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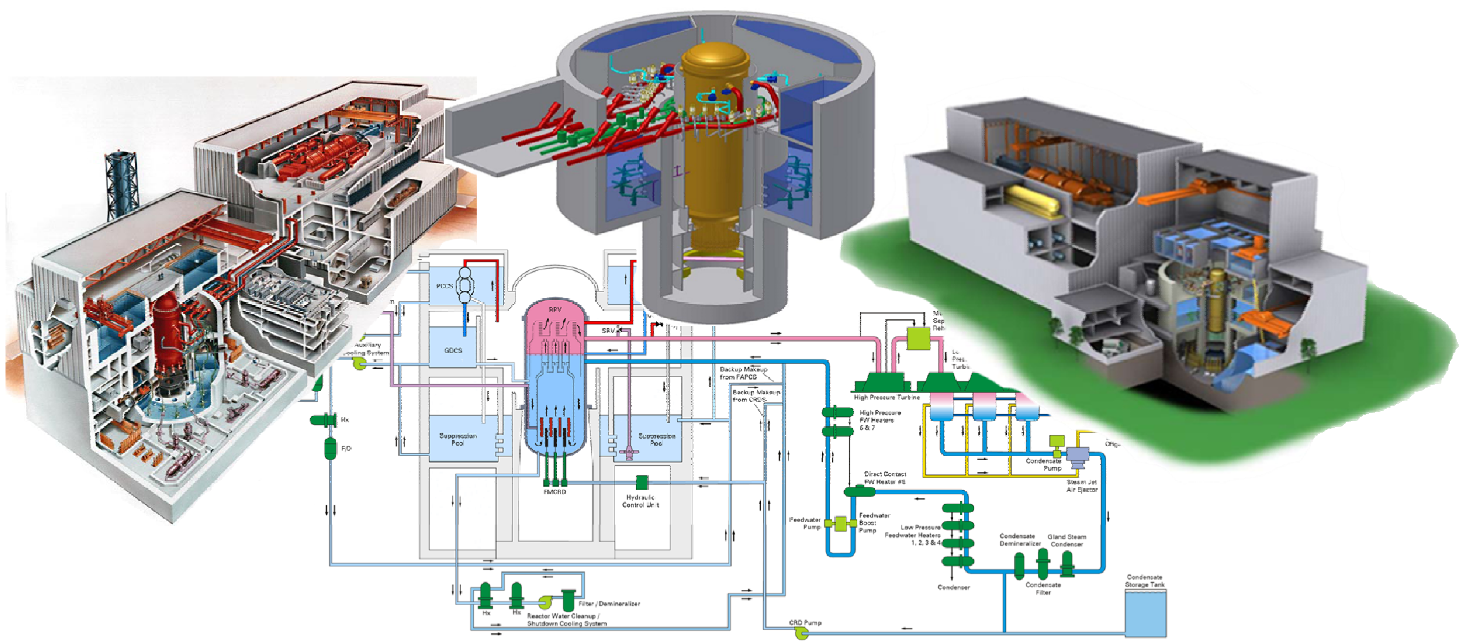

Part II
Introduction to Reactor Technology - BWR

Chapter 8.0, Balance of Plant Systems

HRTD
Human Resources Training & Development

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HUMAN RESOURCES TRAINING & DEVELOPMENT

Introduction to Reactor Technology

This manual is a text and reference document for the Introduction to Reactor Technology for the media briefing. It should be used by students as a study guide during attendance at this course. This manual was compiled by staff members from the Human Resources Training & Development in the Office of Human Resources.

The information in this manual was compiled for NRC personnel in support of internal training and qualification programs. No assumptions should be made as to its applicability for any other purpose. Information or statements contained in this manual should not be interpreted as setting official policy. The data provided are not necessarily specific to any particular nuclear power plant, but can be considered to be representative of the vendor design.
The Introduction to Reactor Technology – BWR briefing manual outlines the differences between the Boiling Water Reactors (BWR), Advanced Boiling Water Reactor (ABWR), and Economic Simplified Boiling Water Reactor (ESBWR). The course is broken down into discussions on design features, facility and plant layout, containment systems, nuclear steam supply systems, control and instrumentation, safety systems, balance of plant systems, normal, abnormal, and emergency operations.
The content of this course was based on the content provided in the following references:

- General Electric Systems Manual
- Introduction to ABWR Manual
- Introduction to ESBWR Course Manual
- Economic Simplified Boiling Water Reactor Plant General Description; June 2006, General Electric Company
- NUREG-1503, Final Safety Evaluation Report Related to the Certification of the Advanced Boiling Water Reactor Design and Appendices, U.S. Nuclear Regulatory Commission Office of Nuclear Reactor Regulation, July 1994
- ABWR, Advanced Boiling Water Reactor Plant General Description, “First of the Next Generation,” GE Nuclear Energy, June 2000
- Nuclear News, World List of Nuclear Power Plants, American Nuclear Society, March 2007
- J. Alan Beard & L.E. Fennern, General Electric presentation to DOE et.al, April 13th 2007, Germantown Md.

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The information contained in this chapter pertains to current operational reactor designs. Advanced reactor designs are provided in separate chapters.

8.0 Balance of Plant Systems

The BWR balance of plant systems are the ones which are immediately involved in the direct cycle BWR concept as part of the steam cycle or else provide an auxiliary function for the direct cycle system. These systems are graphically displayed in Figure 8.0-1. The BWR direct steam cycle starts with the reactor vessel which is part of the reactor coolant pressure boundary and which contains the reactor core. The reactor core provides the heat source for steam generation and consists primarily of the nuclear fuel and control rods for regulating the fission process. The steam generated in the reactor vessel is routed to the steam loads and then condensed into water. The water is then purified, heated, and pumped back to the reactor vessel to again be heated. Water from the reactor vessel is circulated through external pumping loops and then returned to the reactor vessel to provide forced circulation of flow through the reactor core. Reactor water is continuously purified to minimize impurities. Should the reactor become isolated from its main heat sink, an auxiliary system automatically maintains the reactor core covered with water.

8.0.1 Main Steam System

The Main Steam system directs steam from the reactor vessel to the turbine generator, bypass valves, reactor feed pump turbines, and other selected balance of plant loads; directs steam to certain safety related systems under abnormal conditions; and provides overpressure protection for the reactor coolant pressure boundary.

8.0.2 Condensate and Feedwater System

The Condensate and Feedwater system condenses turbine exhaust or bypass steam, removes impurities, heats the feedwater and delivers the water back to the reactor vessel at the required rate to maintain correct inventory. The feedwater piping also provides a means for the Reactor Water Cleanup (RWCU) system, the Reactor Core Isolation Cooling (RCIC) system and the High Pressure Coolant Injection (HPCI) system to discharge water to the reactor vessel.

8.0.3 Reactor Water Cleanup System

The Reactor Water Cleanup (RWCU) system maintains reactor water quality by removing corrosion products, fission products and other impurities that end up in the reactor coolant. The RWCU system also provides a path for the removal of reactor coolant from the reactor vessel during periods of reactor startup and shutdowns.

8.0.4 Reactor Core Isolation Cooling System

The Reactor Core Isolation Cooling (RCIC) system supplies high pressure makeup water to the reactor vessel when the reactor is isolated from the main condenser and/or loss of the reactor feed pumps.

8.1 MAIN STEAM SYSTEM

The purposes of the Main Steam system are:

- to direct steam from the reactor vessel to the main turbine and other steam loads and
- to provide overpressure protection for the Reactor Coolant system.

