincident with a single failure of another EFWS train and a third EFW pump out of service for maintenance, and with one of the operating EFWS trains feeding the ruptured SG, only one intact SG is fed initially by the EFWS. Within 30 minutes, the operator opens the required discharge header cross-connect isolation valves to realign the EFW pump that has been feeding the ruptured SG to an intact SG.

Main Steam Line Break: An MSLB results in a significant reduction in RCS pressure and temperature and an associated positive reactivity addition to the core. At the time of break initiation, the secondary-side pressure decreases, a reactor trip occurs, and the MSIVs close. The EFW pump aligned to the faulted SG automatically starts on low SG level. The EFW pump flow to the depressurized SG is limited by the flow control valve to protect the pump against runout and to prevent RCS overcooling. The flow to the affected SG is isolated manually from the control room within 30 minutes. A minimum of two EFWS trains are normally available to restore and maintain SG water inventories.

In the unlikely event of an MSLB in one steam line coincident with a single failure of another EFWS train and a third EFW pump out of service for maintenance, and with one of the operating EFWS trains feeding the faulted SG, only one intact SG is fed initially by the EFWS. Within 30 minutes, the operator opens the required discharge header cross-connect isolation valves to align the EFW pump that has been feeding the faulted SG to an intact SG.

The EFWS maintains the SG water inventories during the RCS cooldown to RHRS entry conditions.

Main Feedwater Line Break: An FWLB results in a significant loss of SG water mass and causes an RCS heatup. The FWLB is the most limiting accident for EFWS flow. The break results in a reactor trip and closure of the MSIVs. The main steam relief trains open, and low levels are reached in all SGs. The EFWS is automatically actuated, and the EFW pump flow to the depressurized SG is limited by the flow control valve to protect the pump against runout. The flow to the affected SG is isolated manually from the control room within 30 minutes. A minimum of two EFWS trains are normally available to restore and maintain SG water inventories.

In the unlikely event of an FWLB in one feed line coincident with a single failure of another EFWS train and a third EFWS pump out of service for maintenance, and with one of the operating EFWS trains feeding the faulted SG, only one intact SG is fed initially by the EFWS. Within 30 minutes, the operator opens the required discharge header cross-connect isolation valves to align the EFW pump that has been feeding the faulted SG to an intact SG.

The EFWS maintains SG water inventories during the RCS cooldown to RHRS entry conditions.

Table 4-1 Major Steam System Parameters and Turbine-Generator Design Data

Major Steam System Parameters	Value
Steam pressure	1110.9 psia
Steam flow	20,684,700 lb/hr
Steam enthalpy	1186.6 btu/lb_m
Feedwater temperature	446°F
Turbine-Generator Design Data	**Value**
Operating speed	1800 rpm
Frequency	60 hz
Generator output	1710 MW
Power factor	0.90 lagging
Voltage	26 kV nominal

Table 4-2 Main Steam Supply System Design Data

Steam Flow	Rated Conditions
Per steam generator	5.17×10^6 lb/hr
Total	20.68×10^6 lb/hr
Design Conditions	
Design pressure	1435 psig
Design temperature	592°F
Operating Conditions	
Full plant load pressure	1110.9 psia
Full plant load temperature	557.58°F (99.75% quality)
Main Steam Relief Isolation Valve (MSRIV)	
Number per main steam line	1
Normal set pressure	1370 psig
Rated capacity	2,844,146 lb/hr
Code	ASME Code, Section III, Class 2, Seismic Category I
Actuator	Solenoid/Pilot, System Medium Powered, Open/ Closed

Table 4-3 Design Data for Main Steam Safety Valves

Number per main steam line	2
Set pressure, first MSSV	1460 psig
Set pressure, second MSSV	1490 psig
Rated relieving capacity per valve	1,422,073 lb/hr
Relieving capacity per steam line	2,844,146 lb/hr
Valve size	8 x 10 minimum
Design code	ASME Code, Section III, Class 2, seismic Category I

Table 4-4 Main Feedwater Safety-Related Piping and Valves
Sheet 1 of 4

Main Feedwater Piping (Safety-Related Portion)	
Design (VWO) flow rate	21,492,900 lb/hr
Number of lines	4
Main line nominal size	20 in
Piping MFWCKV Outlet to SG	
Schedule	120
Design pressure	1435 psig
Design temperature	600°F
Design code	ASME Section III, Class 2
Seismic design	Category I
Piping MFWIV to MFWCKV	
Schedule	160
Design pressure	2050 psig
Design temperature	600°F
Design code	ASME Section III, Class 2
Seismic design	Category I
Piping Main 20 Inch Line Fixed Point Restraint to MFWIV	
Schedule	140
Design pressure	2050 psig
Design temperature	600°F
Design code	ASME Section III, Class 3
Seismic design	Category I
Piping 10 Inch Line Low Load	
Schedule	140
Design pressure	2050 psig

Table 4-4 Main Feedwater Safety-Related Piping and Valves
Sheet 2 of 4

Design temperature	600°F
Design code	ASME Section III, Class 3
Seismic design	Category I
Piping 4 Inch Line from Fixed Point Restraint to 10 Inch and Very Low Load Line	
Schedule	160
Design pressure	2050 psig
Design temperature	600°F
Design code	ASME Section III, Class 3
Seismic design	Category I
Main Feedwater Full Load Isolation Valves (MFWFLIV)	
Number per main feedwater line	1
Nominal size	20 in
Closing time	25 s
Body design pressure, psig	2050
Design temperature	600°F
Design code	ASME Section III, Class 3
Seismic design	Category I
Main Feedwater Full Load Control Valves (MFWFLCV)	
Number per main feedwater line	1
Nominal size	20 in
Closing time	40 s
Body design pressure	2050 psig
Design temperature	600°F
Design code	ASME Section III, Class 3
Seismic design	Category I

