Westinghouse Technology Systems Manual

Section 12.3

Reactor Protection System – Engineered Safety Features Actuation Signals

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12.3 REACTOR PROTECTION SYSTEM - ENGINEERED SAFETY FEATURES ACTUATION SIGNALS

Learning Objectives:

1. List the engineered safety features (ESF) actuation signals and the accident(s) or conditions which will initiate each one.

2. List the systems or components that are actuated or realigned by each engineered safety features actuation signal.

3. Describe the effects of resetting a safety injection actuation signal and how the reset signal is removed.

12.3.1 Introduction

In response to accidents, the engineered safety features actuation signals actuate or realign safety-related systems, equipment, and/or components and to isolate nonsafety-related systems. Various parameters are monitored by plant instrumentation to determine whether an accident or other condition requiring protective action has occurred. In the reactor protection system (RPS), multiple analog signals for each monitored parameter are compared to bistable setpoints. When enough signals in an appropriate combination have exceeded their respective setpoints, the RPS generates the necessary protective actions.

Each ESF protective function discussed in this section has a set of actuating signals and a set of plant equipment responses. The ESF functions include:

- Safety injection actuation,
- Containment spray actuation,
- Containment isolation,
- Steam line isolation,
- Feedwater isolation, and
- Auxiliary feedwater actuation.

When the RPS senses a condition requiring an ESF actuation, it energizes the appropriate master relay(s), as shown in Figure 12.3-2. Each ESF protective function has an associated master relay or set of master relays. Each master relay operates contacts which energize up to four slave relays. The slave relays actuate ESF equipment through control devices such as valve positioners and motor controllers.

An important feature of the ESF actuation circuitry is the maintenance of independence and redundancy. These features are accomplished by having each separate, independent protection train actuate only those systems and components associated with that train. That is, protection train “A” controls the “A” train ESF equipment such as the “A” train diesel generator, the “A” train residual heat removal (RHR) pump, the “A” train safety injection (SI) pump, and the “A” train isolation and flow control valves. Protection train “B” controls all the train “B” equipment. Since all the safety equipment is fully redundant, a single operable train is required to mitigate the consequences of an accident and to provide protection for the public health and safety. Either protection train may operate a component when it is not assigned to either train.

12.3.2 Safety Injection Actuation

The RPS automatically initiates a safety injection (SI) actuation to limit the consequences of infrequent faults (Condition III events) and limiting faults (Condition IV events) to reduce the potential for a significant release of radioactive material to the environment.

The SI actuation functions to shut down the reactor if it is still operating, to maintain the reactor in a shutdown condition, to provide sufficient core cooling to limit possible cladding and fuel damage, to ensure the integrity of the containment, and to place plant support systems in appropriate post-accident alignments. Figure 12.3-1 illustrates the SI actuation signals and the ESF systems affected by the SI actuation. Each actuation signal and the accidents to which each signal is designed to respond are discussed in section 12.3.2.1.

If the RPS senses conditions associated with either a loss of coolant accident (LOCA) or a secondary system (steam line or feed line) break, it initiates an SI actuation. Either of these accidents requires the operation of various safety features to ensure the safety of the public and to limit core damage. Regardless of the accident, the response of plant equipment to the SI actuation includes:

1. Placing the plant in a safe shutdown configuration, including tripping the reactor and injecting borated water into the reactor coolant system,

2. Providing cool, borated water at a rate sufficient to prevent excessive core damage following a LOCA,

3. Isolating the containment from the outside environment to limit the amount of radioactive effluent releases.

4. Providing a heat sink to remove the residual heat of the reactor core during the injection phase of the accident and to remove decay heat for the long term, and

5. Providing a reliable source of emergency power (running diesel generators) in the event that the preferred source of power is lost.

12.3.2.1 Safety Injection Actuation Signals

The SI actuation signals are discussed in the following paragraphs. The signals are summarized in Table 12.3-1.