The functional classification of the Main Steam system is that of a power generation system. The main steam system does, however, contain three components which are engineered safety features (ESF). These ESFs are the main steam isolation valves, the main steam line flow restrictors and the safety/relief valves.

8.1.1 System Description

The flow path for the Main Steam system is shown on Figure 8.1-1 and Figure 8.1-2. Within the drywell, steam is transmitted from the reactor vessel to the inboard main steam isolation valves via 4 steam lines. Each of the lines contain safety/relief valves, steam line flow restrictors, drain line connection and inboard isolation valves. Also provided from the steam lines is a reliable source of steam for the High Pressure Coolant Injection system and the Reactor Core Isolation Cooling system.

Outside of the drywell, the steam progresses through outboard isolation valves to an equalizing header where all 4 of the steam lines terminate. From the equalizing header steam is routed to the main turbine and a number of auxiliary support systems.

8.1.2 Component Description

The major components of the Main Steam system are discussed in the paragraphs which follow.

8.1.2.1 Safety/Relief Valves

The Safety/Relief valves (11) provide overpressure protection for the reactor vessel and associated piping systems. In addition, a selected number of safety/relief valves are used by the Automatic Depressurization System (ADS).

All of the safety/relief valves are mounted on a horizontal portion of the main steam lines inside the drywell. They are dual actuating valves and discharge to the suppression pool. Actuation is accomplished by any of the following; (l) high system pressure (safety mode); (2) remotely by operator action; (3) the ADS logic .

In the safety mode, the safety/relief valves are actuated by high pressure steam positioning a pilot valve against setpoint spring pressure to depressurize the top of the main valve piston. The removal of steam on top of the main valve piston creates a differential pressure which forces the main valve open. Steam is released through the valve to the suppression pool, lowering reactor pressure.

In the relief mode of operation, air pressure is applied to an air actuator by energizing a solenoid operated valve. The air actuator mechanically positions the pilot valve, depressurizing the top of the main valve piston to cause the main valve to open. The solenoids are energized by switches located in the control room. This type of arrangement provides the control room operator with a means to operate any of the 11 safety/relief valves. Seven of the safety/relief valve solenoids can also be energized by actuation of the Automatic Depressurization System logic.

8.1.2.2 Main Steam Line Flow Restrictors

The main steam line flow restrictor is a engineered safety feature incorporated into the plant design to limit the loss of mass inventory from the reactor during a steam line break. Each flow restrictor is designed to limit steam flow to less than 200% of rated steam flow during a steam line break. The flow restrictors are also used to develop steam flow signals for use in the Feedwater Control system and Primary Containment Isolation system.

8.1.2.3 Main Steam Isolation Valves

The Main Steam Isolation Valves (MSIVs) are provided to limit the release of radioactive materials to the environment following a steam line break outside of containment. Redundant valves are located on each main steam line, one inside and one outside the primary containment. The MSIVs are air/spring operated valves; air to open, air and/or spring to close.

8.1.2.4 Main Steam Line Drains

The main steam line drains are provided to serve a dual function. The first function is to remove moisture from the steam lines prior to and during turbine operation. The removal of moisture helps prevent damage to the turbine blades. The steam line drains also provide the capability to equalize pressure around the MSIVs prior to opening.

8.1.2.5 Bypass Valves

Four bypass valves are used to bypass up to 30% of rated steam flow directly to the condenser when the main turbine is not capable of using the steam. The bypass valves work in conjunction with the turbine control valves to ensure a constant reactor pressure for a given reactor power level. Operation of the bypass valves is automatically controlled by the Electro Hydraulic Control (EHC) system.

8.1.2.6 Turbine Stop Valves

There are four turbine stop valves located in the main steam piping just upstream of turbine control valves. The stop valves are normally open during turbine operation with a rapid closure capability upon detection of potentially unsafe turbine conditions. The number two stop valve also contains an internal bypass which is used to equalize pressure across the stop valves prior to opening.

8.1.2.7 Turbine Control Valves

The control valves regulate the steam flow to the turbine, as controlled by the EHC system, in order to control reactor pressure. The control valves also provide the control mechanism for rolling, synchronizing and loading the turbine generator.

8.1.2.8 Turbine

The main turbine is an 1800 RPM, tandem compound machine, consisting of one high pressure turbine and three low pressure turbines. The steam enters the middle of the high pressure section and works its way toward each end, dissipating its energy to the turbine blades which are attached to a common shaft. Steam exiting the high pressure turbine passes through moisture separators where entrained moisture, which could cause turbine blade damage, is removed prior to entering the low pressure turbines.

Prior to entering the low pressure turbines, the steam passes through the low pressure turbine control and stop valves which are called Combined Intermediate Valves (CIVs) and are actually two valves in one housing. The intercept valves provide throttling to prevent turbine overspeed caused by a rapid reduction in generator load. The CIV stop valve is designed to be fully open or fully closed (open during normal operation) and provides a rapid means of isolating the low pressure turbines from their steam supply when necessary.

There are taps for extracting steam at different stages on the low pressure turbine. This steam is used to preheat the feedwater going back to the reactor vessel.

The exhaust of the low pressure turbine sections is directed to the main condenser, where it is condensed and deaerated, then collected in a hotwell to be pumped by the Condensate and Feedwater system to the reactor vessel.

8.1.2.9 Steam Jet Air Ejector (SJAE)

The Steam Jet Air Ejectors remove noncondensible gases from the condenser and provide the motive force for moving these gases through the Offgas system.

8.1.2.10 Gland Seal Steam

The steam space along the turbine shaft, between the turbine's last stage and atmosphere, is sealed in order to maintain the vacuum in the main condenser and to prevent contaminated steam from leaking to atmosphere. Sealing is accomplished by means of labyrinth type shaft packing which provide a series of throttling that limit steam leakage along the rotating shaft to a minimum as it is throttled from the high pressure space to the low pressure space.

Air and steam, possibly radioactive, are removed from the seals through a steam packing exhaust system and discharged to the plant stack system via a short holdup line (primarily for N^{l6} decay).

8.1.2.11 Other Steam Equipment

The Main Steam system supplies steam to a number of components within the plant. Below is a listing of some of those components and a description of those not covered elsewhere in this manual.

- Off Gas system
- Reactor Feed Pump Turbines
- Reactor Core Isolation Cooling system
- High Pressure Coolant Injection system

8.1.3 System Features

A short discussion of system features is given in the paragraphs which follow.

8.1.3.1 Main Steam Isolation Valves

To minimize the release of radioactive materials to the environment, the MSIVs receive automatic closure signals from the Primary Containment Isolation system. Automatic closure of all eight MSIVs is initiated under any of the following conditions:

- Low-Low Reactor Vessel Water Level,
- High Main Steam Line Radiation,
- High Main Steam Line Flow,
- High Steam Line Area Temperature, or
- Low Steam Line Pressure with the mode switch in Run

MSIV closure, with the reactor critical, can result in a severe pressure and power increase. Because of this, MSIV closure signals the Reactor Protection system to scram the reactor. The valves are required to close in >3 but <5 seconds to minimize the pressure/power increase and, at the same time, limit the release of radioactive material on a downstream line break.

8.1.3.2 Turbine Stop and Control Valve Closure

The hydraulically operated turbine stop and control valves can be tripped closed within 0.1 and 0.2 seconds respectively. Because of the large pressure and neutron flux spikes created by stop valve closure and control valve fast closure, the reactor is automatically scrammed and reactor recirculation pumps tripped if either condition occurs with power above the capacity of the bypass valves.

