

Pressurized Water Reactor
B&W Technology
Crosstraining Course Manual

Chapter 5.0

Auxiliary Feedwater System

TABLE OF CONTENTS

5.0	AUXILIARY FEEDWATER SYSTEM	1
5.1	Introduction.....	1
5.2	System Description.....	1
5.2.1	Auxiliary Feedwater Pumps	1
5.2.2	AFW Pump Suction Header.....	2
5.2.3	Steam Generator Supplies.....	2
5.2.4	OTSG Level Control.....	2
5.3	Component Descriptions	3
5.3.1	Auxiliary Feedwater Pumps	3
5.3.2	Demineralized Water Storage Tank.....	3
5.3.3	AFW Level Control Valves	3
5.3.4	AFW Isolation Valves.....	4
5.3.5	AFW Turbine Steam Supplies.....	4
5.3.6	OTSG Auxiliary Feedwater Header.....	4
5.4	System Operations.....	4
5.4.1	Natural Circulation	4
5.4.2	Small-Break LOCAs.....	5
5.4.3	Loss of Main Feedwater.....	5
5.4.4	Feed-Only-Good-Generator (FOGG) Logic	5
5.5	PRA Insights.....	6
5.5.1	Loss of Main Feedwater.....	6
5.5.2	Small-Break Loss-of-Coolant Accident	6
5.5.3	AFW Failure Modes	6
5.6	Summary.....	7

TABLE

5-1	FOGG Logic.....	8
-----	-----------------	---

LIST OF FIGURES

- Figure 5-1 Auxiliary Feedwater System
- Figure 5-2 AFW Start Signals
- Figure 5-3 AFW Turbine Steam Supplies

This page intentionally blank.

5.0 AUXILIARY FEEDWATER SYSTEM

Learning Objectives:

1. State the purpose of the auxiliary feedwater (AFW) system.
2. List all suction sources for the AFW pumps.
3. List the automatic start signals for the AFW pumps.
4. Explain how the operation of the AFW system helps promote natural circulation in the reactor coolant system.
5. State the purpose of the “feed-only-good- generator” (FOGG) logic and explain how it functions.

5.1 Introduction

The auxiliary feedwater (AFW) system, shown in Figure 5-1, is a safety-related system designed to provide a reliable source of feedwater to the steam generators to remove decay heat during the following occurrences:

1. Loss of reactor coolant flow caused by a loss of offsite power (LOOP),
2. Loss of main feedwater,
3. Pipe rupture in the secondary system,
4. Steam generator tube rupture (SGTR), and
5. Small-break loss-of-coolant accident (SBLOCA).

In addition to providing feedwater under emergency conditions, the AFW system and demineralized water storage tank volume allow the unit to be maintained at hot standby for 4 hours followed by a cooldown to the decay heat removal system initiation point.

5.2 System Description

5.2.1 Auxiliary Feedwater Pumps

The AFW system has two half-capacity motor-driven pumps and a full-capacity steam-driven pump. The motor-driven pumps powered from separate, independent electrical power sources. Redundant steam supplies, one from each steam generator, are connected to the turbine-driven pump. Automatic starts of all AFW pumps provided by any of the following conditions, as shown in Figure 5-2:

1. An engineered safety features actuation system (ESFAS) signal,
2. A low level in either steam generator,

3. Both main feedwater pumps tripped,
4. All reactor coolant pumps (RCPs) tripped, or
5. Low pressure in either steam generator (the Secondary Protection System).

In addition, the two motor-driven pumps automatically start on a loss of offsite power in accordance with the loss-of-offsite-power (LOOP) automatic loading sequence.

5.2.2 AFW Pump Suction Header

The motor-driven pumps share a common suction from the demineralized water storage tank (DWST), and the steam-driven pump has a separate suction. A suction supply from the condensate storage tank (CST) is also available. The normally closed motor-operated gate supply valves opened manually to use this suction source. In addition, in the unlikely event that extended operation at hot standby is required, there is a manually operated cross-connect between the nuclear service water system and the AFW system. This cross-connect would supply spray pond water (non-feedwater quality) to the AFW system.

5.2.3 Steam Generator Supplies

Each motor-driven pump normally supplies feedwater to one steam generator; that is, the 1A pump feeds the “A” once-through steam generator (OTSG), and the 2B pump feeds the “B” OTSG. As shown in Figure 5-1, the turbine-driven pump (3C) normally supplies both steam generators. Manually controlled, air-operated valves (CV-3121 and CV-3122) allow either motor-driven pump to feed both steam generators.

