TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

11.5 AUXILIARY FEEDWATER SYSTEM

Learning Objectives:

1. State the purposes of the auxiliary feedwater system (AFW) System.
2. List all suction sources for the AFW pumps and under what conditions each is used.
3. List the steam supplies to the AFW turbines.
4. State the purpose of the auxiliary feedwater actuation system (AFAS) block signal.
5. List the automatic start signal(s) for the AFW system.
6. Explain how decay heat is removed following a plant trip and loss of off-site power.
7. Explain the bases for a minimum volume of water in the condensate storage tank (CST).

11.5.1 Introduction

The AFW system is a safety-related system that maintains an inventory in the secondary side of the steam generators to ensure a heat sink for the removal of reactor decay heat. The AFW system provides feedwater to the steam generators during normal conditions, emergency conditions, and during cool down of the primary plant in the event that the main feedwater system is inoperative. Also, the AFW system is used to maintain steam generator levels during plant start-ups and shutdowns.

11.5.2 System Description

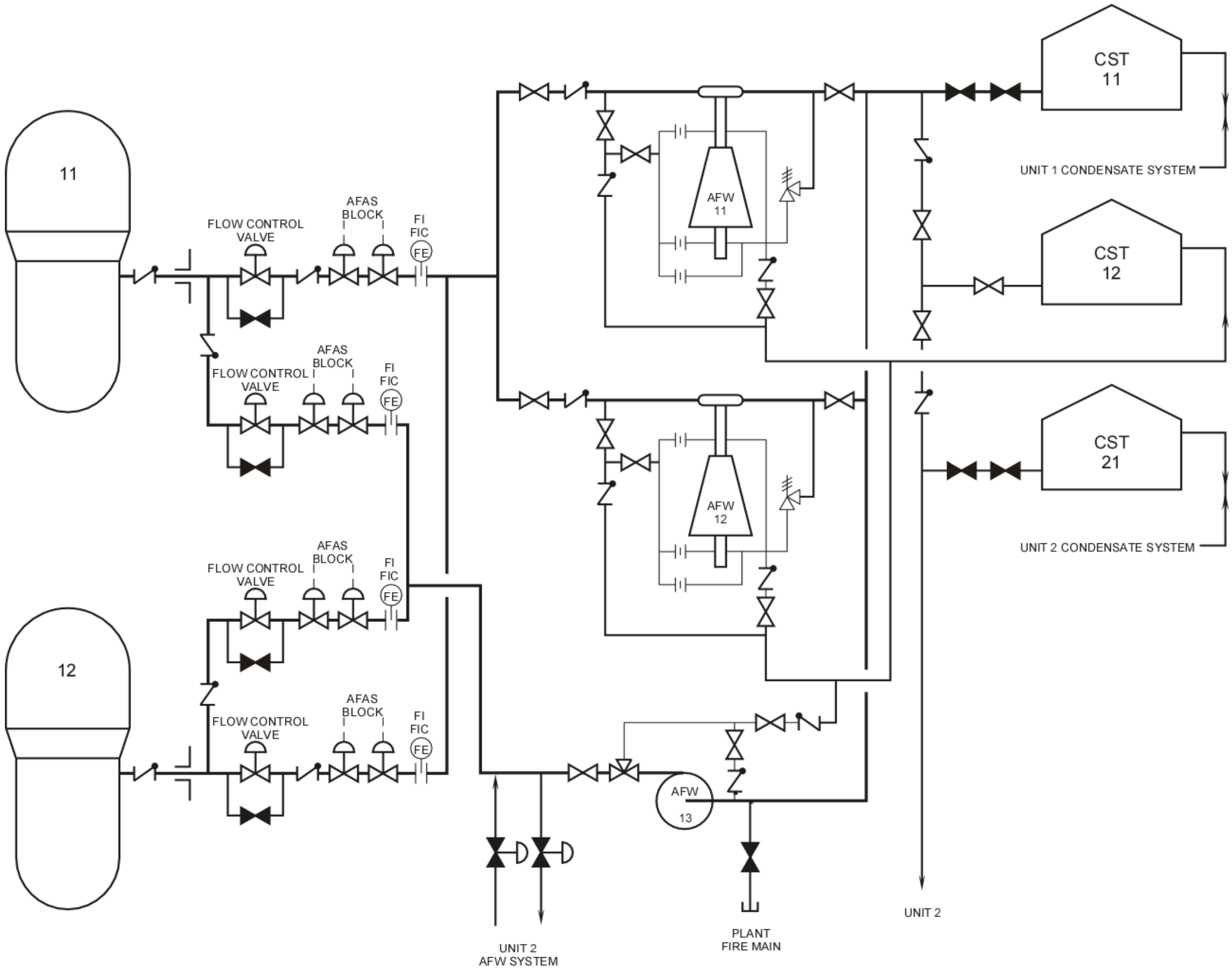

Figure 11.5-1 Auxiliary Feedwater System

The major components of the AFW system are CST 12, two turbine driven AFW pumps, one motor driven AFW pump, eight AFW blocking valves, four AFW flow control valves, and associated piping. During normal plant operation, the AFW system is maintained in a standby mode with its components lined up for automatic actuation.

The AFW pumps take a suction on CST 12 and discharge to four AFW lines. Two AFW lines receive water from the turbine driven pumps, and two AFW lines receive water from the motor driven pump. Each AFW line has two blocking valves in series, followed by a flow control valve. The flow control valves are used to regulate the AFW flow to the steam generators.

After the flow control valves, each motor AFW line connects with a turbine AFW line to send auxiliary feedwater to one steam generator. The AFW flowing into each steam generator maintains level in the steam generator and allows removal of decay heat and cool down of the reactor coolant system (RCS).

The purpose of the two blocking valves in each AFW line is to isolate AFW flow to a steam generator when a rupture has occurred in the steam generator. The four blocking valves for one steam generator shut automatically when an AFAS block signal is generated for that steam generator.

The AFW system can also be used to supply feedwater to the steam generators during a normal plant cool down. In this mode of operation, the AFW system is manually started and supplies feedwater to the steam generators for RCS cool down. The turbine driven AFW pumps are used during plant cool down. The motor driven pump is reserved for emergency use only.

Two cross-connect lines are provided between the unit 1 and unit 2 motor driven AFW pumps discharge lines. The cross-connect lines allow the motor driven AFW pump in one unit to supply feedwater to the AFW system in the other unit, in the event of an AFW system failure. Each cross-connect line has a normally shut, remotely operated, isolation valve.