8.2 CONDENSATE AND FEEDWATER SYSTEM

The purposes of the Condensate and Feedwater system are:

- to condense steam and collect drains in the main condenser, and
- to purify, preheat and pump water from the main condenser to the reactor vessel

The functional classification of the Condensate and Feedwater system is that of a power generation system.

8.2.1 System Description

The Condensate and Feedwater system, shown in Figure 8.2-1, is an integral part of the plant's conventional regenerative steam cycle. The steam exhausted from the two low pressure turbines is condensed in the main condenser and collected in the condenser hotwell, along with various equipment drains. The condensate that is collected in the hotwell is removed by two condensate pumps. The condensate pumps provide the driving force for the condensate which flows through the Steam Jet Air Ejector (SJAE) condensers, steam packing exhaust condenser, and offgas condenser performing a heat removal function. At this point, the condensate is directed to the condensate filter/ demineralizers and, through the process of filtration and ion exchange, impurities are removed. After the demineralizers, booster pumps are used to maintain the driving force of the condensate flow through strings of low pressure feedwater heaters. The feedwater pumps then take the condensate flow and further increase the pressure to a value above reactor pressure. The amount of feedwater flowing to the reactor vessel is controlled by varying the speed of the turbine driven reactor feed pumps. The discharge of the feedwater pumps is directed to the high pressure feedwater heater strings for the final stage of feedwater heating. Two feedwater lines penetrate the primary containment and then further divide into a total of six penetrations which enter the reactor vessel with each supplying feedwater to a feedwater sparger. The feedwater spargers distribute the flow of feedwater within the vessel annulus area.

8.2.2 Component Description

The components that comprise the Condensate and Feedwater system are discussed in the following paragraphs and illustrated in Figure 8.2-1.

8.2.2.1 Main Condenser

The main condenser is a surface condenser with two separate shells with each shell operating at the same vacuum. The condensers serve as the main heat sink for low pressure turbine exhaust and several other flows, such as exhaust steam from the reactor feed pump turbines, cascading low pressure heater drains, SJAE drains, turbine bypass valves, etc. The condenser also provides an area for noncondensible gases from the primary steam to be collected and exhausted via the SJAEs.

The condensed steam and various drains accumulate in the bottom of the condenser in an area termed the hotwell and are designated condensate water.

8.2.2.2 Condensate Pumps

Two motor driven condensate pumps, with a capacity of 60% each, remove water from the main condenser hotwell and discharge to parallel string of auxiliary condensers. The auxiliary condensers consist of two SJAE condensers, two offgas condensers, and one steam seal condenser.

8.2.2.3 Auxiliary Condensers

The auxiliary condensers are shell and tube type heat exchangers with condensate passing through the tubes condensing steam outside the tubes. The auxiliary condensers perform a dual function by condensing the steam and by adding heat to the condensate water.

The SJAE condensers are used to condense the steam exhausted from the first stage SJAE.

The purpose of the steam seal condenser is to condense the leak off from the main and reactor feed pump turbine seals. A vacuum is maintained in the gland seal condenser by one of two blowers which remove noncondensible gases and discharge through a 1.75 minute holdup to the plant stack.

The offgas condenser removes excessive moisture from the offgas process mixture following the recombination of hydrogen and oxygen in the offgas system.

8.2.2.4 Condensate Filter/Demineralizers

The purpose of the condensate filter/demineralizers is to treat the full flow of condensate from the condenser hotwell by removing impurities through filtration and ion exchange. Impurities consist of, but are not limited to, corrosion products and any circulating water in leakage to the condenser.

The condensate filter/demineralizers consist of eight filter/demineralizer units located in individual concrete cells and a common backwash and precoat system.

Each filter/demineralizer unit consists of a vertical cylindrical vessel which houses several nylon filter elements. The filter elements are coated with a mixture of powdered cation and anion exchange resins in hydrogen and hydroxyl forms. The coating is applied to the elements to a thickness of about 0.25 inches.

When a filter/demineralizer unit exceeds a specified differential pressure or when the effluent conductivity increases above 1μmho/cm it is removed from service. With the unit out of service, the spent resin is removed by reversing the normal flow path (backwashing) and sent to the Solid Radwaste system for disposal. A fresh resin slurry is then applied by the precoat system and the unit is placed back in service or standby until needed. The entire backwashing and precoat operation for a single unit requires about one hour.

8.2.2.5 Condensate Booster Pumps

Two, 60% capacity condensate booster pumps take suction on the filter/demineralizers outlet header and discharge to the low pressure feedwater heaters. The condensate booster pumps are motor driven with a discharge pressure of 600 psig.

8.2.2.6 Low Pressure Feedwater Heaters

The low pressure feedwater heaters are arranged in two parallel strings with each string consisting of one drain cooler and four low pressure heaters. The low pressure feedwater heaters utilize extraction steam from the two low pressure turbines to heat the feedwater prior to returning it to the reactor vessel thus increasing plant efficiency. The heaters are constructed so that condensate flows through the heater tubes while extraction steam flows around the tubes. The condensed extraction steam (extraction drains) from each heater flows to the next lower pressure heater by means of the pressure difference between the successive heaters.

8.2.2.7 Reactor Feedwater Pumps

The two feedwater pumps are 60% capacity pumps driven by variable speed steam turbines. The feedwater pumps take the heated feedwater from the outlet of the low pressure feedwater heaters and provide the driving force for returning the feedwater to the reactor vessel. The Feedwater Control system regulates the steam supply to the reactor feed pump turbines thus regulating the speed of the pump to produce more or less flow to the reactor vessel to control vessel water level.

Steam for the reactor feed pump turbines is supplied from two sources, the main steam equalizing header and the high pressure turbine exhaust. During normal operation the steam from the high pressure turbine exhaust is used and the main steam equalizing header serves as the backup supply.

8.2.2.8 High Pressure Feedwater Heaters

The high pressure feedwater heaters represent the last stage of feedwater heating. They consists of two parallel strings with one heater per string. The term high pressure heater is used because they use higher pressure extraction steam and are located at discharge of the feedwater pumps.

8.2.2.9 Feedwater Spargers

The outlet of the high pressure feedwater heaters is arranged so that two feedwater lines penetrate the primary containment. Containment isolation is provided by check valves on both sides of the drywell. Once inside the primary containment, the feedwater lines are divided into six lines. The six feedwater lines have separate reactor vessel penetrations and are equipped with thermal sleeves and a feedwater sparger inside the reactor vessel. The six feedwater spargers provide flow distribution in the vessel downcomer annulus area.

8.2.3 System Features

A short discussion of the system features is given in the paragraphs which follow.

8.2.3.1 Startup Operation

During plant startup, feedwater is required to maintain water level in the reactor when the steaming rate exceeds the Control Rod Drive system input. In plant conditions where the available steam pressure is insufficient to run the Reactor Feed pumps, such as startup, to accomplish the task of maintaining reactor water level the condensate and condensate booster pumps, along with a startup bypass valve are used. The condensate and condensate booster pumps supply the motive force while the startup bypass valve, bypassing the feed pumps, is used to regulate the amount of water addition to the reactor vessel.

When reactor pressure reaches approximately 300 psig, the reactor feed pumps can be started.