Table 4-4 Main Feedwater Safety-Related Piping and Valves
Sheet 3 of 4

Main Feedwater Low Load Isolation Valves (MFWLLIV)	
Number per main feedwater line	1
Nominal size, in.	10
Closing time, sec	20
Body design pressure, psig	2,050
Design temperature, F	600
Design code	ASME Section III, Class 3
Seismic design	Category I
Main Feedwater Low Load Control Valves (MFWLLCV)	
Number per main feedwater line	1
Nominal size, in.	10
Closing time, sec	20
Body design pressure, psig	2,050
Design temperature, F	600
Design code	ASME Section III, Class 3
Seismic design	Category I
Main Feedwater Very Low Load Control Valves (MFWVLLCV)	
Number per main feedwater line	1
Nominal size, in.	4
Closing time, sec	20
Body design pressure, psig	2,050
Design temperature, F	600
Design code	ASME Section III, Class 3
Seismic design	Category I

Table 4-4 Main Feedwater Safety-Related Piping and Valves
Sheet 4 of 4

Main Feedwater Isolation Valves (MFWIV)	
Number per main feedwater line	1
Nominal size, in.	20
Closing time, sec	40
Body design pressure, psig	2,050
Design temperature, F	600
Design code	ASME Section III, Class 2
Seismic design	Category I
Main Feedwater Check Valves (MFWCKV)	
Number per main feedwater line	1
Nominal size, in.	20
Closing time, sec	N/A
Body design pressure, psig	2,050
Design temperature, F	600
Design code	ASME Section III, Class 2
Seismic design	Category I

Table 4-5 Emergency Feedwater System Component Data

Emergency Feedwater Storage Pools		
Quantity		4
Type		Protected reinforced concrete structure
Liner		Austenitic stainless steel
≈ Available Volume		110,000 gal – Pools 1 and 4
		95,600 gal – Pools 2 and 3
Design Code		ACI 349
Seismic Design		Seismic Category I
Emergency Feedwater Pumps		
Pump	Quantity	4
	Type	Horizontal centrifugal, multistage
	Design Flow (@ 122°F)	400 gpm
	TDH	3570 ft
	NPSH Required	14 ft
	NPSH Available	39 ft
	Material	Various
	Design Code	ASME Section III, Class 3
	Seismic Design	Seismic Category I
Motor	Horsepower	650 HP
	Power Supply	6.9 kV, 60 Hz, 3 phase, Class 1E
	Design Code	NEMA
	Seismic Design	Seismic Category I
	Classification	1E