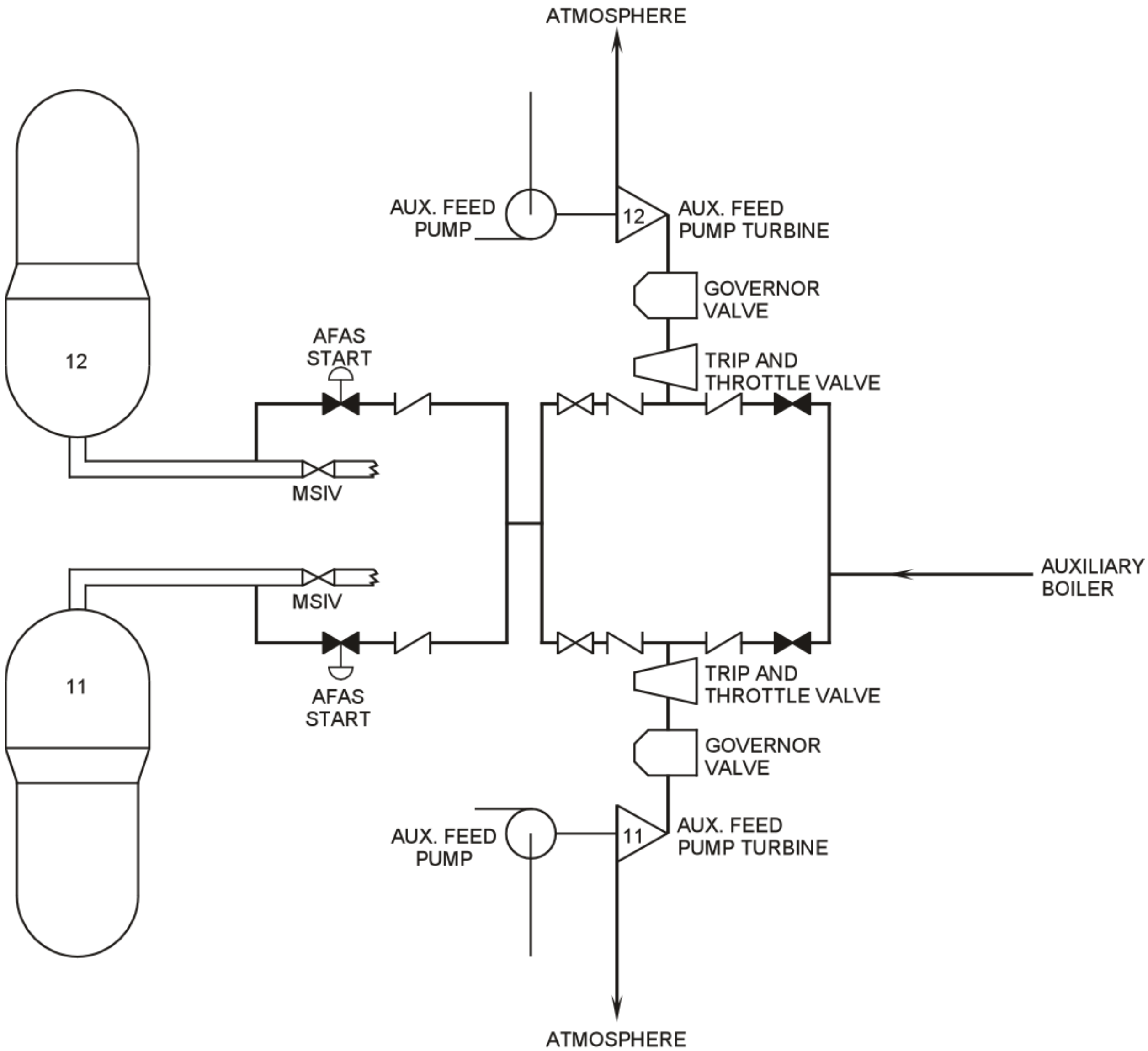

Figure 11.5-2 Auxiliary Feedwater Steam Supply

The two AFW pump turbines are supplied by steam from either the main steam system or the auxiliary steam system. The turbines are normally driven by steam from the steam generators, but the auxiliary boilers can be used as an alternate steam supply. The AFW pump turbines are non-condensing, and exhaust directly to atmosphere. The turbine steam supply line from each steam generator has a steam supply valve which is normally shut. The two steam supply valves open automatically when an AFAS start signal is generated.

11.5.3 Component Description

11.5.3.1 AFAS

The function of the AFAS is to automatically start the AFW system upon low steam generator level, to identify a ruptured steam generator and block AFW flow to the ruptured steam generator.

The AFAS consists of four sensor subsystems and two actuation subsystems. The four sensor subsystems monitor redundant and independent parameters in the steam generators. The subsystems trip when the parameters reach their set points. The two actuation subsystems monitor the four sensor subsystem outputs and, through coincidence logic, determine whether protective action is required.

The AFAS monitors four channels of wide range level indication for each steam generator. When either steam generator has at least two out of four wide range level indication channels at or below the low level setpoint (40%), an AFAS start signal is generated on both actuation channels. The AFAS start signal automatically initiates operation of the AFW system to maintain proper steam generator water inventory.