8.2.3.2 Normal Operation

The number of condensate pumps, condensate booster pumps, and reactor feed pumps in service depends upon the plant power level. Normally, at 100% power all the condensate, condensate booster, reactor feed pumps and seven of the eight filter/demineralizers are in operation. At lower power levels, various combinations of pumps and filter/demineralizers are used. In general, the flow requirements are controlled by the Feedwater Control system regulating the speed of the feed pumps.

8.3 REACTOR WATER CLEANUP SYSTEM

The purposes of the Reactor Water Cleanup (RWCU) system are:

- to maintain reactor water quality by filtration and ion exchange, and
- to provide a path for removal of reactor coolant when required.

The functional classification of the RWCU system is that of a power generation system.

8.3.1 System Description

The RWCU system, shown in Figure 8.3-1, provides a continuous purification of a portion of the reactor recirculation system flow. Water is taken from the Reactor Recirculation system piping and pumped through the regenerative and nonregenerative heat exchangers, filter/demineralizers and returned through the shell side of the regenerative heat exchanger to the feedwater piping. The RWCU system also removes a small portion of water from the reactor vessel bottom head drain to reduce any crud buildup and the possibility of cold water stratification.

8.3.2 Component Description

The major components of the RWCU system are discussed in the paragraphs which follow and can be seen in Figure 8.3-1.

8.3.2.1 RWCU Inlet Piping

The major flow of the RWCU system is taken from the suction of either recirculation pump. This suction is common to the shutdown cooling mode of the Residual Heat Removal system (Section 10.4). An additional source of water is provided by a line from the reactor vessel bottom head drain. Isolation valves are provided both inside and outside of the primary containment for isolating the RWCU system during unsafe conditions.

8.3.2.2 RWCU Pumps

Two RWCU pumps provide the needed motive force for water flow from the recirculation loop, through the RWCU system and back to the reactor vessel via the feedwater system. The RWCU pumps are motor driven, horizontally mounted, centrifugal pumps. Each pump can provide 100% system flow which corresponds to approximately l% of rated feedwater flow.

8.3.2.3 Regenerative Heat Exchangers

The first stage of temperature reduction is accomplished by three regenerative heat exchangers arranged in series. The regenerative heat exchangers transfer heat from the influent reactor water by preheating the RWCU system's effluent. This results in less system heat loss and less thermal stress as the effluent water enters the feedwater system.

8.3.2.4 Nonregenerative Heat Exchangers

The nonregenerative heat exchangers provide the final reduction of water temperature prior to entry into the filter/demineralizers. Unlike the regenerative heat exchangers, the heat removed in the nonregenerative heat exchangers is lost to another system, the Reactor Building Closed Loop Cooling Water system.

8.3.2.5 Filter/Demineralizer Units

The purpose of the filter/demineralizers is to remove soluble and insoluble impurities from the reactor water. This process is accomplished by the water flowing through a finely ground filter aid material (Solka-Floc) and ion exchange resins.

The two filter/demineralizer units are of a pressure precoat type in which the vessel filter tubes are coated with a filter aid and powdered ion exchange resin. These materials serve as the filter media and ion exchange agent and are held on to the screen type tubes by the differential pressure generated by the water flowing through each unit. Flow through the system is automatically controlled by flow control valves located at the outlet of each filter/demineralizer.

Each unit is composed of a pressure vessel which contains the filter tubes, a holding pump, instrumentation, controls, valves, and piping. Air operated inlet and outlet isolation valves and the flow control valve are furnished for each filter/demineralizer unit to permit individual operation and serving. Auxiliary components required for precoating, backwashing, and disposal of the filter media are shared by both filter/demineralizers.

8.3.2.6 RWCU Outlet Piping

Filter/demineralizer effluent line branches into two lines, one line routing water to the regenerative heat exchangers and the other to the blowdown control section. During normal system operation, flow is routed through the shell side of the regenerative heat exchangers, a motor operated discharge isolation valve and into the feedwater lines.

During other operations requiring reactor vessel blowdown, a portion of the flow is routed to the main condenser or to the Liquid Radwaste system. Blowdown flow is directed through a common header which is controlled by a flow control valve and a restricting orifice. The restricting orifice provides a large pressure drop to protect the low pressure downstream piping. If additional flow is required, a motor operated orifice bypass valve can be opened.

8.3.3 System Features

A short discussion of the system features is given in the paragraphs which follow.

8.3.3.1 System Operation

The RWCU system is normally operated continuously during all phases of reactor plant operation to maintain undissolved solids less than 0.01 ppm and conductivity less than 0.1 micro mho/cm. Blowdown (draining) is normally used only to remove excess water from the reactor vessel.

Reactor water quality depends on several factors: corrosion of primary system materials, input of impurities and corrosion products from the Condensate and Feedwater system, piping deposition and re-entrainment at system surfaces, radioactive decay, and removal of impurities (corrosion products and fission products) by the filter/demineralizers.

Impurities in the reactor water are of two forms, soluble and insoluble. By definition, insoluble material is that collectible on a type HA millipore filter paper; the remainder is soluble. The soluble materials are suspended in the water until collected or plated onto some surface.

The insoluble materials are removed by filtration. Corrosion product inputs from the primary systems have been minimized by use of stainless steel vessels, pipes, and heat exchangers. The majority of corrosion product input originates in the condenser and feedwater components where carbon steel piping and components are used. Cleanup system operation is necessary to maintain reactor water purity. Reactor operation without the cleanup system is limited to relatively short periods of time.

8.3.3.1.1 Normal Operation

During normal operation water is taken from the reactor recirculation system piping and pumped through the regenerative and nonregenerative heat exchangers, both filter/demineralizers, and returned through the shell side of the regenerative heat exchanger to the feedwater piping. The RWCU also removes a small portion of water from the reactor vessel bottom head drain to reduce any crud buildup.

8.3.3.1.2 Blowdown

During a plant startup, shutdown, or low steaming rates, it is sometimes necessary for the operator to drain water from the vessel in order to maintain a proper vessel level. This is done with the blowdown portion of the RWCU system. Water, from the outlet of the filter/demineralizers, can be rejected to the main condenser or to the Liquid Radwaste system rather than being returned to the vessel. In this way, water is removed from the reactor. The blowdown flow rate is controlled manually from the control room. The hand operated controller is set to the desired flow and the appropriate motor operated valve is opened, directing flow to either the main condenser or to the Liquid Radwaste system. The main condenser is the preferred blowdown point in order to limit the duty on the liquid waste processing facilities. During the blowdown operation, the greatest duty is imposed on the non-regenerative heat exchangers because the blowdown portion of the return flow that was going to the regenerative heat exchangers is now bypassing them. If, during blowdown operation, high pressure is sensed downstream of the blowdown control valve or if low pressure is sensed upstream, the blowdown control valve will automatically close. The high pressure sensor protects the piping downstream of the control valve and the low pressure sensor prevents draining the entire RWCU system piping in a siphon action to the main condenser or radwaste.

8.3.3.2 Filter/Demineralizer Operations

Filter/demineralizer operations are discussed in the paragraphs which follow.

8.3.3.2.1 Backwashing

As the differential pressure across a filter/demineralizer unit approaches 20 psid, or if the outlet conductivity reaches 0.1µmhos/cm, the filter/demineralizer is removed from service for backwashing and precoating.

Backwashing consists of removing the spent resins from the filter/deemineralizer holding elements. This is accomplished by the use of an air blast injected into the filter/demineralizer to dislodge the precoat. Condensate is then pumped into the filter/demineralizer through the outlet line. The drain line is then opened, and the mixture of water and spent resins is pumped to the cleanup phase separator tank of the radwaste facilities.