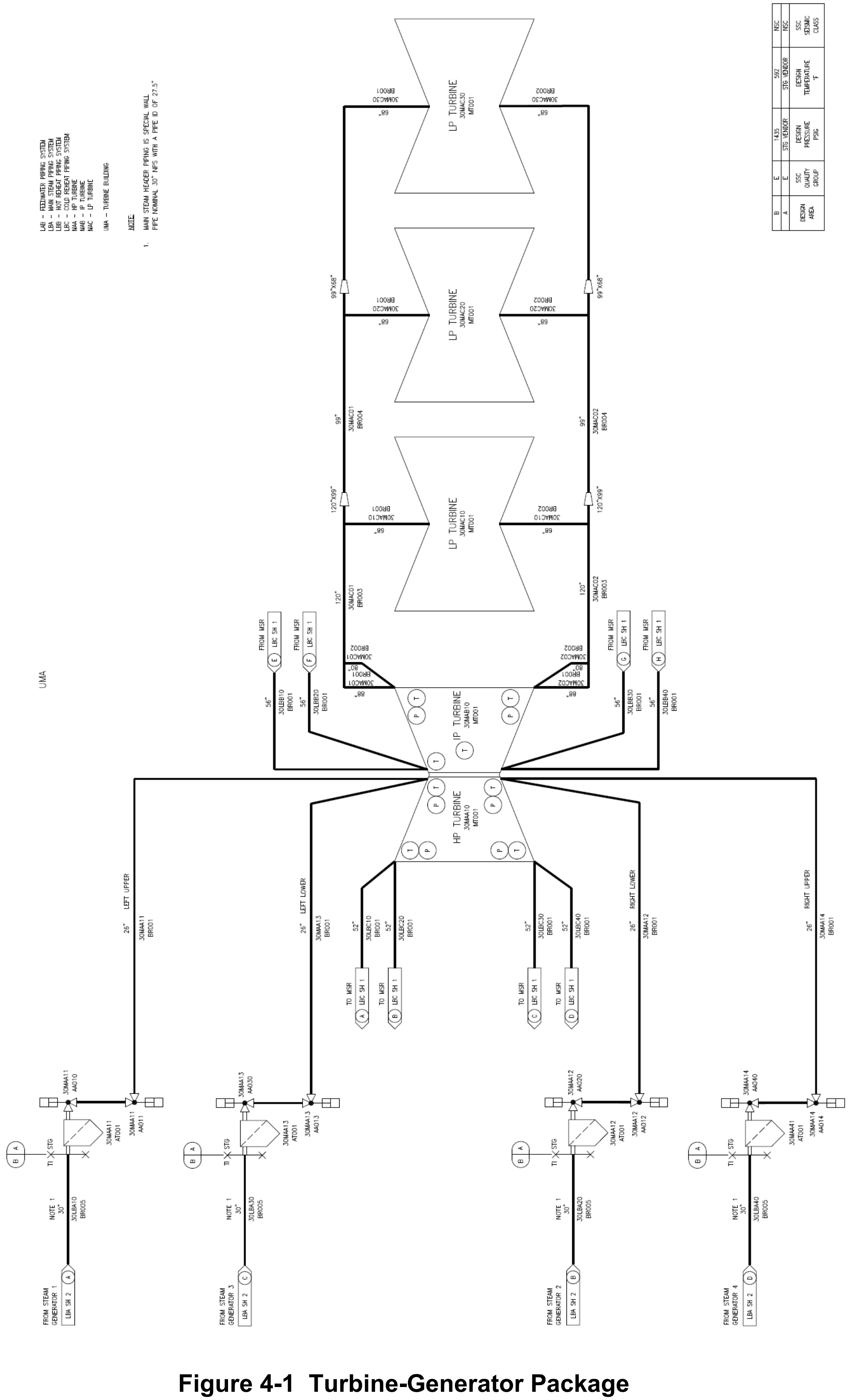

Figure 4-1 Turbine-Generator Package

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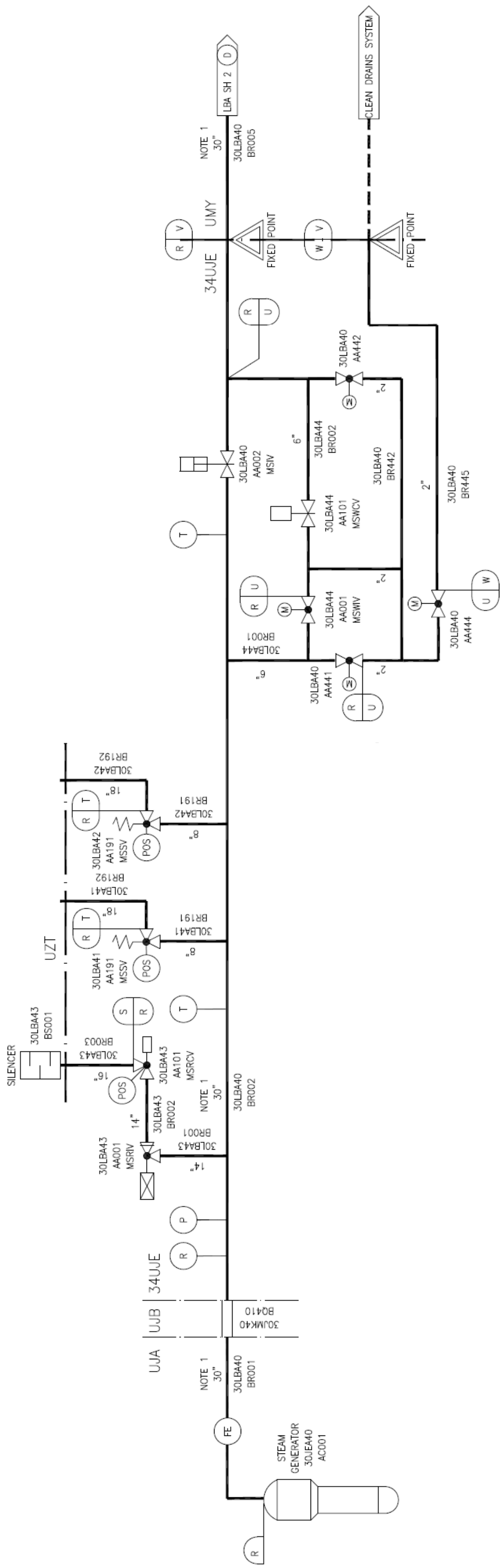

Figure 4-2 Main Steam Supply System
(One Main Steam Line)

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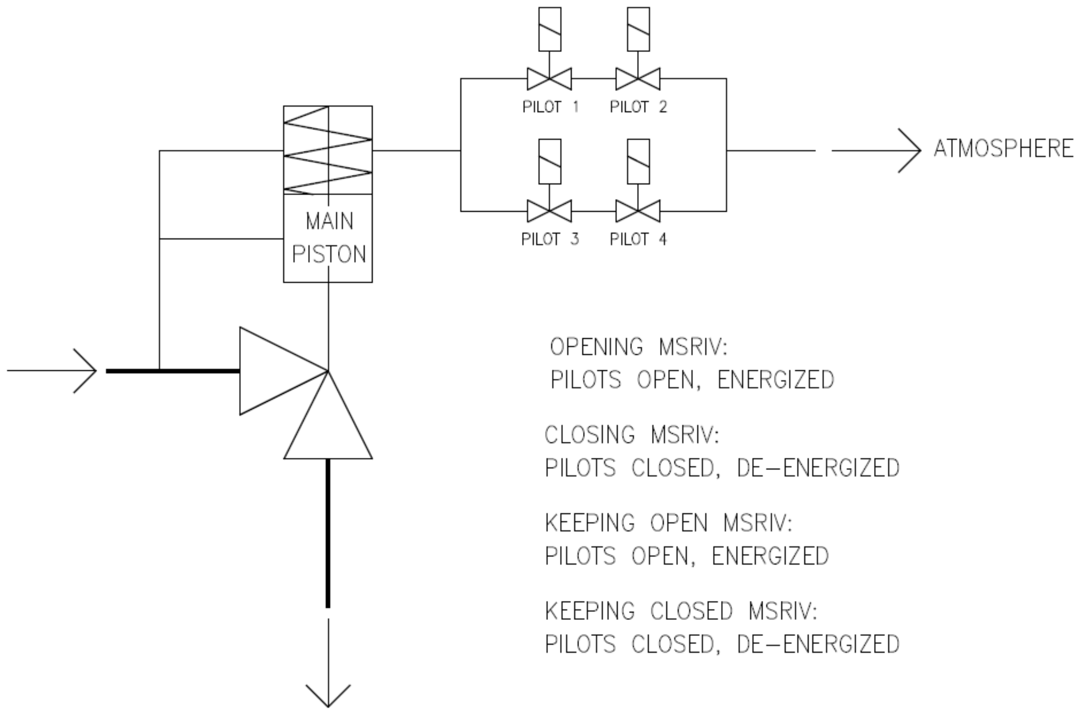