The AFAS also monitors four channels of pressure indication for each steam generator. Each steam generator pressure channel is compared with its corresponding channel from the other steam generator. Four differential pressure channels are thus produced for each steam generator. An AFAS block signal is generated for an individual steam generator when at least two out of four differential pressure channels indicates that the opposite steam generator pressure exceeds the given steam generator pressure by 115 psig.

The AFAS block signal prevents continued feedwater addition to a ruptured steam generator. Feedwater isolation is important for two reasons. First, the addition of feedwater continues the RCS cool down and its associated positive reactivity addition. Second, the feedwater flashes to steam and adds energy to the containment building. An unisolable steam break is terminated by boiling the affected steam generator dry. Only those valves on the affected steam generator are closed, while the unaffected generator is maintained at the proper level for decay heat removal by the AFW System.

11.5.3.2 Condensate Storage Tanks

The AFW pumps can receive a suction from either of three CSTs. Normally both units are lined up to take suction on the number 12 CST.

The purpose of CST 12 is to provide a source of feedwater for unit 1 and unit 2 AFW systems. The tank has a capacity of 350,000 gallons and is protected against tornadoes and tornado-generated missiles by a seismic class I concrete structure.

CSTs 11 and 21 are normally lined up to the condensate system in their respective units. If CST 12 is unable to supply water to the two AFW systems, then CSTs 11 and 21 can be lined up to supply the AFW system of their respective unit.