8.3.3.2.2 Precoating

After the filter/demineralizer is backwashed, it is now ready for a new application of resins. The filter/demineralizer is precoated by circulating a slurry of the resin from the resin feed tank onto the stainless steel resin holding elements.

The slurry deposits evenly on the elements while the water returns to the resin feed tank. Precoat recirculation continues until the return water is clear. At this time, a holding pump is automatically started to maintain the precoat in place on the holding elements. The filter/demineralizer is then returned to service, and the holding pump flow stops as system flow increases.

The holding pump for each filter/demineralizer unit is automatically restarted if the filter/demineralizer outlet flow drops below 90%. This ensures a flow through the filter/demineralizer at all times and prevents the precoat from falling off the elements.

8.3.3.3 Isolation

The inboard and outboard system supply isolation valves automatically close following an isolation signal from any one of the following signals:

- low reactor water level, or
- high area temperatures, or
- high differential flow (between inlet and outlet).

The outboard system supply isolation valve will also automatically close following an isolation signal from any one of the following signals:

- Standby Liquid Control system actuation, or
- filter/demineralizer inlet high temperature.

8.4 REACTOR CORE ISOLATION COOLING SYSTEM

The purposes of the Reactor Core Isolation Cooling (RCIC) system are to provide makeup water to the reactor vessel for core cooling when:

- the main steam lines are isolated, or
- the condensate and feedwater system is not available.

The functional classification of the RCIC system is that of a safety related system.

8.4.1 System Description

The RCIC system (Figure 8.4-1) consist of a steam turbine driven pump, with the necessary piping and valves capable of delivering water to the reactor vessel at operating conditions.

The turbine is driven by steam produced in the reactor and exhausts to the suppression pool. The turbine driven pump unit supplies makeup water from the condensate storage tank, with an alternate supply from the suppression pool, to the reactor vessel via the feedwater piping. Additional discharge flow paths are provided to allow recirculation to the condensate storage tank for system testing and a pump minimum flow line to the suppression pool for pump protection. Sufficient capacity is provided to prevent reactor vessel level from decreasing below the top of the core. The system flow rate is approximately equal to the reactor water boil-off-rate 15 minutes after shutdown with design decay heat.

Initiation of the RCIC system is accomplished either automatically on reactor vessel water level low –low, or manually by the operator.

8.4.2 Component Description

The components of the RCIC system are discussed in the paragraphs that follow.

8.4.2.1 Turbine Trip Throttle Valve

The RCIC turbine trip throttle valve is located upstream of the turbine control valve and provides for rapid turbine isolation during potentially unsafe turbine conditions. Opening of the valve, after a trip, is accomplished from the control room via a control switch. Closure of the valve is by spring force and opening is done by an electric motor.

8.4.2.2 Turbine Control Valve

The turbine control valve is opened by spring force and closed by oil pressure. RCIC turbine speed, and therefore pump flow, can be controlled by throttling the steam supply to the turbine. The RCIC flow control circuit determines the valve position necessary to produce the required pump discharge flow and then adjusts the oil pressure to the control valve.

8.4.2.3 RCIC Turbine

The RCIC turbine is designed to accelerate rapidly from a cold standby condition to full load conditions within 20 seconds. The RCIC turbine is a horizontally mounted radial re-entry,

noncondensing turbine designed to operate with a steam supply pressure ranging from 1150 psig to 150 psig. The RCIC turbine operates with a 10 psig exhaust pressure, exhausting to the suppression pool under water.

8.4.2.4 Pump Suction Valves

Motor operated valves are used to line up RCIC pump suction from either the condensate storage tank or from the suppression pool.

Check valves are provided to prevent flow between the condensate storage tank and the suppression pool when both suction valves are open. Any time level in the condensate storage tank reaches a minimum level or the suppression pool reaches a maximum level, the suppression pool suction valve opens. When the suppression pool suction valve is fully open, a close signal is transmitted to the condensate storage tank suction and test return valves.

8.4.2.5 RCIC Pump

The RCIC pump is a turbine driven, horizontal, multistage, centrifugal pump with a capacity of 400 gpm. The RCIC pump is designed for water temperature between 40°F and 140°F. To ensure adequate net positive suction head (NPSH), the pump is located at a lower elevation than its sources of water.

8.4.2.6 RCIC Flow Controller

The RCIC system utilizes a flow controller to automatically or manually control system flow upon initiation. Selection of either automatic or manual mode is performed by the control room operator. In the automatic mode (normal position), the controller compares actual RCIC system flow (sensed by a flow element on the discharge of the pump) with the desired flow setpoint (adjusted by the operator at the controller). Any deviation between actual and desired flow is then converted into a hydraulic signal which positions the control valve as required to balance the flow signals. In manual mode the operator has direct control of RCIC system flow. The operator simply adjusts a manual potentiometer, at the flow controller, to create a signal used for positioning the control valve to obtain the desired flow.

8.4.3 System Features

A short discussion of the system features is given in the paragraphs which follow.

8.4.3.1 RCIC Automatic Initiation

Following a reactor scram from power operation, fission product decay continues to produce heat. This heat will raise reactor pressure causing steam flow to the bypass valves or through the safety/relief valves. The steam flow will cause vessel water level to decrease if the feedwater system is not available. The RCIC system will maintain sufficient reactor water level until the reactor is depressurized and cooled down to a point where the shutdown cooling mode of the Residual Heat Removal system can be placed in operation.

The RCIC system is automatically initiated if vessel level decreases to a low-low water level. When the initiation signal is received, several actions occur. The turbine steam supply shutoff valve opens to admit steam to the turbine. The normal discharge path to the reactor is aligned, the test return line isolates and at the same time, the discharge valve to the feedwater piping opens.

As the turbine begins to roll, an attached lube oil pump builds up oil pressure and the turbine flow control system begins to throttle the turbine control valve. As the turbine speed continues to increase, pump flow and discharge pressure increase until a flow of 400 gpm is achieved (flow controller setting).

Once initiated, the RCIC will remain in operation until either manually secured, an automatic isolation signal is generated, a turbine trip signal is received or reactor vessel water inventory reaches +56" (high level point). At +56" increasing, the turbine steam supply shutoff valve closes to secure the RCIC system. The system will automatically reinitiate when level decreases to the low-low setpoint.

8.4.3.2 Automatic Isolation

The RCIC system steam supply line is an integral part of the nuclear system process barrier and it will be automatically isolated upon detection of a leak. Automatic isolation signals include any one of the following: RCIC high steam line flow, RCIC steam line area temperature high, low steam supply pressure or high pressure between turbine exhaust rupture diaphragms.

Once an isolation signal is generated, the following automatic actions occur:

- isolation signal seals in,
- inboard and outboard steam supply isolation valves shut,
- turbine trip throttle valve trips closed,
- pump discharge valve shuts, and
- pump minimum flow valve shuts if open.

8.4.3.3 RCIC Turbine Trips

The RCIC turbine is automatically shut down by closing the turbine trip throttle valve to protect the physical integrity of the RCIC system. If any of the following conditions are detected the RCIC system will automatically trip:

- isolation signal,
- high turbine exhaust pressure,
- low pump suction pressure or
- overspeed.

