

Pressurized Water Reactor
B&W Technology
Crosstraining Course Manual

Chapter 1.0

General Plant Description

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1.0 GENERAL PLANT DESCRIPTION

Learning Objectives:

1. Identify the major components included in the primary and secondary cycles.
2. Describe what is meant by the integrated control system.
3. Describe how reactor coolant temperature and secondary system pressure change with load.

1.1 Introduction

A typical Babcock & Wilcox pressurized water reactor (PWR) dual-cycle plant consists of (1) a reactor and two closed reactor coolant loops connected in parallel to the reactor vessel (primary) and (2) a separate power conversion system for the generation of electricity (secondary). The use of a dual cycle minimizes the quantities of fission products released to the main turbine, condenser, and other secondary plant components, and subsequently to the atmosphere.

1.2 Plant Layout

The entire reactor coolant system, including the steam generators, is located in a Seismic Category I reactor building (Figure 1-1), which isolates the radioactive reactor coolant system from the environment in the event of a leak. The reactor building is designed to contain the pressure produced by a complete rupture of a reactor coolant system loop.

All potentially radioactive auxiliary systems are located in the Seismic Category I auxiliary building, which is located adjacent to the containment building. All ventilation from this building is passed through High Efficiency Particulate Air (HEPA) and/or charcoal filters to minimize plant releases.

A fuel storage area (part of the auxiliary building) is provided for handling and storage of new and spent fuel.

The control room and office space are located on the upper floor of the auxiliary building. All necessary control and monitoring equipment is centralized in the control room to provide efficient and safe control of the reactor plant. Control room habitability is assured by providing two remote air intake structures in addition to the normal air intake on the auxiliary building.

The turbine building contains all the secondary and secondary support systems. The main turbine and auxiliaries, moisture separator reheaters, feedwater heaters, main

condenser, hotwell, condensate booster and feedwater pumps, etc., are located in the turbine building.

Adjacent to the turbine building and toward the containment is the water treatment building, which houses the condensate polishing and make-up water treatment facilities. The main steam and feedwater isolation area is between the water treatment building and containment.

1.3 Primary Cycle

The reactor coolant system (primary system) (Figure 1-2) consists of a reactor and two closed reactor coolant loops connected in parallel to the reactor vessel. Each loop contains two reactor coolant pumps, a steam generator, loop piping, and instrumentation. The primary system also contains an electrically heated pressurizer connected to one of the loops.

High-pressure water is pumped through the reactor core to remove the heat generated by the nuclear fission. In each loop, the heated water leaves the reactor vessel and passes through the coolant loop piping to the steam generator, where the hot reactor coolant passes down through the tubes to give up its heat to the feedwater to generate steam. The reactor coolant then passes to the suction of the reactor coolant pump, which pumps it into the reactor vessel to complete the cycle.

1.4 Secondary Cycle

The secondary or steam system (Figure 1-3) begins in the shell side of the steam generator(s) where the incoming feedwater is boiled as it picks up energy from contacting the steam generator tubes containing hot reactor coolant. These steam generator tubes provide the barrier between the primary and secondary cycles.

Superheated steam leaving the steam generators passes through steamline isolation valves and is directed to the high-pressure section of the main turbine (Figure 1-3a). After leaving the high-pressure turbine, the low-energy, moisture-laden steam is routed to moisture separator reheaters where the excess moisture is removed and a small amount of superheat is applied.

The dry, reheated steam then enters the low-pressure turbines, where energy is removed, and exits to the main condenser. Provisions are made to bypass the turbine and dump steam directly to the main condenser under certain plant conditions.

In the condenser, the steam is condensed by passing over tubes containing circulating water and collected in the condenser hotwell. Condensate is then pumped from the hotwell by condensate pumps that discharge into a common header, which carries the condensate through the gland steam condenser and the condensate demineralizers (Figure 1-3b). The

condensate is discharged through three parallel strings of feedwater heaters before reaching the suction of the main feedwater pumps.

The feedwater pumps discharge through two strings of parallel feedwater heaters, through feedwater regulating valves, and into the steam generators, where the cycle starts over again (Figure 1-3c).

1.5 Control Systems

1.5.1 Integrated Control System

The Integrated Control System (ICS) (Figure 1-4) provides total control of the reactor power level, turbine-generator load, feedwater flow, and steam dump valves. The ICS allows the maneuvering of plant electrical load between 15% and 100% power at a rate of 5% per minute. The ICS will also run back turbine load in the event of primary or secondary system malfunctions.

When load changes are made with this control system, automatic rod motion, turbine valve position changes, feedwater valve position changes, and feedwater pump speed changes occur simultaneously.

1.5.2 T_{avg} and Steam Pressure Programs

Unlike other commercial PWR designs, the Babcock & Wilcox nuclear steam supply system operates with a constant average coolant temperature (T_{avg}) above 15% reactor power and a constant steam pressure throughout the load range (Figure 1-5). Values of 601° F and 1035 psia are used in the B&W 205 fuel assembly plants. The operating 177 fuel assembly plants use 579° F and 885 psig.

1.5.3 Reactor Coolant Pressure Control

Pressure in the reactor coolant system is controlled by use of a pressurizer attached to one of the reactor coolant hot legs. A hot leg is the piping supplying hot water, T_h , from the reactor to the steam generator; a cold leg is the piping returning cold water, T_c , from the steam generator to the reactor.

The pressurizer is maintained at saturation temperature for the desired reactor coolant pressure (2,195 psig) by electrical heaters. Because it is maintained approximately half full of saturated water with a steam overpressure, the pressurizer acts as a surge volume for expansion and contraction of the reactor coolant. The pressurizer is the hottest point in the reactor coolant system; therefore, it is the only location where a steam void can be formed. The rest of the reactor coolant system is filled with subcooled water.

If it is desired to increase reactor coolant system pressure, the heaters are energized to raise the pressurizer temperature and thus the pressure. To reduce pressure, subcooled reactor coolant from the cold leg (T_c) is sprayed into the steam volume to condense some of the steam bubble.

Overpressure protection is provided by safety and relief valves, which relieve from the pressurizer steam space.