Figure 4-3 Main Steam Relief Isolation Valve Actuator

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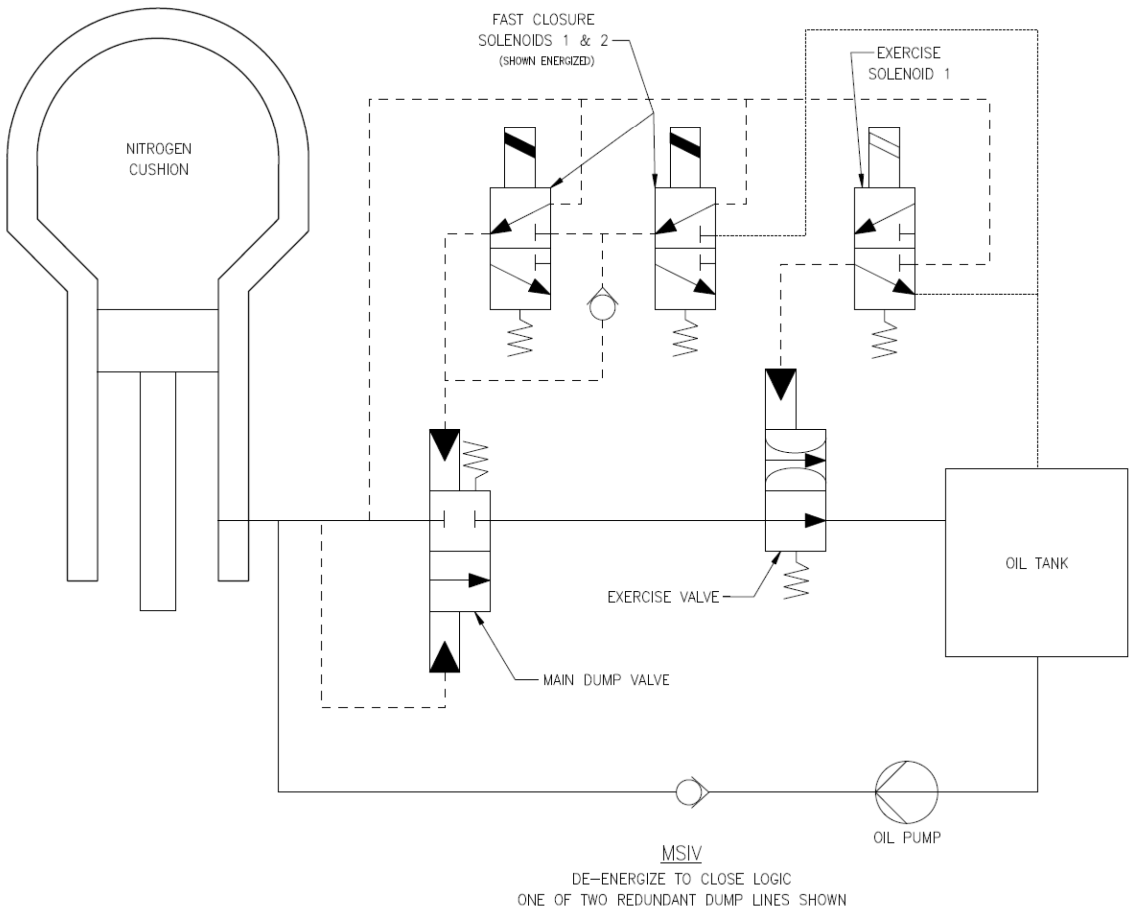