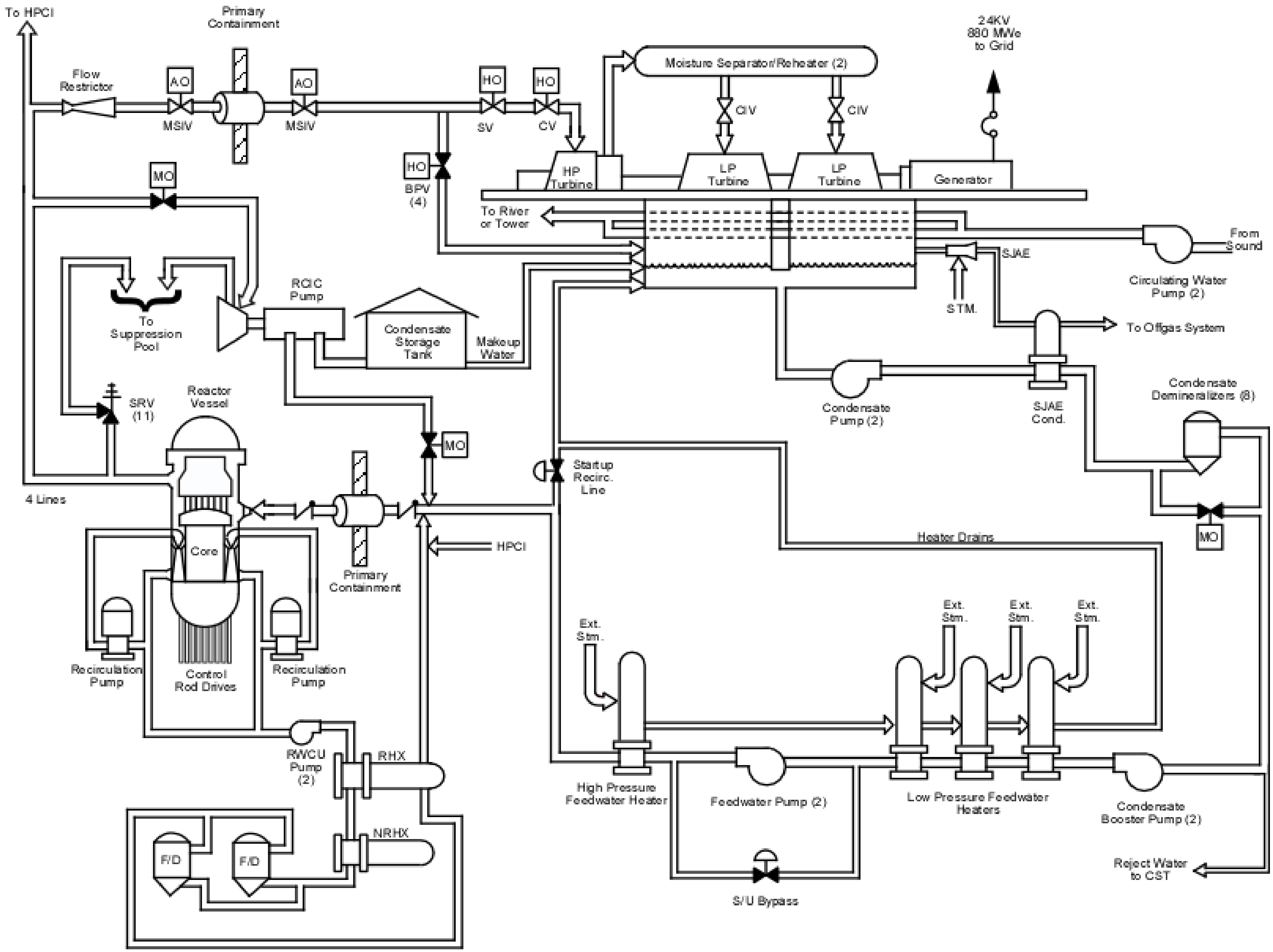

Figure 8.0-1, Simplified BWR Systems Diagram

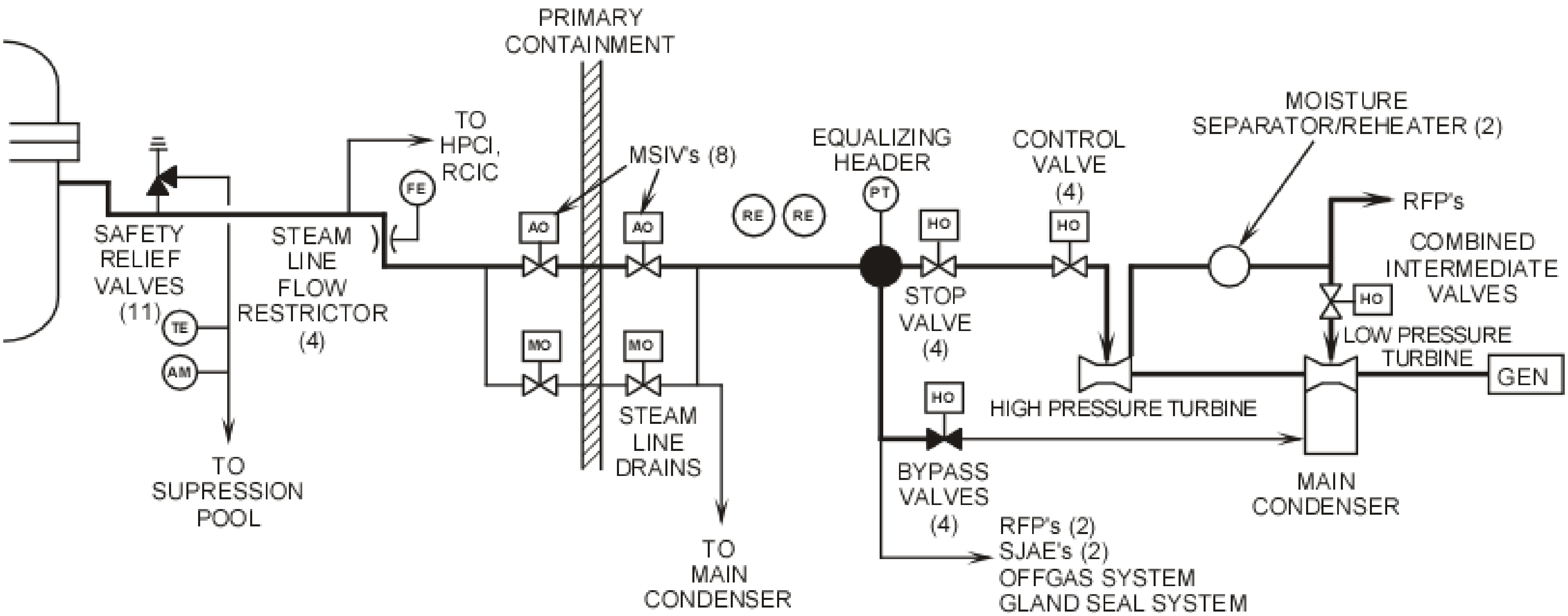

Figure 8.1-1, Simplified Main Steam System