1.5.4 Reactor Protection

A Reactor Protection System (RPS) provides protection for the reactor fuel and its cladding by providing automatic reactor shutdowns (trips). Inputs of reactor power, and reactor coolant pressure, temperature and flow are used to protect the core against departure from nucleate boiling and excessive linear heat rates. Departure from Nucleate Boiling (DNB) limits protects the cladding from high-temperature-induced failures, and the maximum linear heat rate limit prevents centerline fuel melting that could lead to cladding destruction.

The RPS is a redundant four-channel system that operates on a two-out-of-four logic to generate the following reactor trips:

- (1) high power trip
- (2) flux / delta flux / flow trip
- (3) power / pumps trip
- (4) high T_h trip
- (5) high RCS pressure trip
- (6) low RCS pressure trip
- (7) variable low pressure trip
- (8) high containment pressure trip
- (9) anticipatory trips

1.6 Engineered Safety Features

Several engineered safety features have been incorporated into the design of the plant to reduce the consequences of accidents. These features include emergency core cooling systems, steamline and feedwater isolation, the reactor building spray system, and the auxiliary feedwater system.

1.6.1 Emergency Core Cooling Systems

Two separate and redundant trains of emergency core cooling provide borated water from the borated water storage tank (BWST) to the reactor coolant system for core cooling in the event of a loss of coolant accident. Each train consists of a high-pressure injection pump, which provides low-volume, high-pressure coolant to the reactor coolant cold legs,

and a low-pressure injection pump, which provides a high volume of coolant at low pressures directly to the reactor vessel.

In addition to the pumped injection systems, two passive core flood tanks inject water into the reactor vessel. The tanks are pressurized with nitrogen and filled with borated water. If system pressure decreases below tank nitrogen pressure, borated water is forced into the reactor vessel.

1.6.2 Steamline and Feedwater Isolation

To mitigate the consequences of a steamline break accident, isolation of the steam generator steam and feedwater lines is provided. Isolation is accomplished on low steam or high-high reactor building pressure by the closing of the Seismic Category I steam and feedwater isolation valves.

1.6.3 Reactor Building Spray System

The reactor building spray system injects borated water into the reactor building atmosphere to reduce reactor building pressure and temperature during loss-of-coolant or steamline break accidents. In addition to cooling, the spray system reduces the reactor building fission product concentration by the addition of sodium hydroxide to the spray fluid.

1.6.4 Auxiliary Feedwater System

The auxiliary feedwater system is a separate but redundant system that provides emergency feedwater to the steam generators for decay heat removal in the event of a loss of main feedwater. A demineralized storage tank provides approximately 300,000 gallons of water for use by the auxiliary feedwater system.

1.6.5 Engineered Safety Features Actuation System

The engineered safety features actuation system consists of three analog systems that sense the requirement for the actuation of emergency equipment, and two digital subsystems that provide the mechanism for actual actuation of the emergency equipment. The analog subsystems receive inputs of reactor coolant pressure, reactor building pressure, and BWST level. If two of the three analog subsystems sense that the inputs have reached predetermined setpoints, then both digital channels will actuate the redundant emergency equipment.

1.7 Support Systems

1.7.1 Makeup and Purification System

Reactor coolant cleanup and chemistry control are accomplished by the makeup and purification system (Figure 3-1). This system is supplied with reactor coolant through a letdown system that bleeds a small amount (50 gpm) of reactor coolant to the ion exchangers. A flow rate of 50 gpm is sufficient to purify approximately one reactor coolant system (RCS) volume in a 24-hour period. The letdown flow is cooled by component cooling water in the non-regenerative heat exchangers. Letdown flow is manually controlled by a flow control valve which also acts to reduce letdown pressure from RCS system pressure to approximately 125 psig. The flow is purified by filters and passes through ion exchangers before being collected in the Makeup Tank.

Makeup pumps then return the purified coolant back to the RCS, thus reducing the concentration of corrosion and fission products in the reactor coolant. The makeup and purification system also performs the following functions: maintains water level in the pressurizer when the RCS is hot, adjusts the boric acid concentration of the reactor coolant for chemical shim control, provides high-pressure seal water for the reactor coolant pump seals, and doubles as the high-pressure injection system during emergency conditions.

1.7.2 Radioactive Liquid Waste System

The radioactive liquid waste system collects, stores, and processes radioactive waste liquids generated during plant operation and refueling, either for recycle within the plant or for discharge off-site. The process operations available to treat the liquid wastes are filtration, evaporation, and demineralization.

1.7.3 Radioactive Waste Gas System

Radioactive gaseous wastes, passing through gaseous (hydrogenated) vents and aerated vents and containing various levels of radioactivity, are treated before being released to the environment. Continuous degasification and purification of the reactor coolant letdown minimize the consequences of any reactor coolant leakage. This degasification and purification process produces gaseous streams, which are circulated through hydrogen recombiners for hydrogen removal and then to gas decay tanks to provide holdup time for the decay of noble gases. Gaseous wastes produced by other phases of plant operation are similarly treated.

1.7.4 Radioactive Solid Waste System

The radioactive solid waste system provides holdup, packaging, and storage facilities for eventual offsite shipment and ultimate disposal of solid radioactive waste material. Available process operations are solidification of liquid wastes, holdup for decay, dilution

with inert material, and baling for volume reduction. Shielding as required during the processing and shipment of the solid wastes is included in the planned operation of the solid waste system.

1.8 Steam and Power Conversion System

The steam and power conversion system consists of a turbine-generator, main condenser, vacuum pumps, turbine seal system, turbine bypass system, hotwell pumps, condensate booster pumps, main feed pumps, main feed pump turbines, feedwater heaters, heater drain pumps, and condensate storage system. The system is designed to convert the energy produced in the reactor to electrical energy through the conversion of a portion of the energy contained in the steam supplied from the steam generators, to condense the turbine exhaust steam into water, and to return the water to the steam generators as feedwater.

The turbine-generator unit consists of a tandem arrangement of one double-flow, high-pressure turbine and two or three double-flow, low-pressure turbines driving a direct-coupled generator at 1800 rpm. The condenser is a two pass, twin bank, rectangular, radial flow type, surface condenser consisting of two or three shells. The condenser has a separate shell under each of the low pressure turbines, with a hotwell located directly below the tube bundle of each condenser shell. The condensate draining from the tubes falls through a band of steam and is reheated to saturation temperature before falling into the hotwell. The condensate is removed through outlets feeding the condensate pumps.

Safety valves, modulating atmospheric dump valves, atmospheric dump valves, as well as a turbine bypass to the condenser are provided in the ~~steamlines~~steam lines.