Figure 4-4 Main Steam Isolation Valve Actuator

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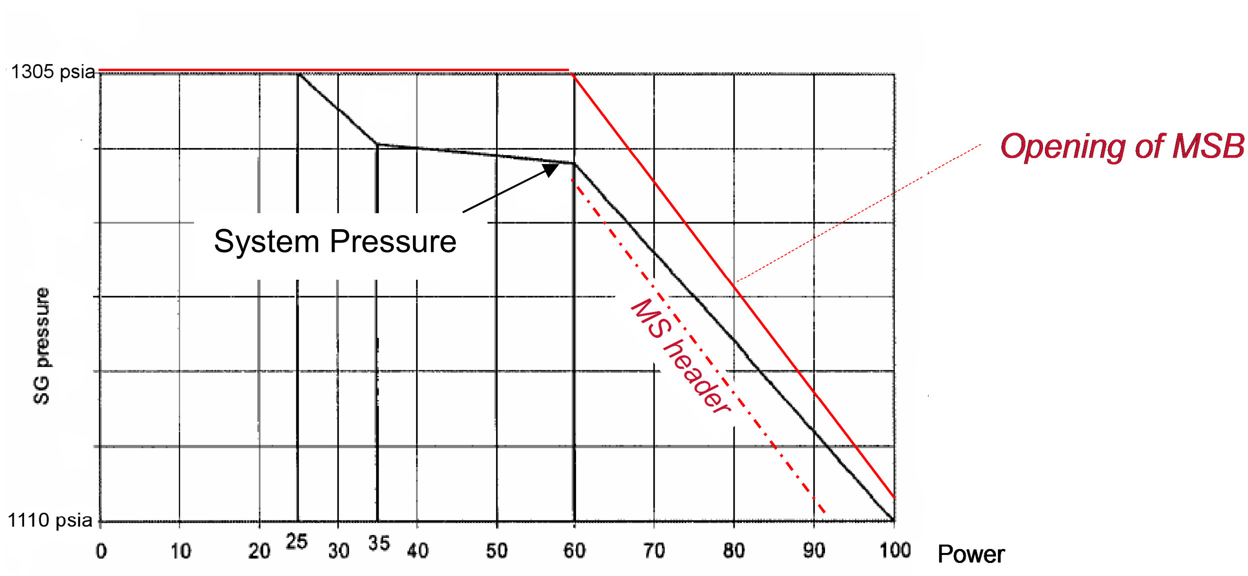

Figure 4-5 Turbine Bypass (Main Steam Bypass) Control

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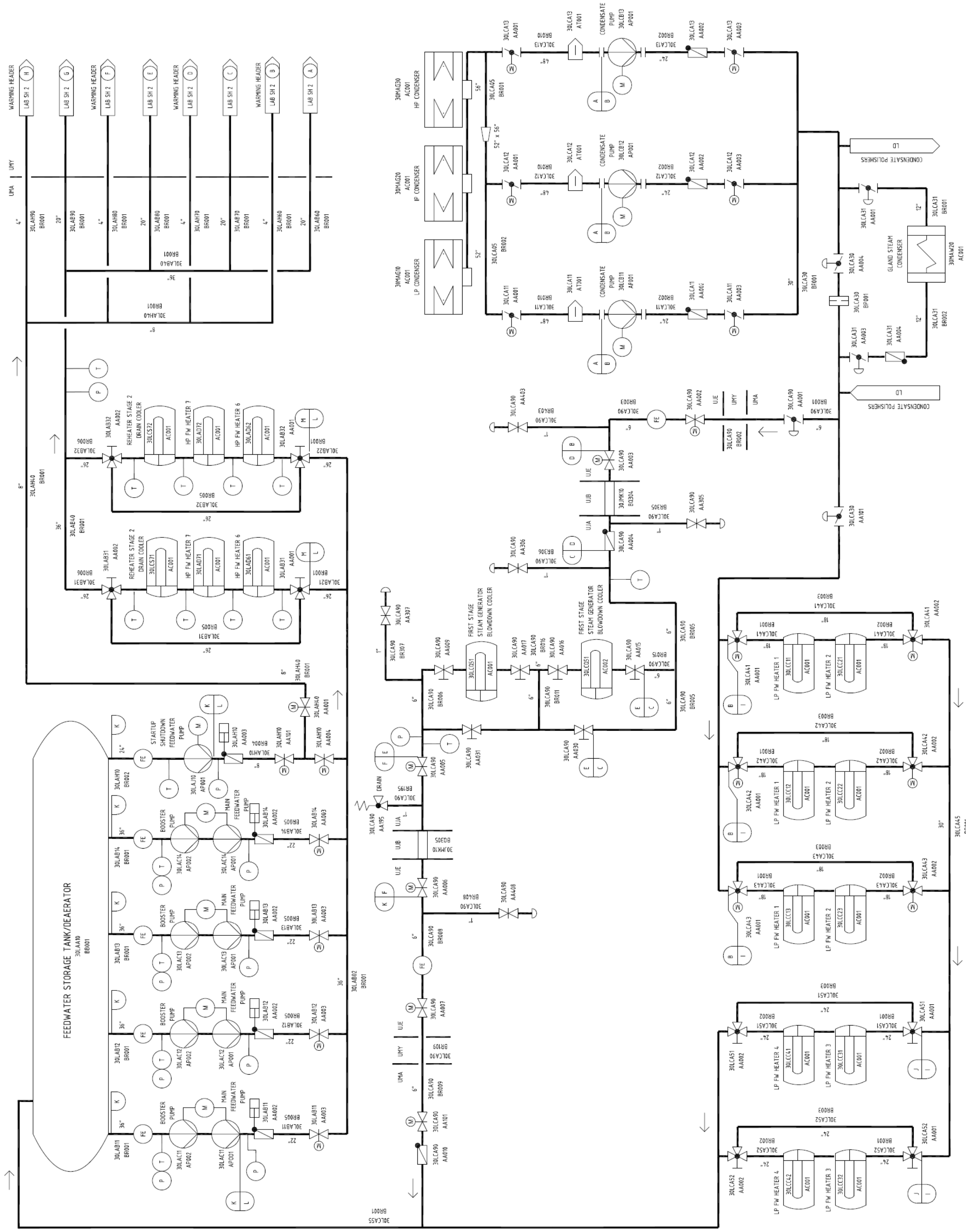