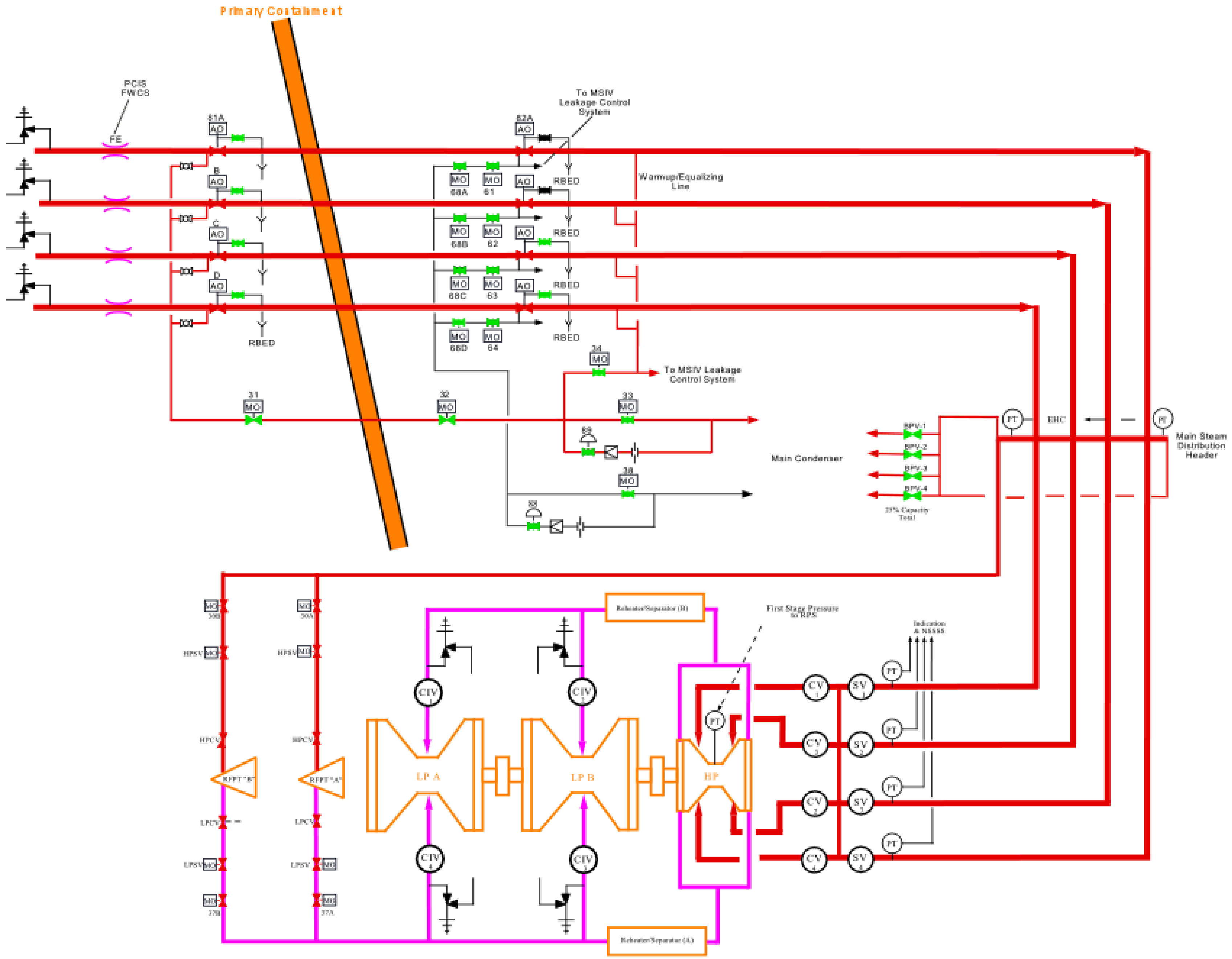

Figure 8.1-2, Main Steam System

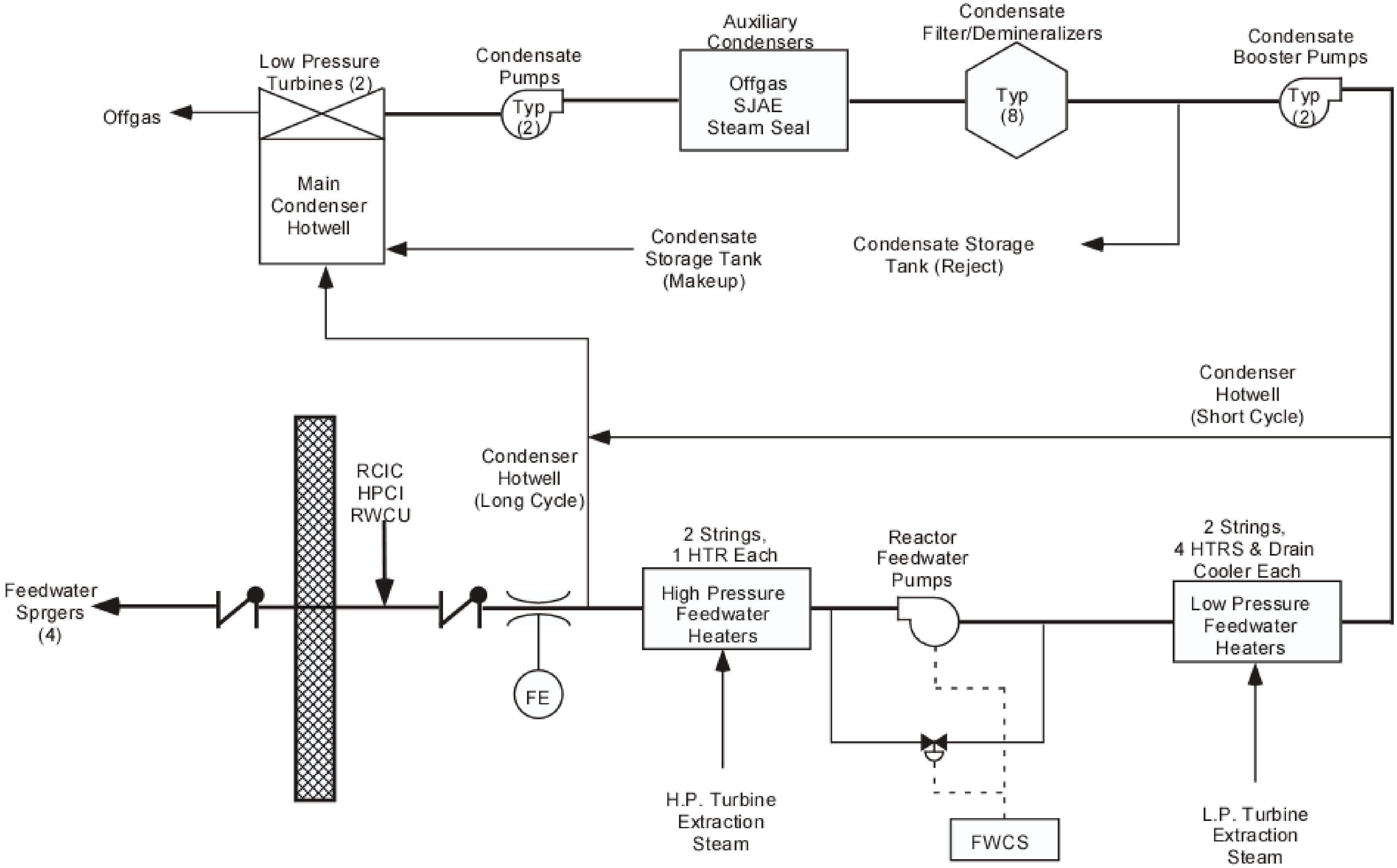

Figure 8.2-1, Condensate and Feedwater System