1.9 Plant Electrical System

The plant electric power system consists of the main generator, station auxiliary transformers, backup auxiliary transformers, diesel generators, batteries, and electrical distribution system. Under normal operating conditions, the main generator supplies electrical power through isolated-phase buses to the main step up transformers and the unit station auxiliary transformers located adjacent to the turbine building. The primaries of the unit station auxiliary transformers are connected to the isolated-phase buses at a point between the generator terminals and the low-voltage connection of the main transformers. During operation station auxiliary power is taken from the main generator through these transformers. Auxiliary power can be supplied from the 230-kv transmission system through the backup auxiliary transformers. The standby onsite power is supplied by two diesel generators.

The plant distribution system can receive ac power from either the nuclear power unit, the two independent preferred (offsite) power circuits, or the two 7000-kw diesel generator standby (onsite) power sources and distribute it to both safety-related and nonsafety-

related loads in the plant. The two preferred circuits have access to the Washington Public Power Supply System transmission network, which in turn has multiple interties with other transmission networks.

The safety-related loads for each nuclear unit are divided into two redundant load groups. Each redundant load group of each unit has access to a standby source and to each of the two preferred offsite sources. One diesel generator and one load group can provide all safety functions in each unit.

The vital ac and dc control and instrument power system consists of four 125-v batteries, eight battery chargers, and four 120-vac inverters with their respective safety-related loads. The 125-v dc distribution system is a safety-related system that receives power from eight independent battery chargers and four 125-vdc batteries and distributes it to safety-related loads. The 120-vac distribution system receives power from four independent inverters and distributes it to the safety-related loads.

1.10 Fuel Handling System

The fuel handling system is located in the reactor building and fuel building (part of the auxiliary building). The refueling canal is located in the reactor building and is flooded only for refueling. The fuel pool is flooded whenever spent fuel is in the pool. The reactor building and fuel building are connected by a fuel transfer system, which carries the fuel through transfer tubes penetrating the reactor building, and by a personnel hatch to be used by refueling personnel. The fuel handling equipment is designed to handle the new and spent fuel from the time it enters the site until it leaves the site.

New fuel assemblies are removed one at a time from the shipping cask and stored dry in the fuel storage racks located in the fuel storage area. New fuel is delivered to the reactor vessel by placing a fuel assembly into the new fuel elevator, lowering it into the transfer canal, taking it through the fuel transfer system, and placing it in the core with the main fuel bridge. Spent fuel is removed from the reactor vessel by the fuel bridge and placed in the fuel transfer system. In the spent fuel pool, the fuel is removed from the transfer system and placed in the storage racks. After a suitable decay period, the fuel is removed from storage and loaded in a shipping cask for removal to a reprocessing plant.

Spent fuel is handled entirely under water from the time it leaves the reactor vessel until it is placed in a cask for shipment from the site. Underwater transfer of spent fuel provides an effective, economic and transparent shield, as well as a reliable cooling medium for removal of decay heat.

Handling and storage of both new and spent fuel assemblies are accomplished with equipment and procedures that ensure that all fuel arrays are maintained subcritical.

1.11 Cooling Water Systems

1.11.1 Condenser Circulating Water System

The circulating water system consists of a compartmented sump for storage of circulating water inventory, four 25% horizontal, centrifugal double suction pumps, three mechanical draft cooling towers, interconnecting piping and associated control valves and instrumentation. Water flows by gravity from each of the cooling towers into a common sump under the circulating water pump house. The circulating water pumps take suction from this sump.

The discharges of the pumps join in a common manifold which directs the water from the circulating water pump house to the turbine building. The circulating water is then directed through the tubes of the main condenser, absorbing heat from the turbine exhaust steam. The heated circulating water leaves the condenser and is distributed to each cooling tower, where it is cooled by evaporation and returned to the sump in the circulating water pump house.

1.11.2 Component Cooling Water System

The Component Cooling Water (CCW) system is the intermediate, closed-loop cooling water system between the components handling reactor coolant system fluids and the Nuclear Service Water (NSW) system. Two basic purposes of the system are removing energy from the components and heat exchangers that are handling radioactive fluids and serving as buffers against leakage from the nuclear systems to the NSW system and to the heat sink.

The CCW is necessary for plant operation and is designed to remove heat from components such as the reactor coolant pumps and the letdown heat exchanger.

1.11.3 ~~Emergency Shutdown Water System and~~ Nuclear Service Water System

The nuclear service water (NSW) system transfers heat from safety-related components to the normal heat sink (cooling towers) during normal operations and to the ultimate heat sink (spray pond) during emergencies. The NSW system normally receives its water supply from the service water system (SWS). However, during emergencies, the NSW system is supplied by the emergency shutdown water (ESW) system.

Two completely redundant trains of NSW are installed. Each of the trains removes heat from one-half of the safety-related equipment. A single failure of any component in one NSW train will not result in a loss of cooling capability in the redundant train.

The ESW system provides cooling water from the ultimate heat sink (spray pond) to the NSW system during plant emergencies.

The ESW system consists of two 100% redundant trains, each serving one of the NSW trains.

The shutdown cooling water (SCW) system is a subsystem of the NSW system and provides cooling water to the decay heat removal system and reactor building spray system during normal and emergency operations. The SCW system is a closed-loop cooling water system that provides a barrier between the radioactive components that it cools and the non-radioactive NSW system. Heat exchangers in the SCW system are cooled by the NSW system.

~~The nuclear service water (NSW) system provides cooling water to the safety-related components during normal power operation and normal shutdown. During plant emergencies, the NSW system provides cooling water from the ultimate heat sink via the emergency shutdown water (ESW) system. The NSW system consists of two 100% capacity trains, each of which is supplied by the respective train of the ESW system. Provisions are made to ensure a continuous flow of cooling water to those systems and components necessary for plant safety either during normal operation or under accident conditions.~~

~~The Emergency Shutdown Water (ESW) system provides cooling water from the ultimate heat sink (spray pond) to the Nuclear Service Water (NSW) system during plant emergencies. The ESW system consists of two 100% redundant trains, each serving one of the 100% capacity nuclear service water trains.~~

~~During plant emergencies, the ESW system automatically pumps cooling water from the spray pond to the NSW system. Heat absorbed by the NSW system is transferred back to the spray pond via the ESW system and dissipated with spray headers.~~

1.12 Summary

The typical Babcock & Wilcox two-loop plant consists of a pressurized-water reactor used as a heat source for a separate steam and power conversion system for the generation of electricity. All radioactive or potentially radioactive systems are located in seismic Category I structures, and all ventilation from these structures passes through a filtering process to minimize radioactive releases.