Figure 4-6 Condensate and Feedwater System (Sheet 1)

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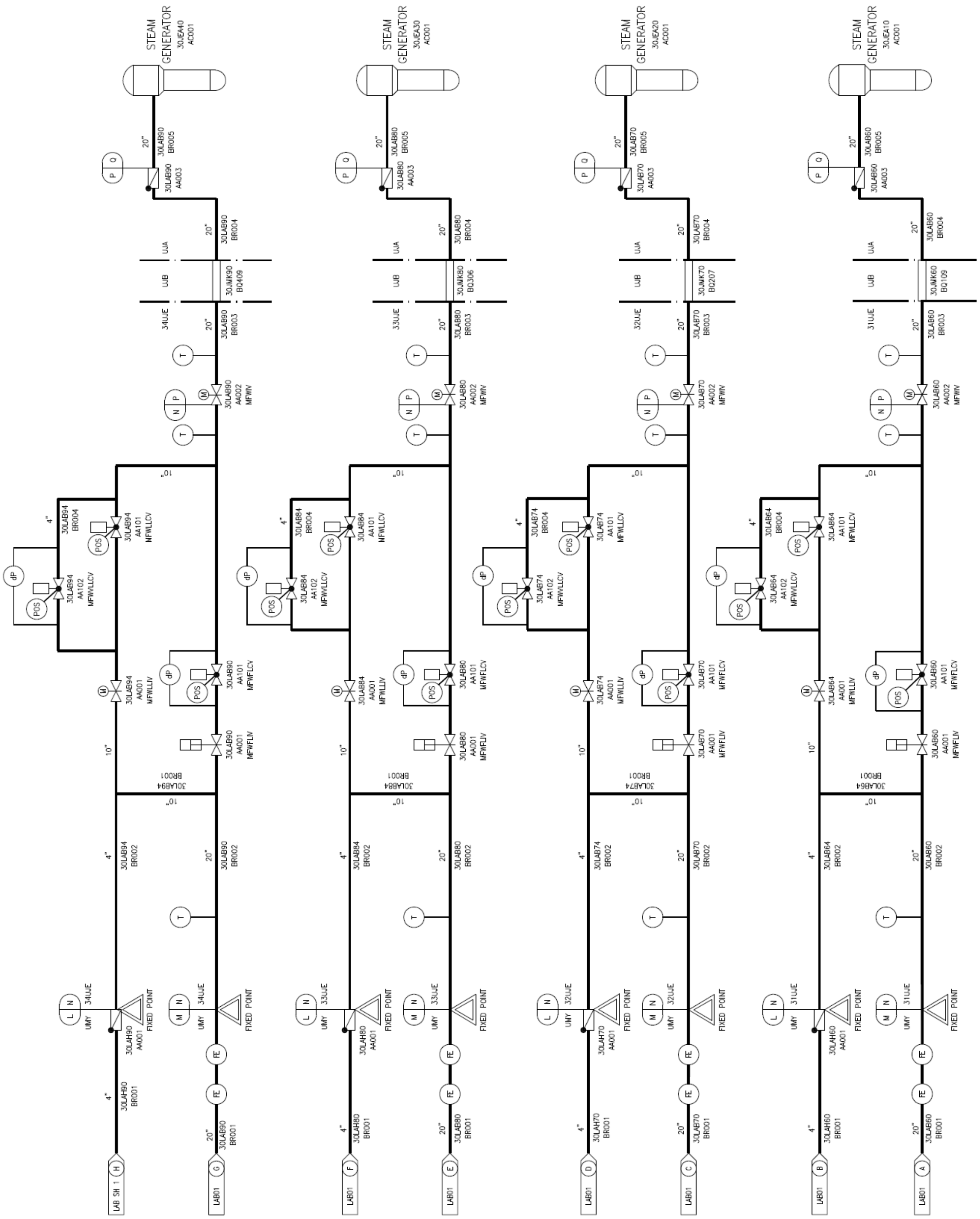

Figure 4-7 Condensate and Feedwater System (Sheet 2)