The CST supply is the preferred source of emergency feedwater to the steam generators because of its purity. Plant technical specifications require a minimum volume of 150,000 gallons of condensate quality water to be available for the AFW system. The minimum water volume ensures that a sufficient heat sink is available to maintain the RCS in a hot standby condition for six hours while dumping steam to the atmosphere through the safety valves or atmospheric dumps with a concurrent and total loss of offsite power.

In addition to its emergency function, the CST also supplies water to the AFW pumps during portions of a plant heat up. Water from the CST will be used as the suction source until plant power has been escalated to 5%. At this point, at least one main feedwater pump is operating and the AFW steam generator supply is not required. Above 5%, the AFW system is aligned to its emergency system lineup with CST 12 as its suction source.

An additional source of AFW can be supplied from the opposite unit through a cross-connect to the motor driven pump discharge lines. A last means of AFW supply can be taken from the plant fire main system to the suction of the motor driven pump. Of course, this low quality water should only be used as a last resort.

11.5.3.3 Electric Driven AFW Pump

The electric driven AFW pump is a multistage, horizontal centrifugal pump powered from the class 1E electrical distribution system. The pump has a design flow rate of 450 gpm. A minimum flow of 140 gpm through the pump is required for proper pump cooling. The recirculation path is controlled by an automatic recirculation valve to provide a flow of 140 gpm, a portion of which is returned to the suction of the pump; the remaining recirculation flow is returned through a common AFW recirculation line back to CST 12. The automatic recirculation valves also act as check valves to prevent reverse flow.

The electric motor is a 500 hp, 4000 Vac, induction motor powered from the 4.16 kVac unit bus 11.

11.5.3.4 Turbine Driven AFW Pump

The steam driven pump turbine is a single stage, solid wheel, non-condensing unit rated at 600 hp at 3990 rpm. The turbine, manufactured by the Terry Steam Turbine Company, is designed for variable speed operation and is equipped with an electro-hydraulic actuator for speed control, an over speed trip mechanism, and an integral trip throttle valve. The turbine is designed for rapid starting and will operate with steam pressures as low as 50 psig. The turbine is normally supplied from the main steam system but may also be supplied from the auxiliary steam system for start-up and shutdown operations.

The AFW pump turbine exhausts to the atmosphere via individual exhaust pipes to the top of the auxiliary building roof. All valves in the steam supplies to the turbine are powered from the instrument air system to ensure operability during a complete loss of ac power. Turbine speed is manually controlled by a hand indicating controller (HIC) in the main control room.

The pumps that are driven by the AFW pump turbines are six stage, horizontal, centrifugal pumps manufactured by Byron Jackson. Each has a rated capacity of 700 gpm. A minimum flow of 80 gpm through each pump is required to ensure proper pump cooling. A recirculation line is provided for each pump to ensure that the minimum flow is met. A portion of the pump's discharge passes through the recirculation line back to CST 12. A flow orifice in each recirculation line is sized to pass the minimum allowable flow.

11.5.4 Small Break LOCA

The characteristics of a small break loss of coolant accident (SBLOCA) are different from a large break loss of coolant accident (LBLOCA).

In the LBLOCA, the RCS flashes to steam and depressurizes through the break very rapidly. The decrease in RCS pressure actuates the engineered safety features (ESF) equipment and allows the safety injection tanks (SITs) to reflood the core. After the core is reflooded, the flow from the high pressure safety injection (HPSI) pumps and the low pressure safety injection (LPSI) pumps removes the core’s decay heat. The availability of the AFW system during a large break is not important. However, AFW is vital for core safety, if a SBLOCA occurs.

Consider the following SBLOCA scenario without the availability of AFW:

1. The SBLOCA causes a slow depressurization of the RCS,
2. The depressurization causes the formation of steam in the RCS,
3. The ESF equipment is actuated, but will not pump into the RCS until its pressure is below the shutoff head of the injection pumps. The SITs will not provide water to reflood the core,
4. When RCS pressure decreases to approx-imately 1400 psig, the HPSI pumps will start to pump into the core. However, the flow rate may be insufficient for decay heat removal,
5. A heat up of the core will begin. Since the RCS is in a saturated condition, its pressure will also increase and
6. When pressure exceeds the shutoff head of the HPSI pumps, core cooling stops and severe core damage can result.