The plant is controlled with the integrated control system, which matches megawatt generation with plant conditions. Support systems are provided to add makeup water to the reactor coolant system, to purify reactor coolant water, to provide chemicals for corrosion and reactor control, to cool system components, to remove decay heat when the reactor is shut down, and to provide for emergency core cooling.

The various safety and design criteria for the systems and components that are briefly highlighted in the above sections will be discussed more fully in the following chapter.

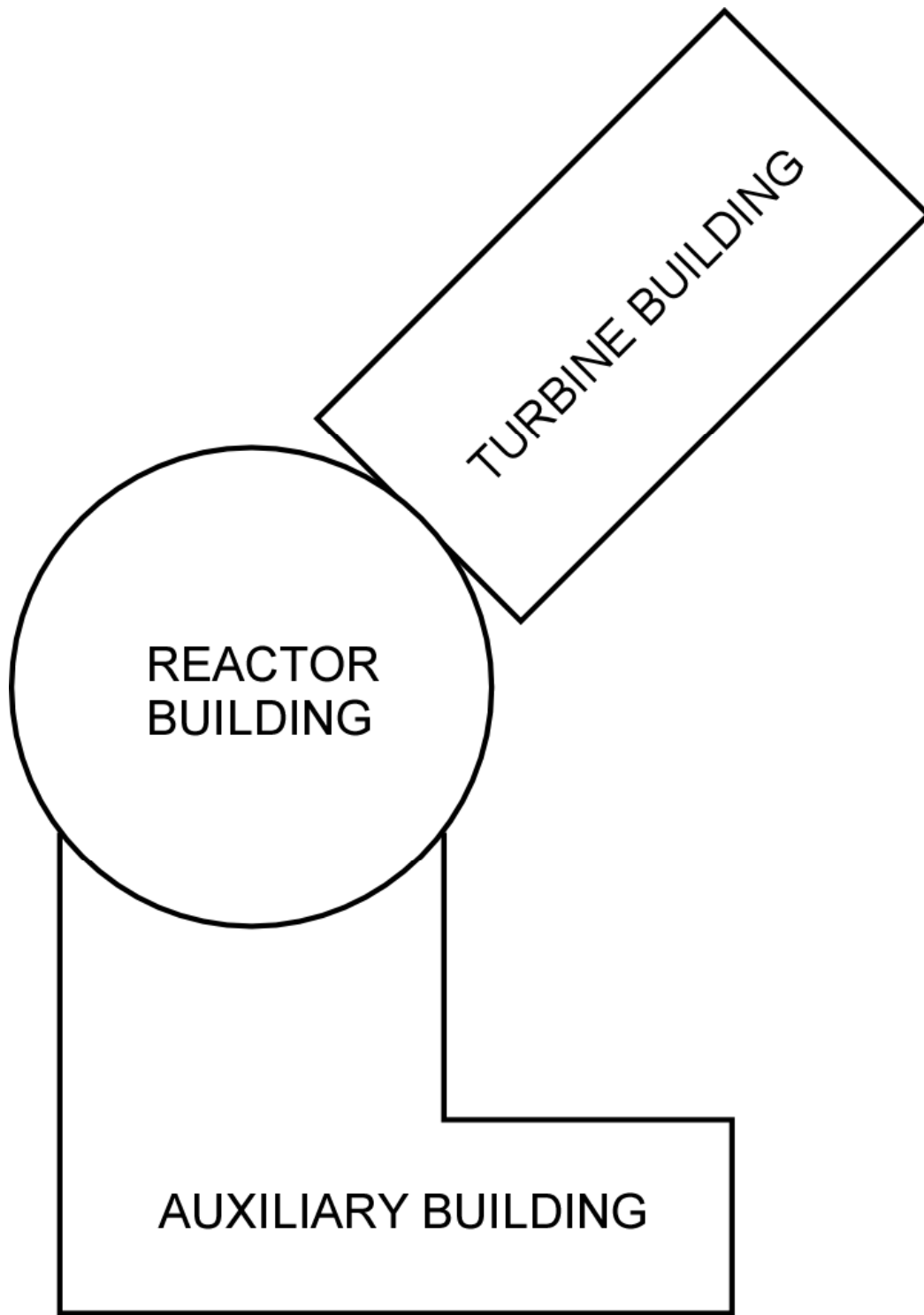


Figure 1-1 Partial Layout

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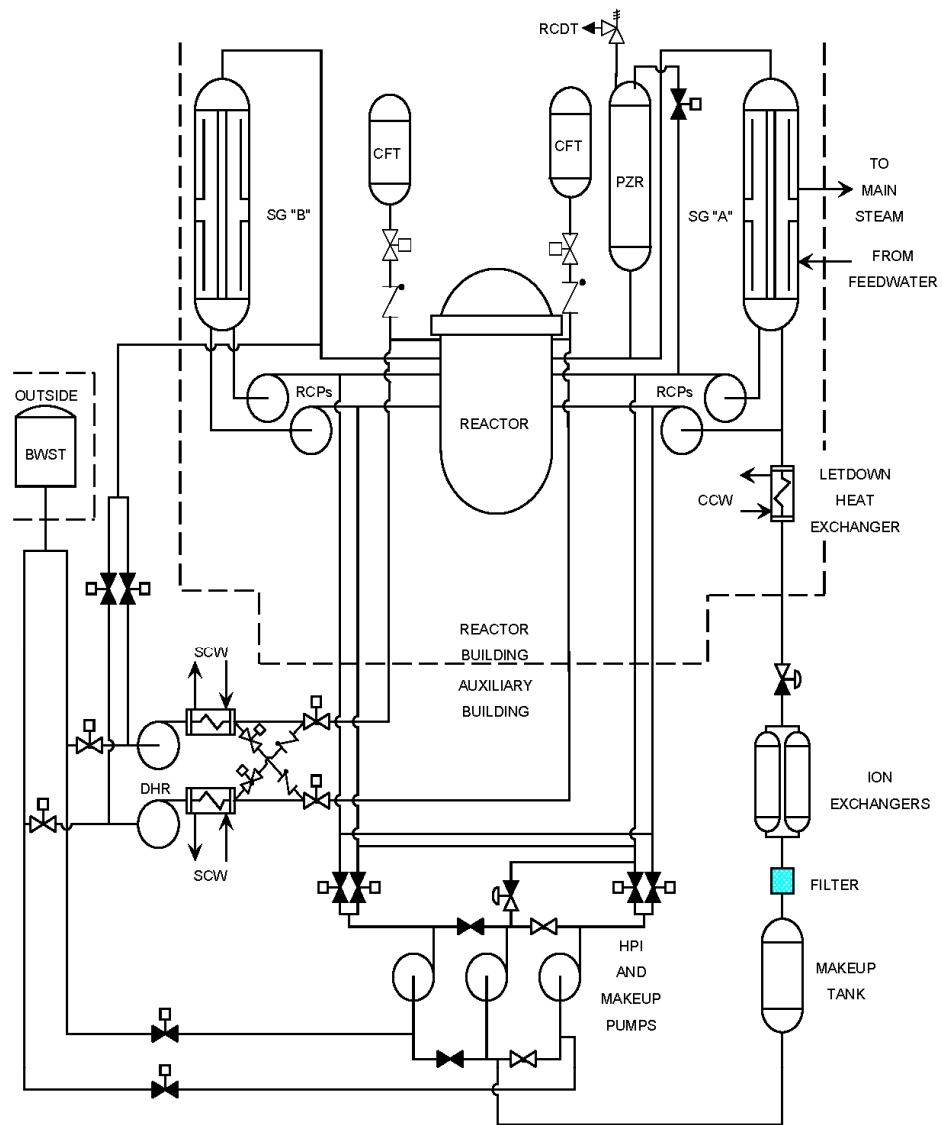


Figure 1-2 Simplified Plant Composite Flow Diagram

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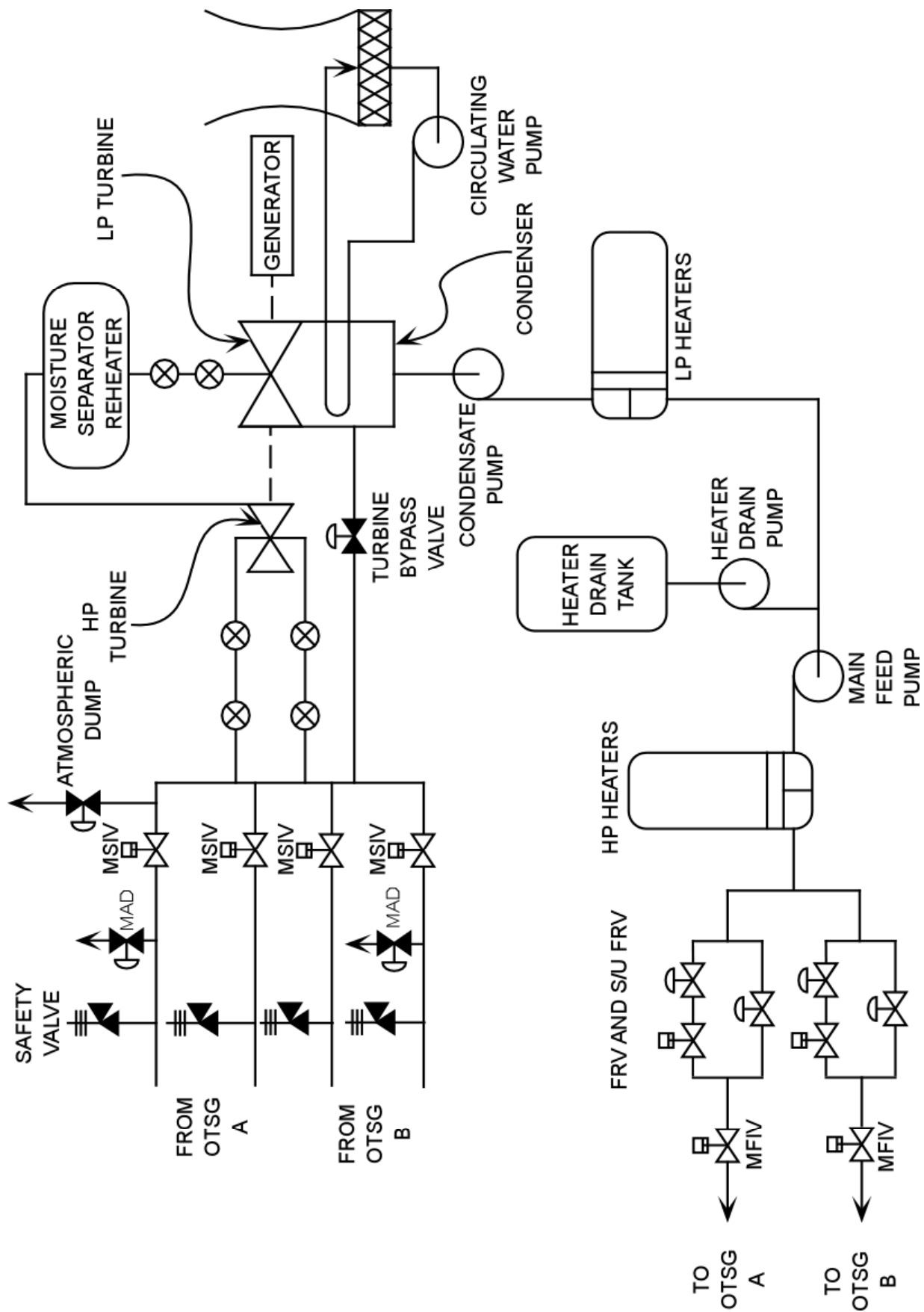