Low Pressurizer Pressure

The logic for the low pressurizer pressure SI actuation is shown in Figure 12.3-4. The actuation setpoint is 1807 psig, with a coincidence of two-out-of-three channels. This SI actuation signal is designed to respond to the drop in reactor coolant pressure which accompanies inventory loss during a LOCA. A steam line break could also trigger this actuation signal due to the decrease in primary pressure resulting from coolant contraction. During a normal cooldown and depressurization of the plant, this signal is manually blocked when pressurizer pressure drops below 1915 psig on two-out-of-three channels (the P-11 permissive).

High Containment Pressure

The high containment pressure SI actuation signal, shown in Figure 12.3-5, is designed to serve as a backup protection signal in response to any high energy line break, primary or secondary, inside the containment. Also, the high containment pressure signal would initiate an SI actuation if the break is large enough to cause a sufficient increase in containment pressure, but not large enough to trigger an SI actuation from any other signal. The setpoint for this protection signal is 3.5 psig. This SI actuation signal cannot be blocked by the operator.

High Steam Line Flow Coincident with Either Low Steam Line Pressure or Low-Low T_{avg}

The combination of high steam line flow in conjunction with either low steam pressure or low-low T_{avg} arises when a steam line break occurs downstream of the main steam line isolation valves (MSIVs) and check valves. A steam line break at this location is common to all steam generators. It causes a steam flow increase and a steam pressure decrease in each main steam line. The increased steam flow increases the heat removal from the reactor coolant and thus reduces the reactor coolant temperature (T_{avg}). As shown in Figure 12.3-6, the high steam flow setpoint is a function of turbine impulse pressure, allowing it to vary with plant power. In addition to initiating an SI actuation, this signal initiates isolation of the steam lines (see section 12.3.5).

The control room operator may manually block this actuation signal, as shown in Figure 12.3-6. Permissive P-12 (T_{avg} < 553°F) provides an input into the logic that allows the control room operator to block this signal. Bypassing this signal allows the operating staff to cool down and depressurize the plant without inadvertently actuating an SI or initiating steam line isolation on high steam flow.

High Steam Line Differential Pressure

This actuation signal is indicative of a steam line break upstream of the MSIVs and main steam check valves. With this break location, the pressure in the affected steam line pressure drops to a value significantly lower than the pressures of the other steam lines when the affected steam line’s check valve seats. If the pressure in the affected steam line is 100 psi lower than the pressure in at least two of the remaining three steam lines, as shown in Figure 12.3-7, the necessary coincidence for this actuating signal is satisfied. This SI actuation signal cannot be blocked by the operator.

Manual

The manual function allows the operator to initiate an SI actuation (from either of two main control board locations) at any time.

12.3.2.2 Safety Injection Functions

When an SI actuation is initiated, as shown in Figure 12.3-1, by any of the previously described signals, various actions are completed to place the plant in a safe shutdown configuration. The specific actions that occur are as follows:

1. Reactor trip: A trip shuts down the reactor if one has not already occurred.

2. Emergency core cooling system actuation: The discharge of the centrifugal charging pumps is realigned from the normal charging path of the chemical and volume control system to the high head cold-leg injection path. The suctions of the charging pumps are realigned from the volume control tank to the refueling water storage tank (RWST). In addition, the SI actuation starts the centrifugal charging pumps (one may already have been running), the safety injection pumps, and the residual heat removal (RHR) pumps. The RHR and SI systems are normally aligned to inject borated water from the RWST into the reactor coolant system cold legs. Refer to Section 5.2 for detailed descriptions of these systems.

3. Containment isolation Phase A: Refer to section 12.3.4.1.

4. Auxiliary feedwater (AFW) actuation: The AFW system provides a reliable, safety-grade source of water to the steam generators to ensure that a reactor heat sink is available.

5. Main feedwater (MFW) isolation: Refer to section 12.3.6.

6. Emergency diesel generator startup: The diesel generators are the emergency power source for the engineered safety features. They are started by any SI actuation, regardless of the status of offsite power. The diesel generators run unloaded if offsite power is maintained. If the preferred power source (offsite power) is lost, the diesel generator output breakers automatically close onto the dead class IE buses.