If the AFW system is available, then the above scenario will not occur. With AFW, the steam generators are available for decay heat removal. This heat removal coupled with HPSI flow will prevent core damage.

11.5.5 PRA Insights

The proper operation of the AFW system is important for the prevention of core melt in pressurized water reactors. According to the Calvert Cliffs PRA, the system contribution to core melt frequency is 32%. The following sequences illustrate the importance of the AFW system.

The sequence starts with a transient that results in a loss of both of the main feedwater pumps or a similar event that causes a loss of feedwater flow. If the AFW system fails, then decay heat removal is lost. The loss of decay heat removal will result in a heat up of the RCS. The RCS heat up causes a decrease in RCS density and a large insurge into the pressurizer. As pressurizer level increases, the RCS pressure will increase. When the set point for the power-operated relief valves (PORVs) is reached, the valves will open. If the PORVs fail to close (or cycle open and close), then a LOCA will result. All that is needed for core melt in this sequence is a failure of the HPSI system to deliver proper flow. Calculations performed by EG&G for station blackout indicate that approximately 86 minutes are available to start an AFW pump in order to prevent core uncovery.

In the Calvert Cliffs PRA, no credit was given for the possible use of primary feed and bleed. There are two questions about the feasibility of using this method. First, the thermal-hydraulic consideration that, due to the low shutoff head of the HPSI pumps, it may not be possible to reduce the pressure sufficiently by opening the PORVs within the short time available (~10 minutes) to initiate feed and bleed. Second, at the time of the PRA, Calvert Cliffs had no procedures for performing this action. The action required the removal of two trip units from the RPS to de-energize bistables in order to keep the PORVs continuously open. The plant has since been modified and switches added for operating the PORVs.

As a result of design changes in the AFW system, a motor-driven AFW pump has been added to each unit at Calvert Cliffs. These motor-driven pumps can each cross feed the other unit and supply sufficient water to cool down the plant. The actions required can be performed in the control room. The necessary actions require recovering AFW by either:

1. Starting, an assumed locked out, AFW pump 12,
2. Realign AFW pump 11 from test,
3. Recover offsite power (if lost) or
4. Cross feed from unit 2.

The risk reduction factors associated with the AFW system are relatively low, with the highest value (1.09) being a local fault (or maintenance) effecting the 11 turbine-driven AFW pump. The risk achievement factor, associated with a local fault of the condensate storage tank suction valve for the 12 AFW pump, was 601.

Failure to deliver auxiliary feedwater to the steam generators can be caused by many different failure modes. From the description of the system in this section, a common mode failure is required for total system inoperability. One such common mode failure could occur if the AFW isolation valves were incorrectly adjusted and could not open properly. A second common mode failure that has been observed at operating PWRs is the leakage of the check valves in the supply lines to the steam generators. Hot fluid from the steam generators leaks through the check valves and into the pump casings (assuming that the isolation valves are open and the pump discharge check valve also leaks). When the pump starts, it quickly becomes vapor bound and cavitates. Of course, when the pump cavitates, flow is not available from the pump.

11.5.6 Summary

The AFW system is a fully qualified safety system designed to provide feedwater to the steam generators to maintain decay heat removal capabilities. The design basis assumes that the main feedwater system and/or the condensate system is inoperative, due to a total loss of offsite power or other system failure. In addition, the AFW system is used to supply normal feedwater to the steam generators during plant start-ups and shutdowns.

The AFW system is designed to maintain its functional capability in the event of a steam generator rupture and/or a single active failure in an AFW system component.

The minimum required flow to ensure adequate RCS decay heat removal can be supplied by any one of the three AFW pumps.The pumps normally receive water from CST 12 but can also receive water from CSTs 11 or 21.

Control of AFW flow is accomplished by control valves in the pump supply. The AFW valves and pumps are controlled by the AFAS.

Table 11.5-1 Motor Driven AFW Pump Design Parameters

Pump	
Quantity	1
Type	Eight-stage, horizontal, centrifugal, split case
Manufacturer	Ingersol - Rand
Capacity	450 gpm
Minimum flow	140 gpm
Head	2800 feet
Design pressure	1800 psig
Design temperature	110 °F
Motor	
Quantity	1
Type	Two pole, squirrel cage induction
Manufacturer	Westinghouse
Horsepower	500 hp
Speed	3560 rpm
Power	4.16 kVac, 3 phase, 60 Hz.