Figure 1-3 Simplified Secondary Plant

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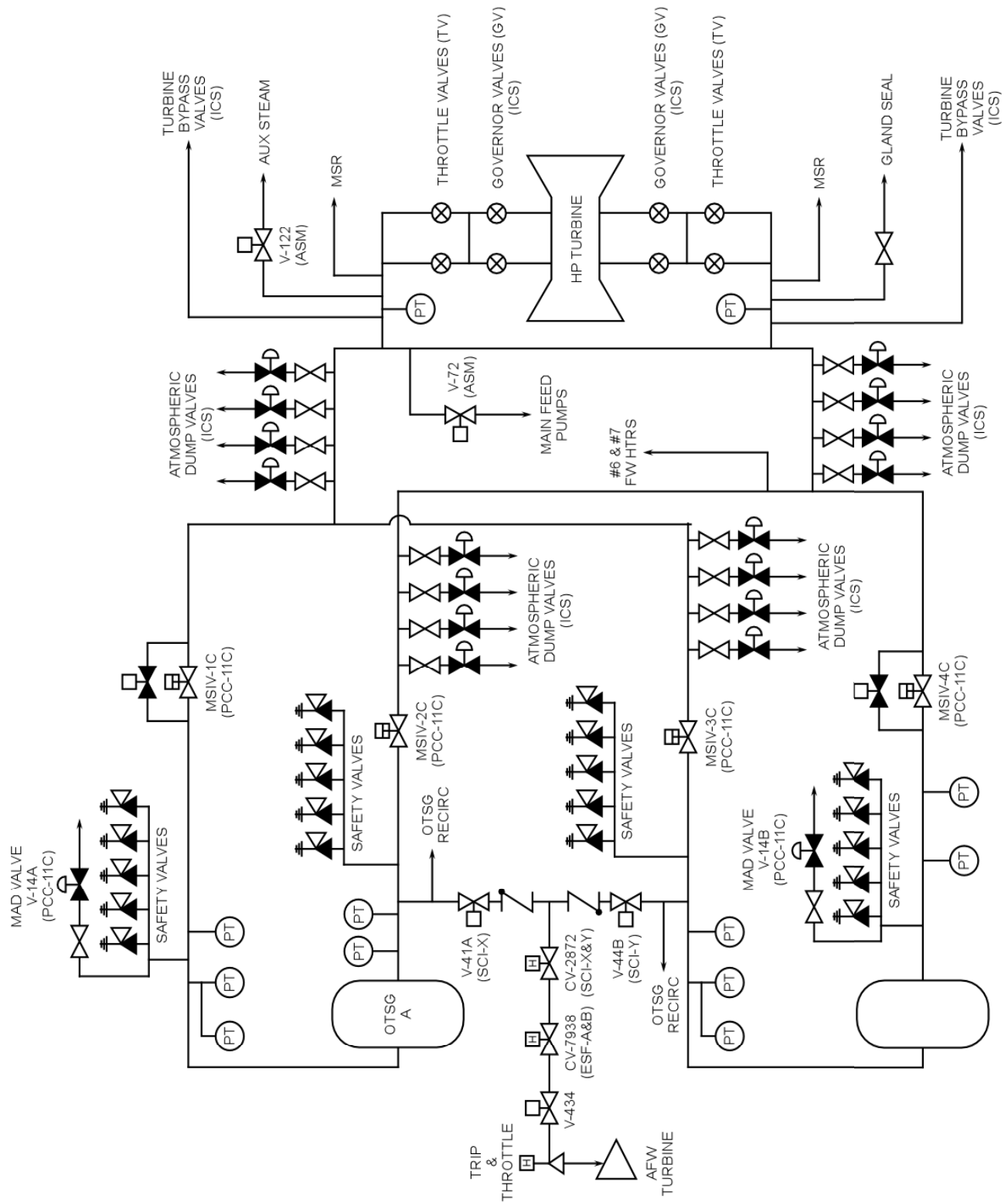


Figure 1-3a High Pressure Main Steam System

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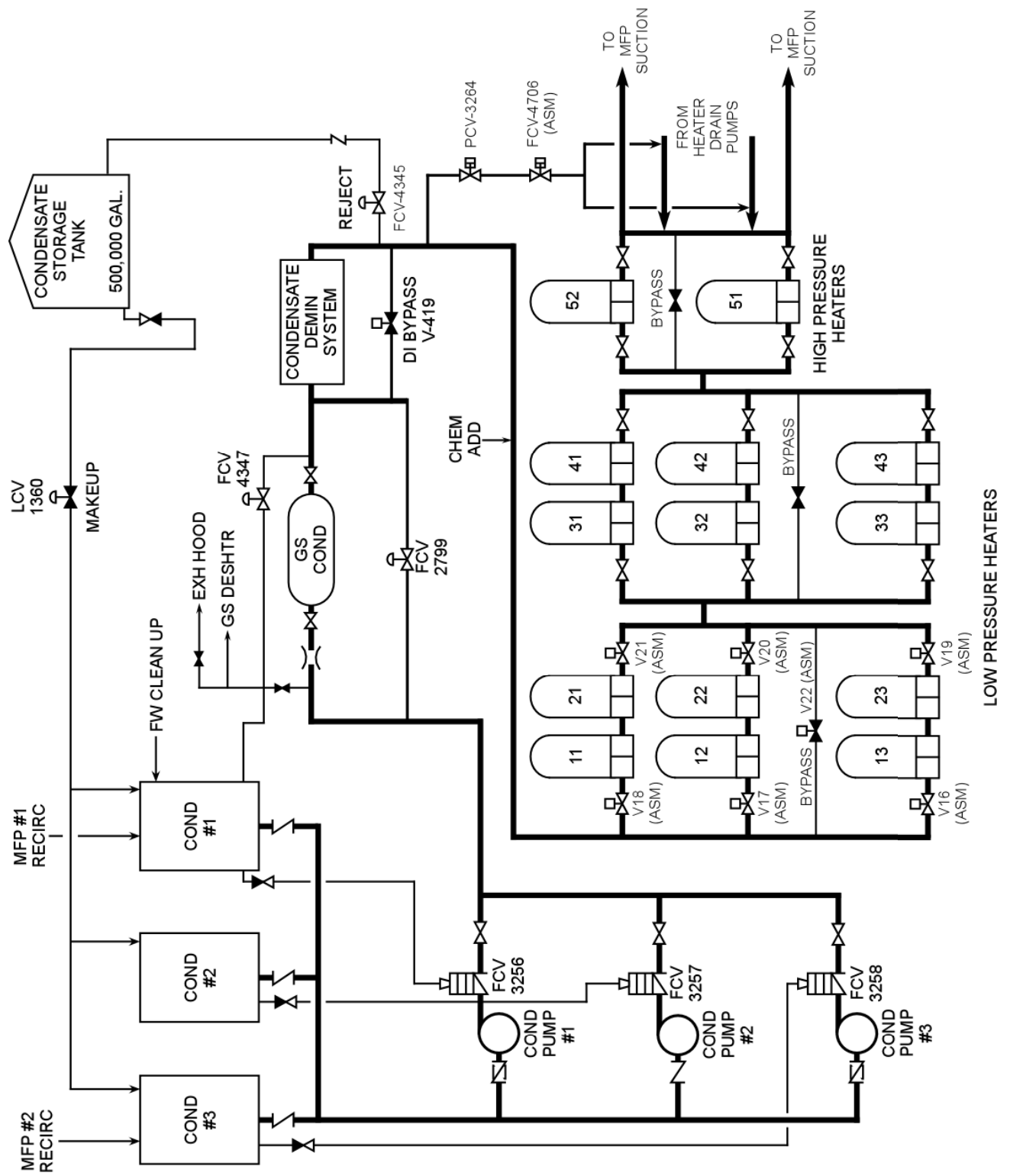