7. Auxiliary cooling system alignment: The service water system (SWS) and the component cooling water (CCW) system automatically realign to their emergency configurations. In addition, start signals are sent to pumps in each system.

8. Control room ventilation isolation: The normal ventilation supply to the control room is isolated to prevent the entry of smoke or radioactivity from the auxiliary building. In addition, the control room emergency ventilation system, which recirculates control room air through filters and charcoal adsorbers, is actuated.

9. Containment ventilation isolation: The containment purge supply and exhaust systems and the hydrogen vent system, if operating, are isolated by the SI actuation as part of isolating the containment from the environment.

12.3.2.3 SI Actuation Reset

As shown in Figure 12.3-3, an automatic SI actuation places a retentive memory device in the “ON” position. In the “ON” position, energized relay K1 closes two K1 contacts in the retentive memory circuit. One K1 contact provides power to the output relays, and the other K1 contact completes an alternate power-supply circuit for relay K1. This means that the protective functions described above continue to receive an actuation signal even if the original SI signal clears.

The control room operator cannot interrupt any of the SI-initiated functions until the reset logic is satisfied. This “locking out” of the operator prevents the interruption of a valid SI actuation. Additionally, the design basis accident (DBA) sequencers initiate many of the SI functions; interrupting the start sequence before it is finished could leave some systems incorrectly aligned.

To prevent the interruption of any SI actuation, the reset logic must be satisfied before the reactor operator can manually reset (turn off) the SI actuation signal. When the retentive memory is turned on (relay K1 in Figure 12.3-3 energizes), the K1 contact in the reset circuit closes, thus starting the energizing sequence for the time delay relay (relay TD). The time delay relay produces an output (energizes) some time after it is started (usually 45 - 60 sec). After the time delay relay times out, it energizes and closes the TD contact in the reset circuit. This action, along with the P4 contact being closed by the reactor trip (permissive P-4 is described in Section 12.2), allows the operator to reset (turn off) the SI actuation signal by depressing the control room reset pushbutton. The time delay ensures that all system and component realignments are complete prior to the SI reset.

As shown in Figure 12.3-3, closing the TD contact and depressing the reset pushbutton energize relay R1 and thus close an “a” contact (labeled R1), which is located in the reset circuit in parallel with the reset pushbutton. After this contact closes, the control room operator can release the reset pushbutton without de-energizing the R1 relay. The reset signal is thus maintained.

Relay R1 also opens two “b” contacts. One of these “b” contacts is located in the time delay circuit. Opening this contact (labeled R1) de-energizes the TD relay. Simultaneously opening the other “b” contact (also labeled R1) in the retentive memory portion of the circuit de-energizes relay K1, thereby removing power from the output relays. As long as the R1 relay remains energized, the retentive memory is in the “OFF” position, and all automatic SI actuation signals are blocked.

As described in the preceding paragraphs, resetting the SI actuation places the retentive memory device in the “OFF” position. Removing the “ON” signal from the SI actuation circuitry does not turn off any ESF equipment, realign any valves, or change any functions initiated by the SI actuation. When the operator depresses the reset pushbutton, the only response is the removal of the start signal. However, after turning off the actuation circuitry the control room operators can change system alignments, start or stop equipment as needed, and control the plant as required by the plant's emergency operating procedures to recover from the accident (or SI actuation conditions).

As mentioned above, a significant feature of the SI actuation reset is that the reset blocks any further automatic SI actuations. However, a manual SI actuation is still available. If the control room operator depresses either of the two manual SI actuation pushbuttons located in the main control room, relay K2 energizes. When this relay energizes, it closes contact K2 in the "ON" side of the retentive memory and thus energizes relay K1. This action provides power to the output relays (actuates the ESF loads). Meanwhile, "b" contact K2 opens in the "OFF" side of the retentive memory. When it opens, it de-energizes relay R1, which closes "b" contact R1 in the "ON" side of the retentive memory. With this contact closed, relay K1 remains energized after the operator releases the manual SI actuation pushbutton.