Table 11.5-2 Turbine Driven AFW Pump Design Characteristics

Pump

Quantity	2
Type	Six-stage, horizontal, centrifugal, split case
Manufacturer	Byron Jackson Division, Borg Warner Corporation
Capacity	700 gpm
Minimum flow	80 gpm
Head	2490 feet

Turbine

Quantity	2
Type	Single-stage, non-condensing
Manufacturer	Terry Steam Turbine Company
Overspeed trip	5250 rpm
Horsepower	80 hp - 600 hp
Speed	2000 rpm - 3990 rpm
Inlet steam pressure	64 psia - 1000 psia
Backpressure	17 psia - 25 psia
Inlet temperature	300 °F - 545 °F

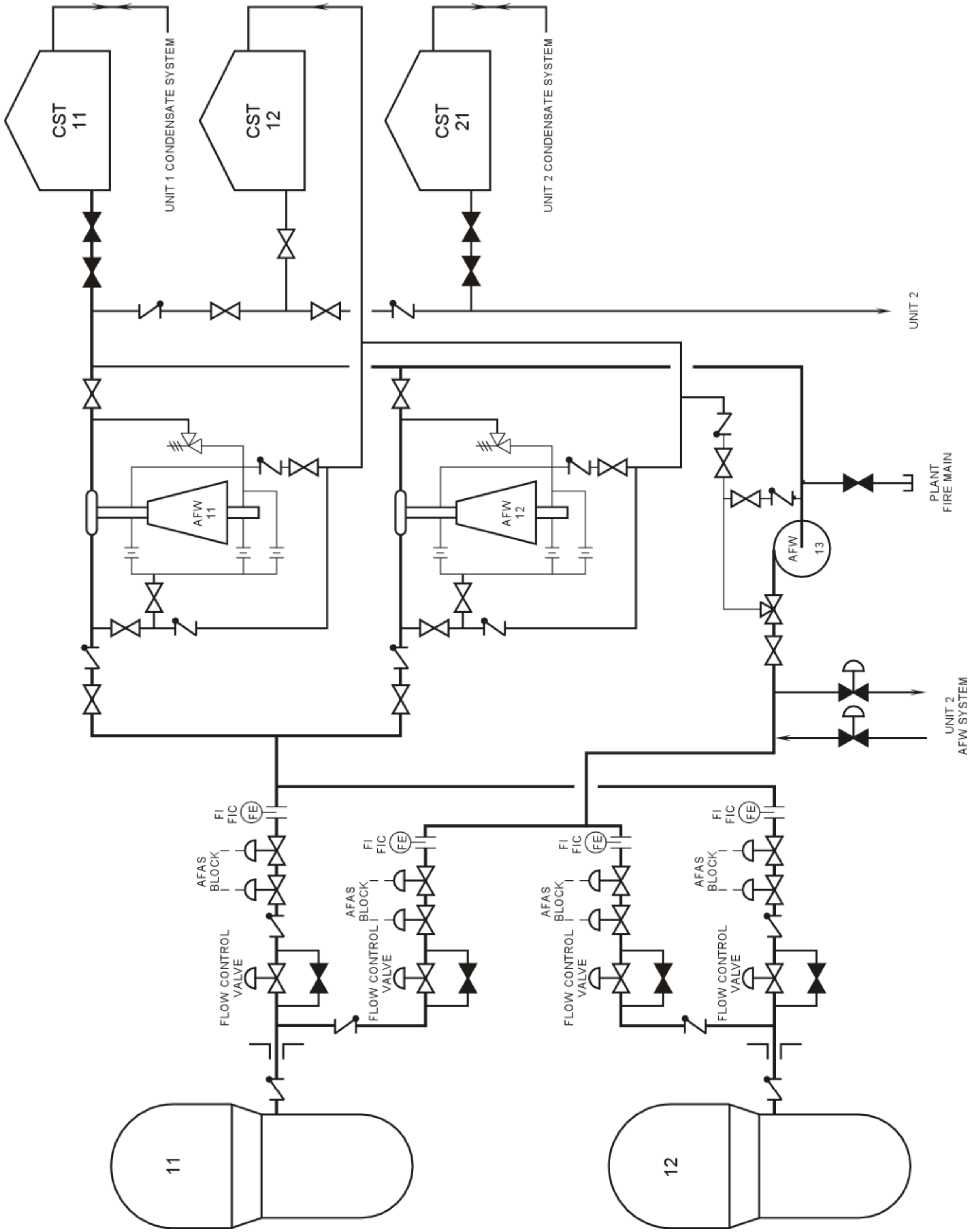

Figure 11.5-1 Auxiliary Feedwater System

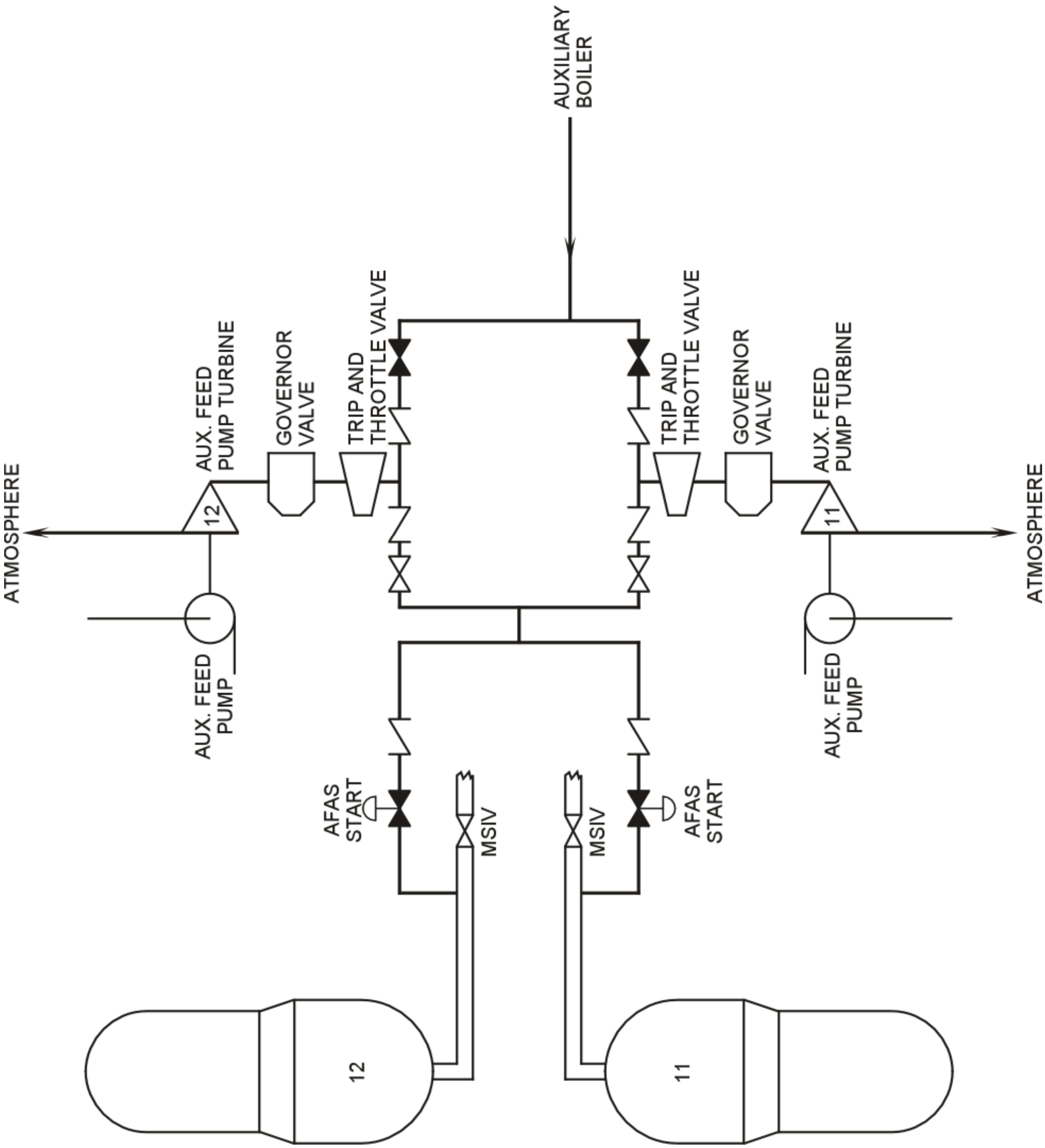

Figure 11.5-2 Auxiliary Feedwater Steam Supply