Figure 1-3b Condensate System

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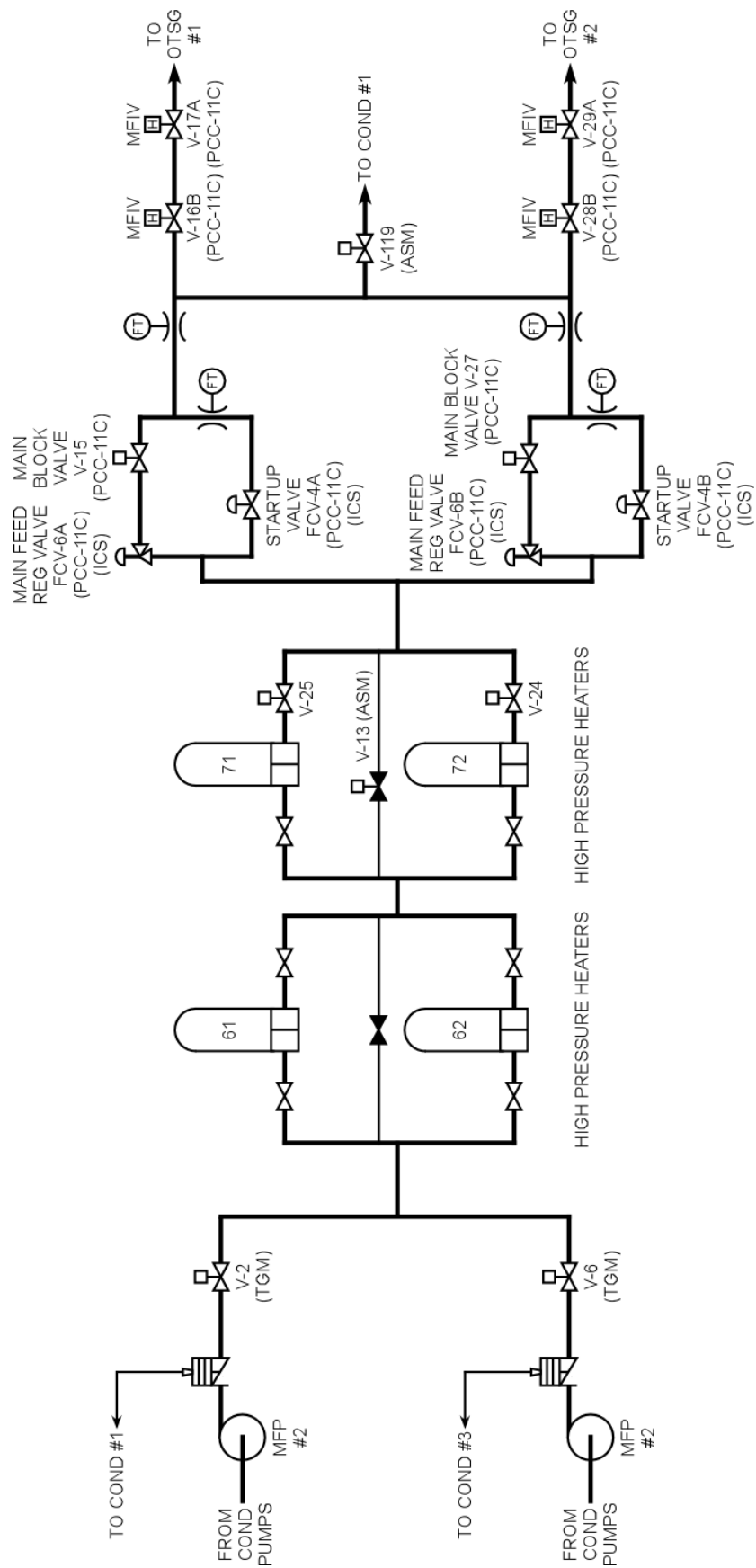