5.2.4 OTSG Level Control

Air-operated valves LCV-4025 and LCV-4026 control steam generator level for the “A” OTSG, and LCV-4007 and LCV-4009 for the “B” OTSG. The level control system for each valve receives a level input signal from a startup range OTSG level transmitter in the essential controls and instrumentation (ECI) system. This signal is compared with a level setpoint, and the resultant error signal modulates the control valve using a proportional-plus-integral controller. Manual control is available in both the main and auxiliary control room. Parallel flowpaths (one from a motor-driven pump, one from the turbine-driven pump) and redundant instrumentation and control power supplies for the level control valves ensure flow to each OTSG. Motor-operated block valves (V-14A and V-31B in the “A” OTSG supply, V-37A and V-20B in the “B” OTSG supply) provide redundant feedwater isolation of an OTSG. The turbine-driven and motor-driven pump discharge lines combine to supply the auxiliary feed ring in each OTSG.

5.3 Component Descriptions

5.3.1 Auxiliary Feedwater Pumps

The 1A and 2B AFW pumps are ten-stage centrifugal pumps rated at 600 gpm each and driven by 4160-vac, 800-hp electric motors. The A-train pump motor is connected to the A-train 4160-vac vital bus, and the B-train pump motor is connected to the B-train 4160-vac vital bus. The 1600-hp turbine-driven pump (3C) is a six-stage centrifugal pump rated at 1325 gpm. Both motor-driven pumps together, or the turbine-driven pump alone can deliver the 1200-gpm minimum flow requirement at a discharge pressure equal to that of the highest safety valve setpoint plus accumulation (1260 psig).

5.3.2 Demineralized Water Storage Tank

The DWST, a 460,000-gallon tank, is the normal suction supply for the AFW system. In addition to the AFW system, the DWST also supplies demineralized water to other plant systems. The supply line is connected to the tank at an elevation above the 330,000-gal elevation. This arrangement ensures that a volume of 330,000 gallons is always available to the AFW system, which takes suction from the bottom of the DWST. The 330,000 gallon volume is based on the ability to remove decay heat following a loss of offsite power through the modulating atmospheric dump and/or safety valves, while replacing secondary inventory with the AFW system. It is assumed that the unit will be maintained at hot standby for 4 hours before a cooldown to the temperature required for decay heat removal system operation is initiated. The assumption is 6 hours are required for the cooldown.

5.3.3 AFW Level Control Valves

The AFW level control valves are air-operated and receive a level control signal from the ECI system. In automatic control, the actual steam generator level is compared to a level setpoint, and proportional-plus-integral controllers based on the error modulate the valves. The level setpoint is 2 feet, unless all the reactor coolant pumps are tripped (which would occur with a LOOP), in which case the level setpoint is 6 feet. The operator may also take manual control, which would be necessary to raise the OTSG levels to the loss of subcooling margin setpoint. Modulating or closing of the control valves require that solenoids that govern the flow of air to the valve operators energize, allowing the valves to position or close. Air pressure in a valve operator pushes against a spring that will open the valve fully on a loss of air pressure.

The DC power supplies to the level control valves are arranged so that the loss of a single DC bus will not prevent the feeding of the OTSGs. The level control valve (CV-4025) in the supply line from the 1A feed pump to the "A" OTSG is supplied from an "A" train DC bus, while the level control valve (CV-4026) in the supply line from the turbine-driven pump to the "A" OTSG is supplied from a "B" train DC bus. CV-4007 in the supply line from the 2B pump to the "B" OTSG, is powered from a "B" train DC bus, while CV-4009, the

redundant "B" OTSG level control valve, is supplied from an "A" train DC bus. The level control valves will fail open on a loss of power or a loss of instrument air.

5.3.4 AFW Isolation Valves

The normally open motor-operated isolation valves (V-14A, -31B, -37A and -20B) receive open or close signals from different sources. The valves receive confirmatory open signals when the AFW system receives a start signal. The close signal for the valves is a feed-only-good-generator signal (FOGG), discussed in section 5.4.4.

The valves receive power from redundant 480-vac buses. V-14A, the isolation valve in the supply line from the 1A pump to the "A" OTSG, receives power from the "A" train vital 480-vac distribution system, while V-31B, in the supply line from the turbine-driven pump to the "A" OTSG, receives power from the "B" train. A similar arrangement exists for the "B" OTSG; V-20B receives power from the "B" train, and V-37A receives power from the "A" train. These valves fail in their existing position on a loss of power.