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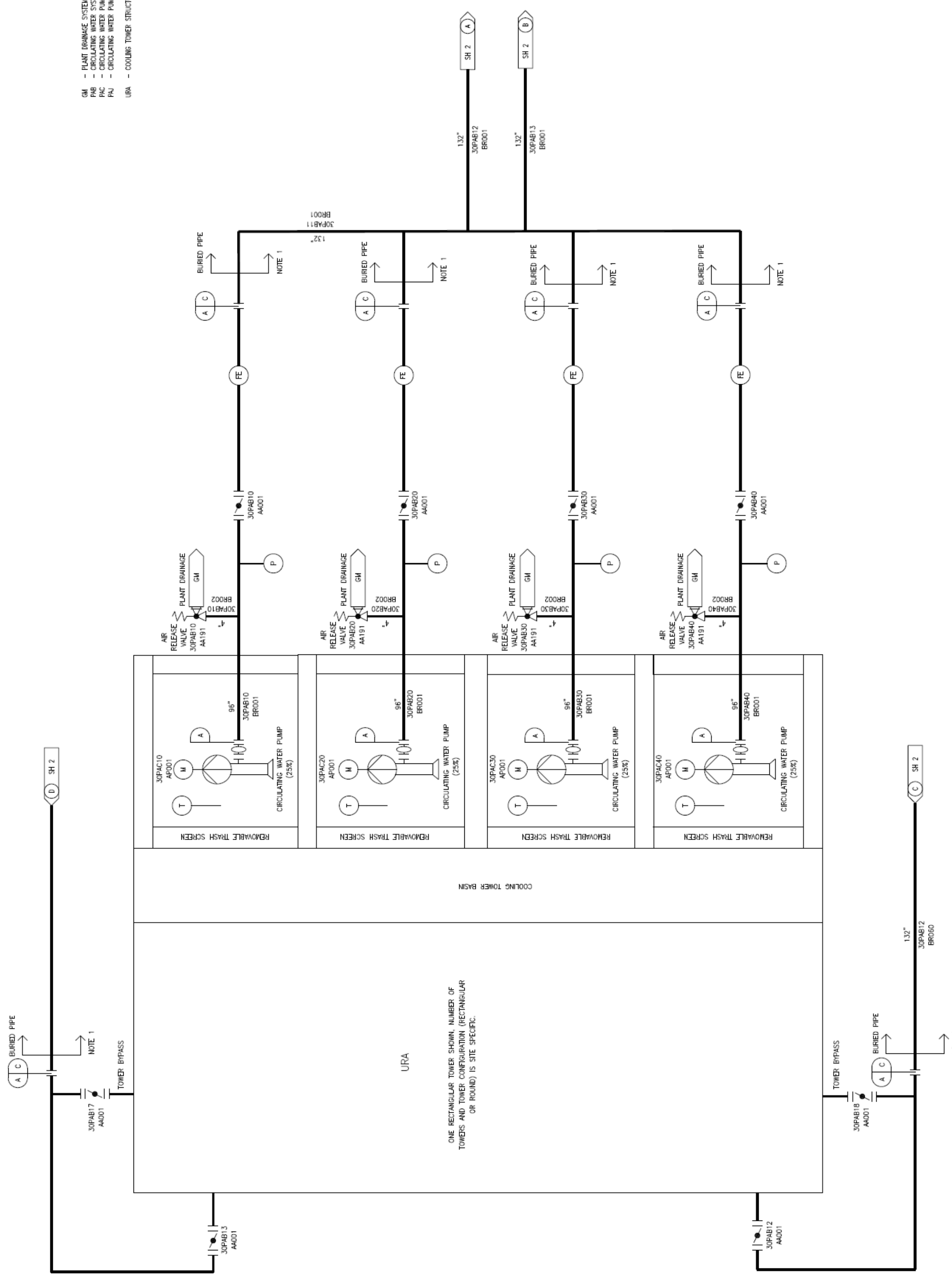

Figure 4-8 Condenser Circulating Water System (Sheet 1)

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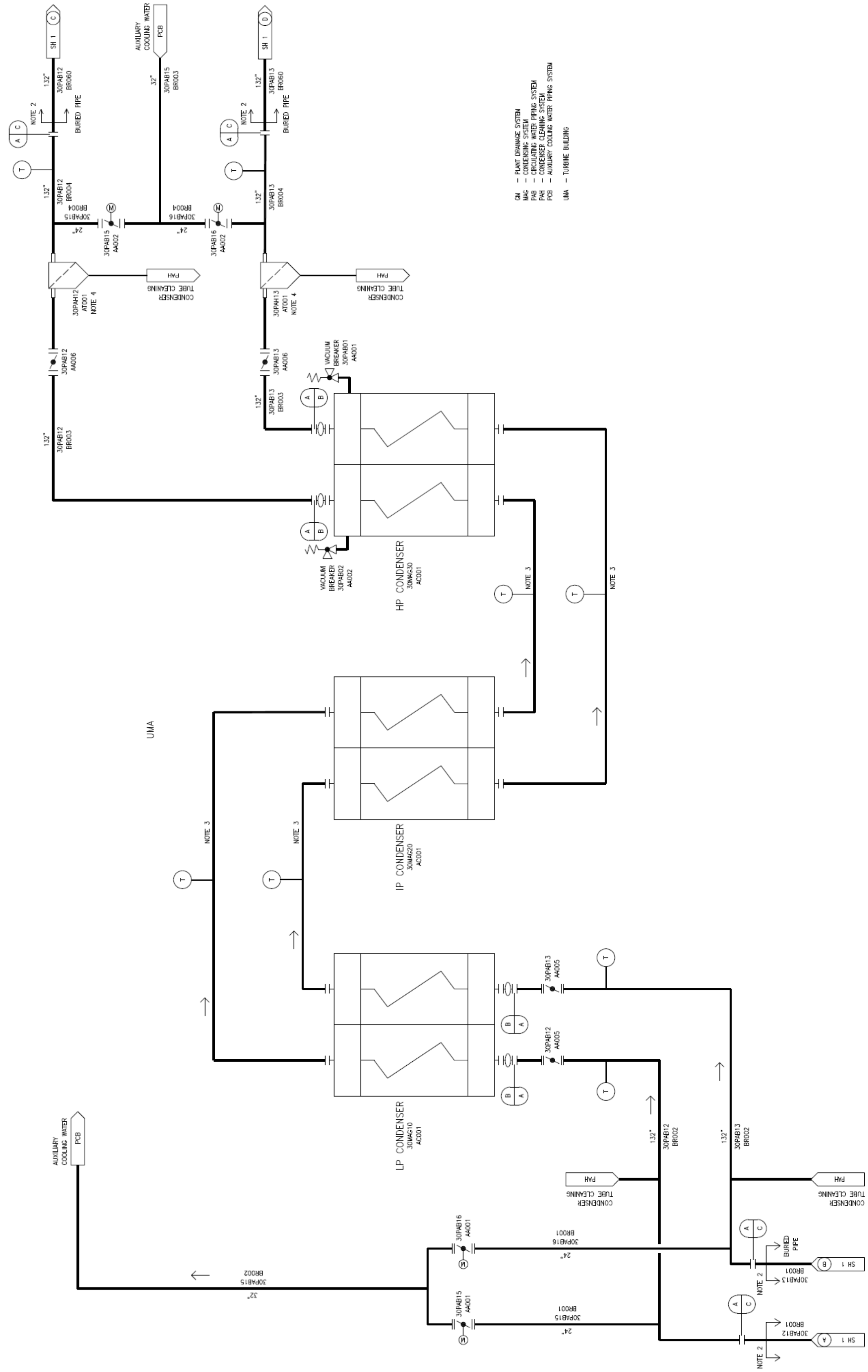