Figure 1-3c Feedwater System

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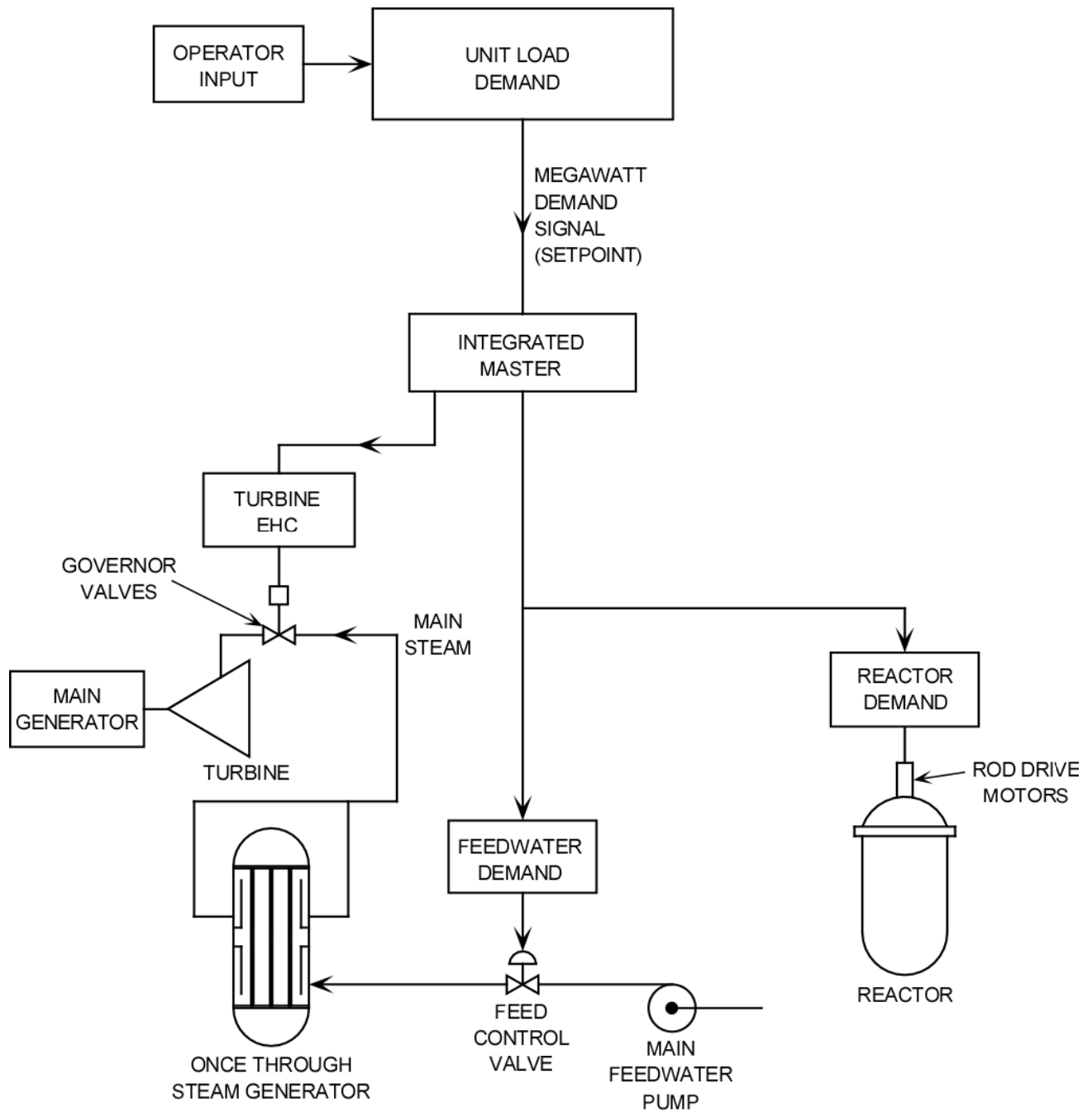


Figure 1-4 Basic Integrated Control System

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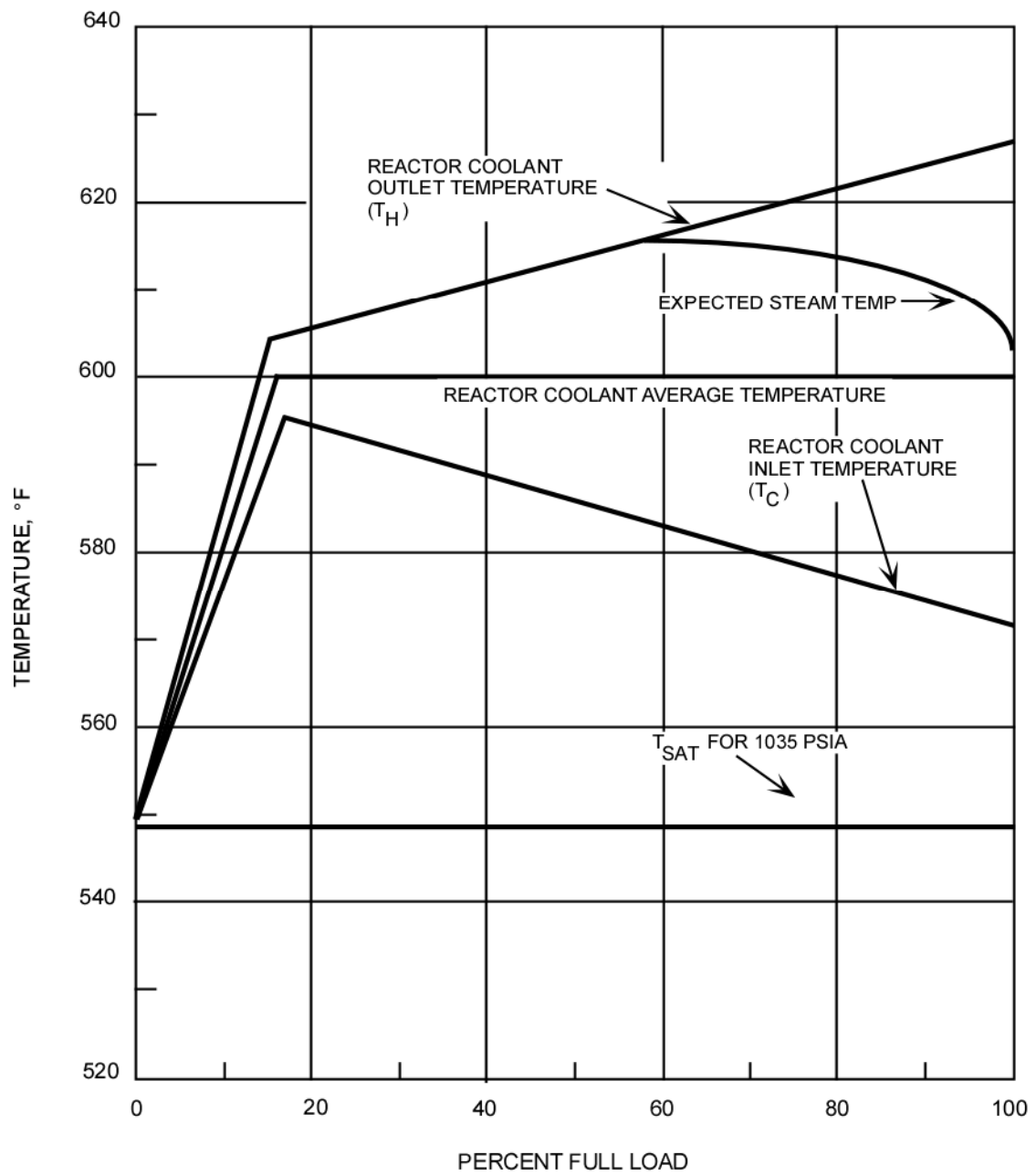


Figure 1-5 Reactor Coolant and Steam Temperature vs. Load

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