5.3.5 AFW Turbine Steam Supplies

The steam supply from each OTSG to the AFW pump turbine (Figure 5-3) is controlled by a normally open motor-operated valve (V-41A and V-44B). In the event of a steamline break, the valve associated with the affected OTSG will automatically close. If the break is in the common supply line (downstream of the check valves), both valves will close.

Three series isolation valves are installed in the common supply line. The first of these valves (CV-2872) will automatically close in the event of a piping break in the common supply line. The second valve (CV-7938) is the only normally closed valve in the steam supply to the turbine. This valve will automatically open if any AFW start signal occurs. The final valve (V-434) is a maintenance isolation valve.

5.3.6 OTSG Auxiliary Feedwater Header

The 6-inch auxiliary feedwater line enters each OTSG through inlet nozzles in the upper shell just below the upper tubesheet. The nozzles penetrate the shell and the upper shroud. Auxiliary feedwater sprays directly on the tubes near the top of the generator to raise the thermal center of the heat sink and thereby promote natural circulation or boiler-condenser cooling if needed.

5.4 System Operations

5.4.1 Natural Circulation

During a loss of forced RCS flow (i.e., loss of reactor coolant pumps), the reactor's decay heat transfers to the steam generators by natural circulation flow. Natural circulation

flow results from the density difference between the hot reactor outlet water (T_h) and the cold steam generator outlet water (T_c), and by the height differential between the thermal centers of the reactor vessel and the OTSGs.

Two conditions must be met to maintain natural circulation flow: (1) steam must be removed from the steam generator, and (2) feedwater must be supplied continuously to the OTSGs. Safety-related modulating atmospheric dump valves satisfy the first condition, and the AFW system satisfies the second condition. As described in Chapter 2.4, Once-Through-Steam-Generators, auxiliary feedwater enters the OTSG through the inlet nozzles in the upper shell just below the tube sheet. The nozzles penetrate the shell and the upper shroud. Auxiliary feedwater sprays directly on the tubes near the top of the OTSG to raise the thermal center of the heat sink and thereby promote natural circulation. Natural circulation is the core-cooling mode following a loss of offsite power.

If a loss of offsite power does occur, both main feedwater pumps will be lost. Either the loss of both main feedwater pumps, loss of all RCPs, or the low steam generator level signal will start the turbine-driven AFW pump. The motor-driven pumps will start at the proper time in the LOOP loading sequence after the diesel generators have started.

5.4.2 Small-Break LOCAs

For certain size SBLOCAs, the HPI system may not supply enough flow to adequately cool the core. In these accidents, the operation of the AFW system is necessary to help remove decay heat from the core.

5.4.3 Loss of Main Feedwater

If both main feedwater pumps are lost, a reactor trip will be generated by high reactor coolant system pressure or the anticipatory loss of feedwater trip. An automatic start signal for the AFW system occurs by the loss of both main feedwater pumps. The pumps will start, and the level control valves will modulate to control steam generator level at the 2-ft. setpoint.

5.4.4 Feed-Only-Good-Generator (FOGG) Logic

The steamline break accident upstream of the main steam isolation valves can only be terminated by allowing the affected OTSG to boil dry. Therefore, the main and auxiliary feedwater (AFW) supplies to the affected OTSG must be isolated. The Secondary Protection System on low OTSG pressure isolates the main feedwater supply. (Chapter 10.2 of this manual describes the Secondary Protection System.)

Since AFW supplies the unaffected or least affected OTSG for decay heat removal, the isolation scheme must decide which generator to isolate. This decision involves a comparison of OTSG pressures, as shown in Table 5-1. The FOGG logic will never isolate

both OTSGs. The control valves for the unaffected or least affected OTSG are enabled for level control.

5.5 PRA Insights

The proper operation of the AFW system is important to the prevention of core melt in pressurized water reactors. According to the ANO-1 PRA, the system contribution to core melt frequency is 59%. The following sequences illustrate the importance of the AFW system.

5.5.1 Loss of Main Feedwater

The sequence starts with a transient resulting 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 heatup of the reactor coolant. Of course, the reactor coolant heatup causes a decrease in density and a large in-surge into the pressurizer. As pressurizer level increases, pressure increases. When the lift setpoint for the power-operated relief valve (PORV) is reached, the valve will open. If the PORV fails to close, then a loss-of-coolant accident will result. All that is needed for core melt in this sequence is a failure of the high-pressure injection system to deliver proper flow.