Figure 4-9 Condenser Circulating Water System (Sheet 2)

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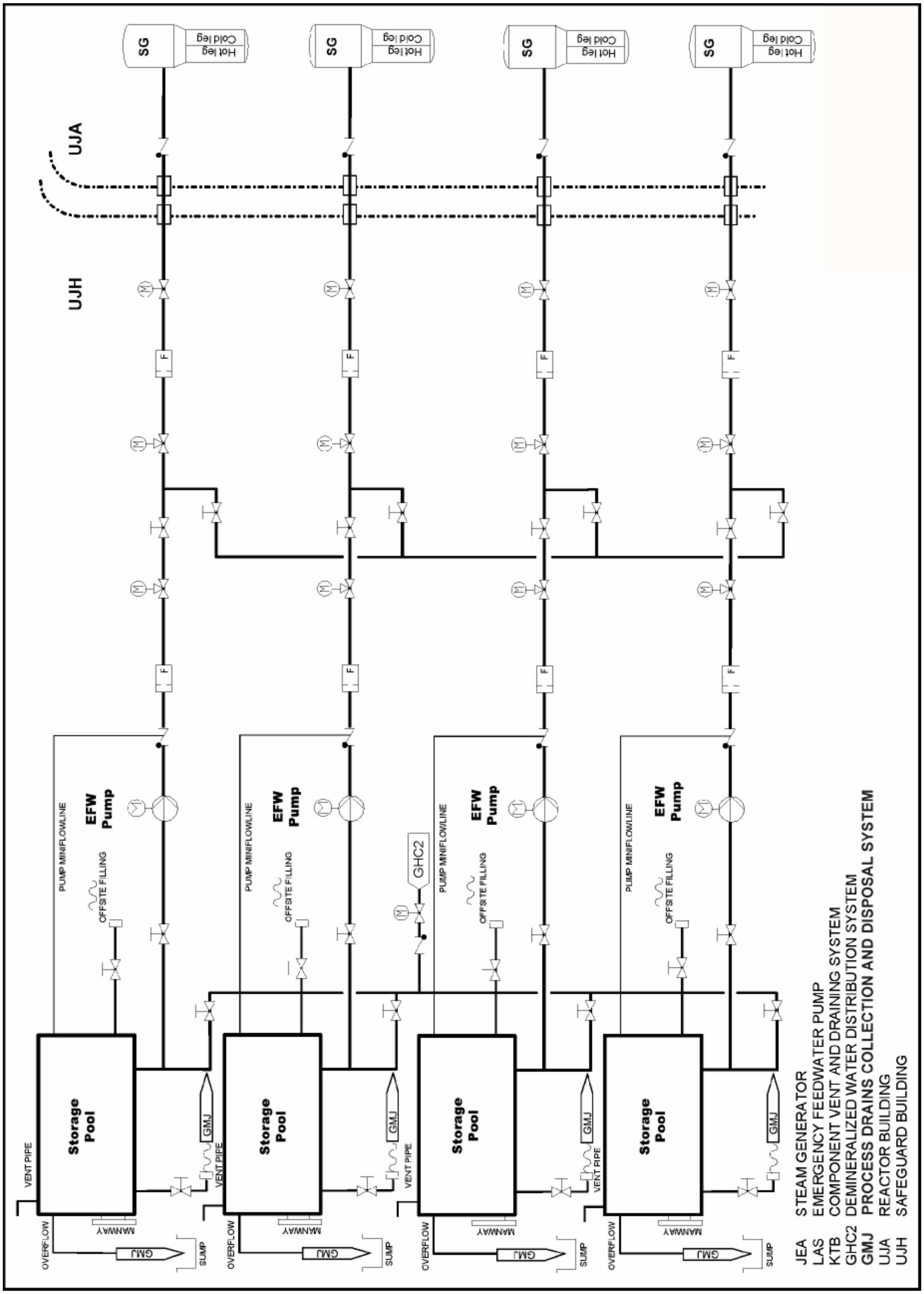

Figure 4-10 Emergency Feedwater System

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