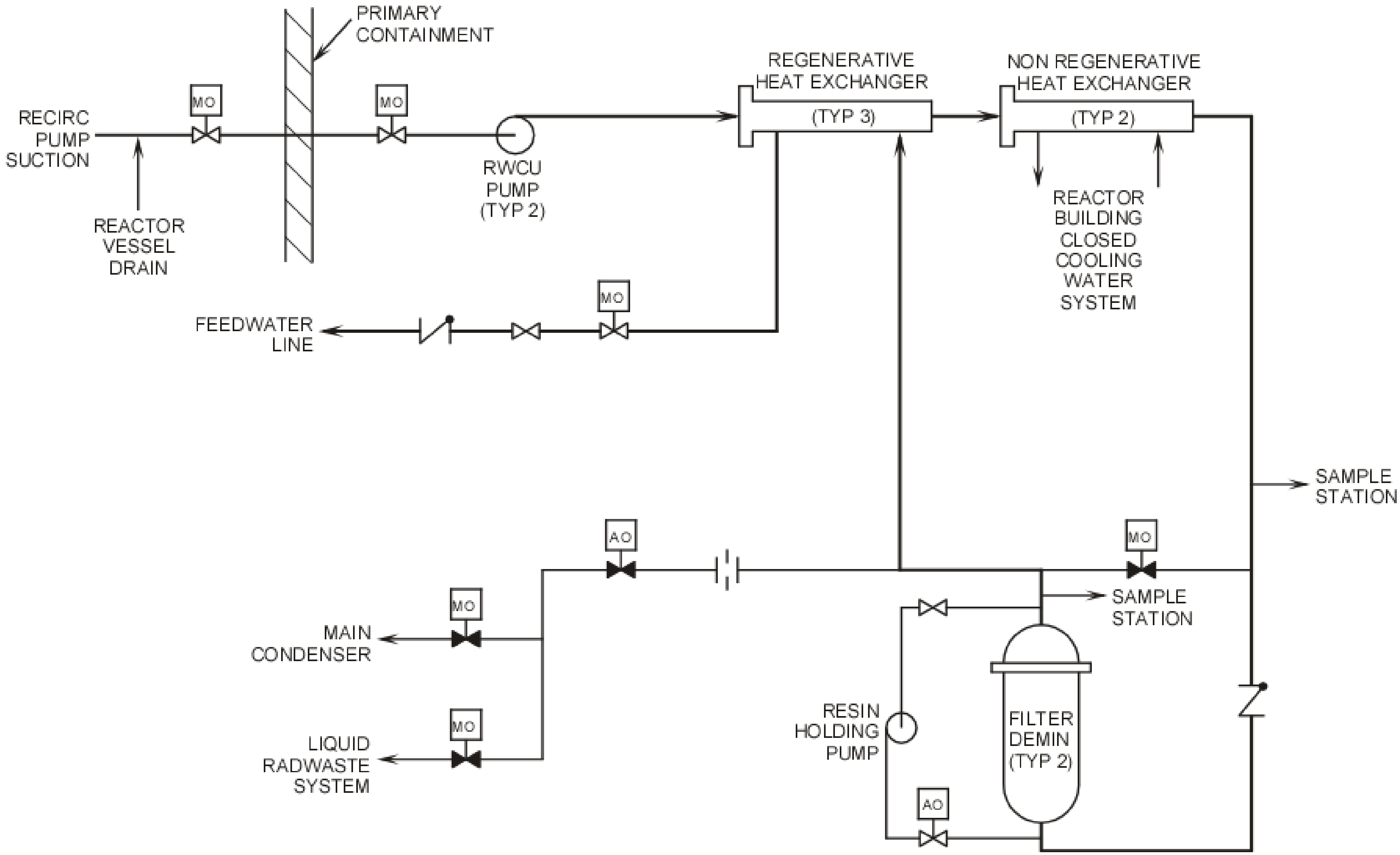

Figure 8.3-1, Simplified Reactor Water Cleanup System

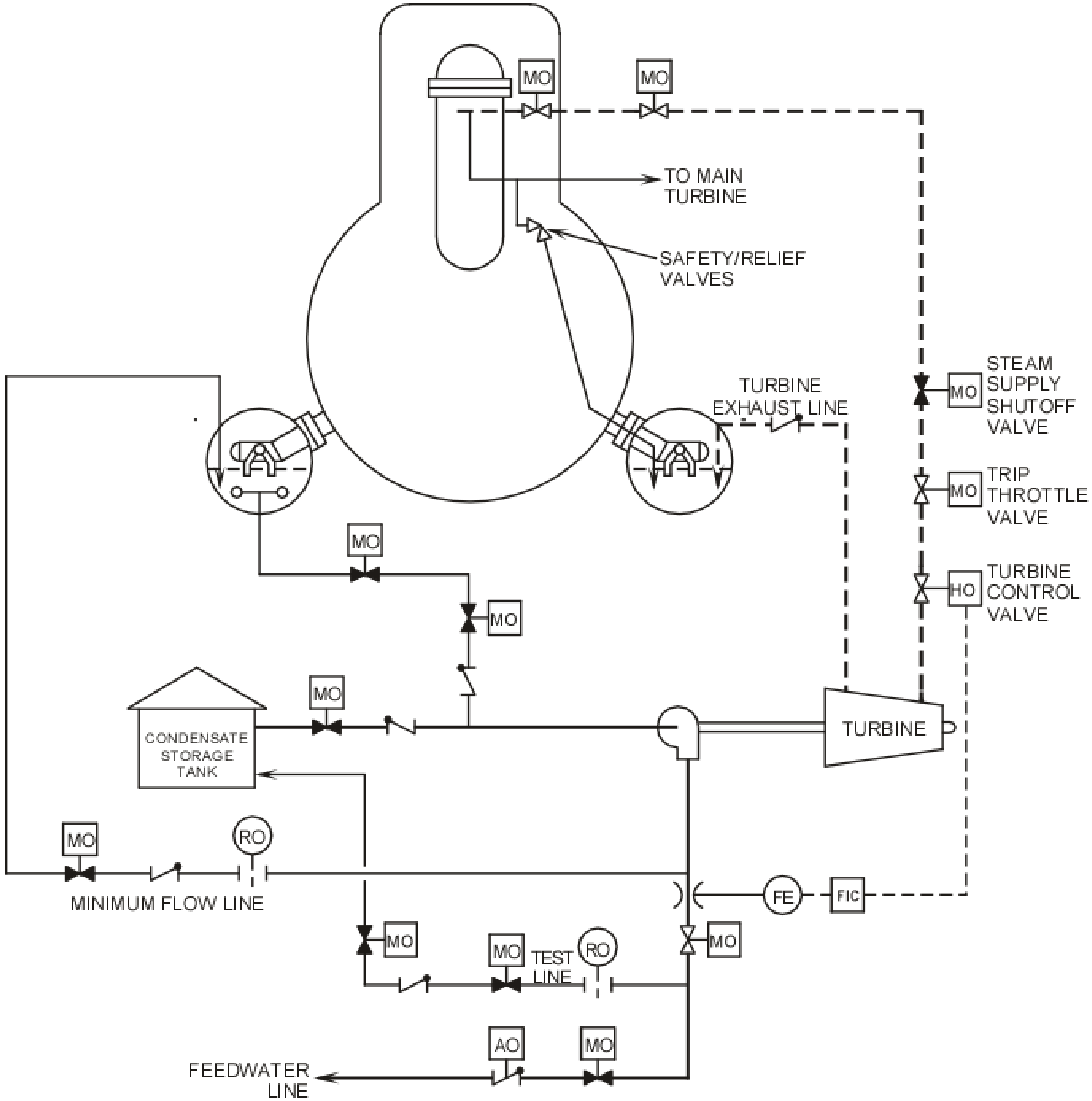

Figure 8.4-1, Reactor Core Isolation Cooling System