5.5.2 Small-Break Loss-of-Coolant Accident

In this sequence, a small-break loss-of-coolant accident is postulated along with a failure of the AFW system. As previously stated, for certain size breaks, AFW flow and high-pressure injection are required for proper core cooling. Since only high-pressure injection is available, there is insufficient decay heat removal capability. The lack of decay heat removal leads to inadequate core cooling. Plant emergency procedures require the operator to verify high-pressure injection flow and then to open the PORV. The opening of the PORV will increase the break size and increase high-pressure injection flow. This operation is called "bleed and feed" core cooling. If the operator fails to initiate this action or if the PORV fails to open, then the inadequate core cooling can lead to core melt.

5.5.3 AFW Failure Modes

Failure to deliver auxiliary feedwater to the steam generators are caused by many different failure modes. For the system described in this section, a common-mode failure would be the most likely cause of total system inoperability. One such common-mode failure would occur if the AFW isolation valves have been incorrectly adjusted and can 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 pump discharge check valves also leak). When the pumps start, they

quickly become vapor bound and cavitate. Of course, when the pumps are cavitating, flow is not available from the pumps.

5.6 Summary

The AFW system is a safety-related system designed to provide a heat sink for decay heat removal during abnormal or accident conditions.

TABLE 5-1 FOGG Logic

OTSG Pressures (psig or psid)	"A" OTSG Valves		"B" OTSG Valves	
	Control	Isolation	Control	Isolation
1. A > 800, B > 800	Enabled	Open	Enabled	Open
2. A > 800, B < 800	Enabled	Open	Closed	Closed
3. A < 800, B > 800	Closed	Closed	Enabled	Open
4. A & B < 800, $\Delta P < 100$	Enabled	Open	Enabled	Open
5. A & B < 800, A - B > 100	Enabled	Open	Closed	Closed
6. A & B < 800, B - A > 100	Closed	Closed	Enabled	Open

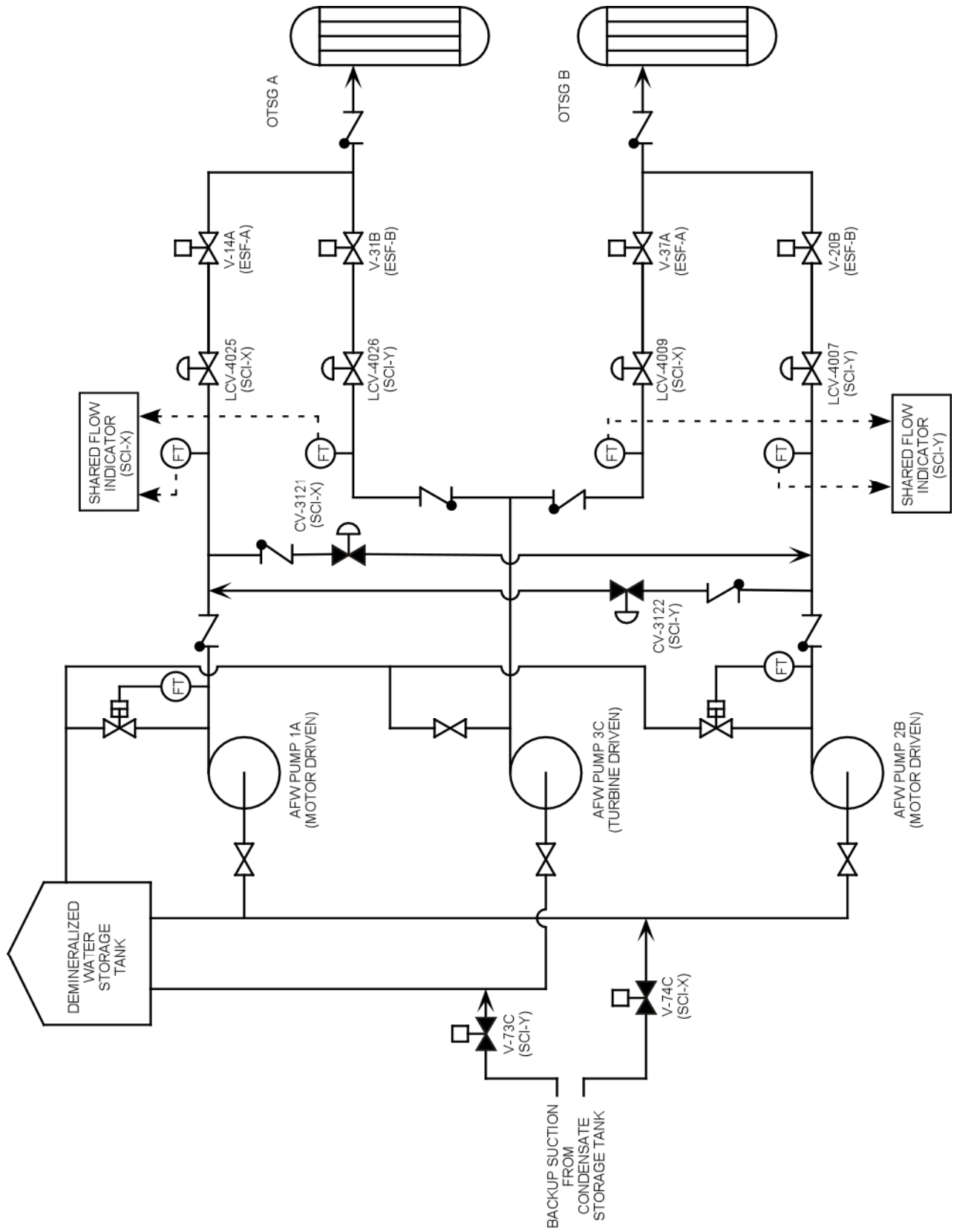


Figure 5-1 Auxiliary Feedwater System

This page intentionally blank

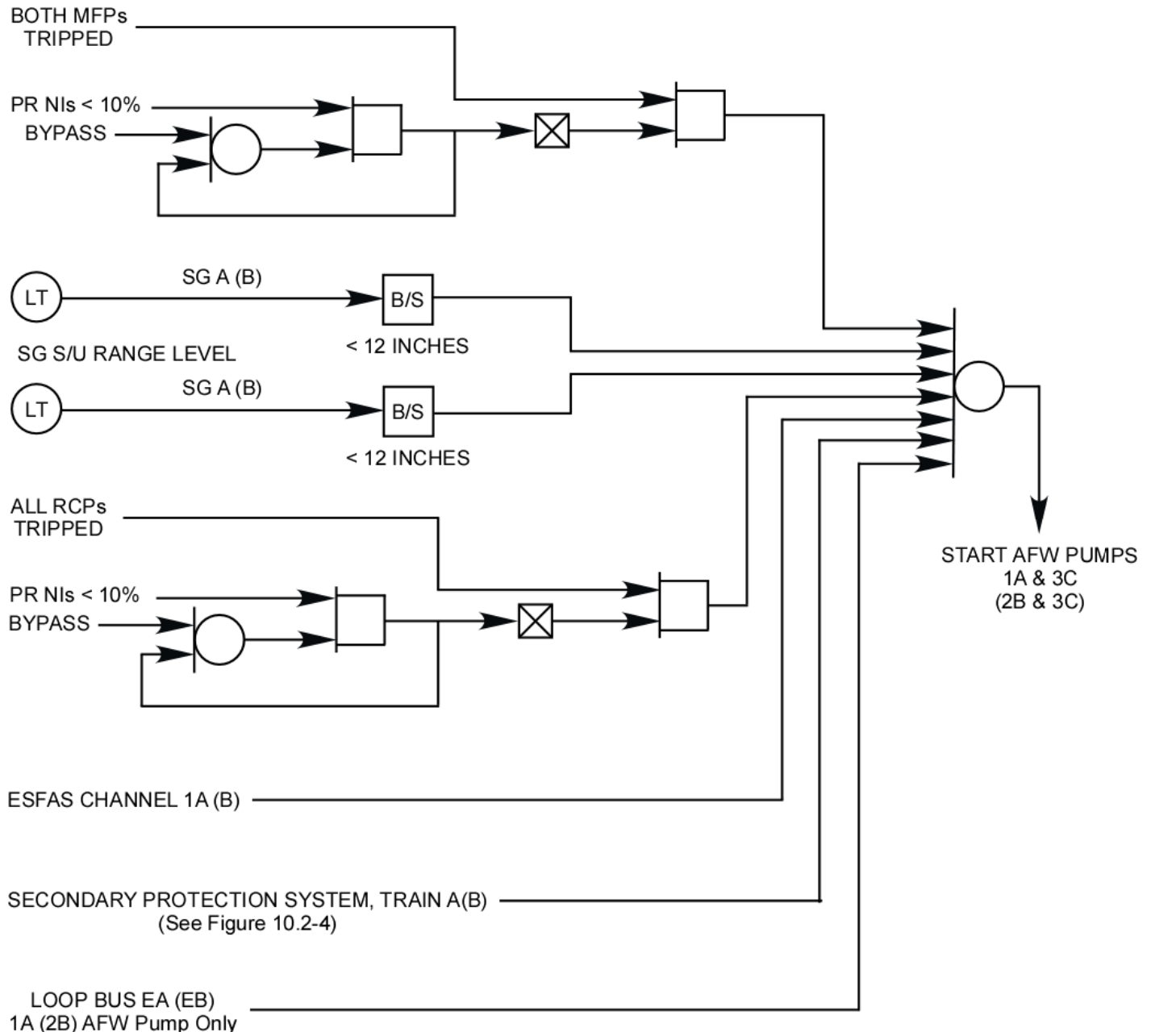


Figure 5-2 AFW Start Signals

This page intentionally blank

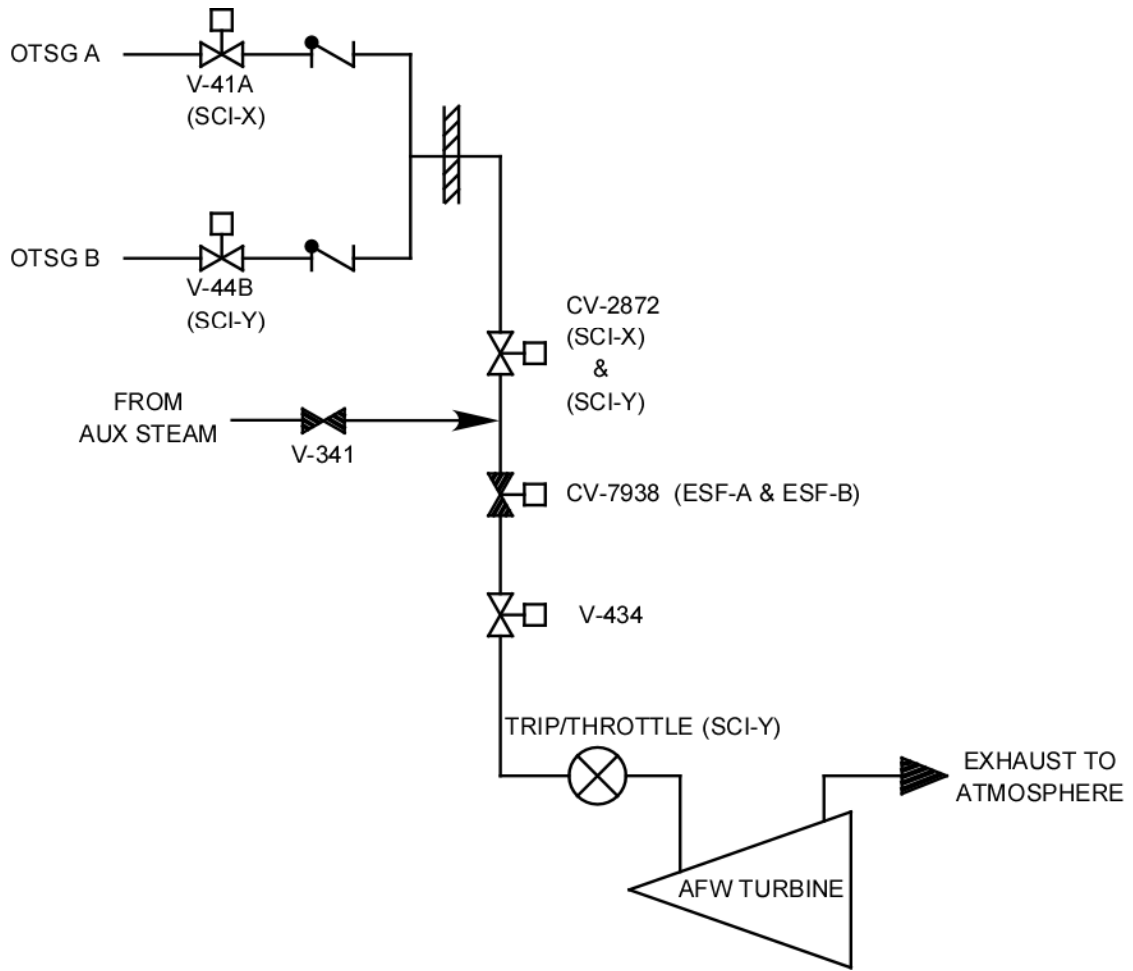


Figure 5-3 AFW Turbine Steam Supplies

This page intentionally blank