De-energizing the R1 relay also simultaneously opens the R1 contact in parallel with the reset pushbutton and closes the R1 contact in the time delay relay circuit. The operator is again prevented from resetting the actuation until the time delay relay times out.

After the control room operator resets the SI actuation, all automatic SI actuation signals are disabled until the control room operator manually initiates an SI actuation or until the reactor trip input to the reset circuit (permissive P-4) is cleared by closing the reactor trip breakers. Before closing the reactor trip breakers, the operator should ensure that all SI actuation signals have cleared. Otherwise, when the control room operator closes the reactor trip breakers and removes the reset signal, the actuation sequence restarts.

12.3.3 Containment Spray Actuation

12.3.3.1 Containment Spray Actuation Signals

The containment spray system is automatically actuated by a high-high containment pressure signal, as shown in Figure 12.3-5. The setpoint is 30 psig. A very high containment pressure is indicative of a large line break; operation of the containment spray system is needed to reduce the containment temperature and pressure. The containment spray system can also be manually actuated. The actuation signals are summarized in Table 12.3-1.

12.3.3.2 Containment Spray Actuation Functions

A containment spray actuation signal starts the containment spray pumps, opens the spray header isolation valves, and aligns the spray additive tank to the suctions of the pumps. Starting the spray pumps also requires initiation of the DBA sequencers by an SI actuation. Refer to Section 5.4 for additional details concerning the containment spray system.

12.3.4 Containment Isolation

12.3.4.1 Containment Isolation Phase A

Phase A Actuation Signals

Containment isolation Phase A is automatically actuated by a safety injection actuation. Most containment penetrations are thus isolated when there is evidence of an accident in progress, so that the potential release of radioactivity to the environment is minimized. A Phase A isolation can also be manually actuated. The actuation signals are summarized in Table 12.3-1.

Phase A Functions

Redundant isolation valves and dampers (one inside containment, one outside containment) are shut in all non-essential lines which penetrate the containment. The containment penetrations which remain unisolated are the CCW supply and return lines for the reactor coolant pumps (RCPs) and the main steam lines.

Continued forced circulation of coolant by the RCPs, although not essential for safe shutdown of the plant, is the preferred method of decay heat removal. CCW flow to the RCP heat exchangers is thus maintained even during an accident, unless the CCW isolation valves are closed by a containment isolation Phase B signal (see Section 12.3.4.2).

The MSIVs are not closed by a Phase A isolation so that steam flow to the steam dump system is available for core decay heat removal. The MSIVs are automatically closed by a steam line isolation actuation (see Section 12.3.5).

12.3.4.2 Containment Isolation Phase B

Phase B Actuation Signals

Containment isolation Phase B is automatically actuated by a high-high containment pressure signal. Phase B isolation should be simultaneous with containment spray actuation. Phase B isolation is manually actuated when containment spray is manually actuated. The actuation signals are summarized in Table 12.3-1.

Phase B Functions

A Phase B isolation shuts the isolation valves in the CCW supply and return lines to the RCPs. Together with isolation of the main steam lines (see Section 12.3.5), a Phase B isolation completes isolation of containment penetrations when there is a large break inside containment.

12.3.5 Steam Line Isolation

12.3.5.1 Steam Line Isolation Actuation Signals

The main steam lines are isolated by (1) a high-high containment pressure signal or (2) high steam flow coincident with low-low T_{avg} or low steam pressure. Together with a containment isolation Phase B (see Section 12.3.4.2), the first main steam line isolation signal completes isolation of containment penetrations when there is a large break inside containment. The second signal isolates the steam lines when there is evidence of a steam line break downstream of the MSIVs; this action should isolate the break from the steam generators and end its effects on the plant. Note that, as shown in Figure 12.3-6, manually blocking the high steam flow SI actuation does not block the high steam flow steam line isolation. The actuation signals are summarized in Table 12.3-1.

12.3.5.2 Steam Line Isolation Functions

A steam line isolation actuation closes all MSIVs, all MSIV bypass valves, and all steam line high pressure drain valves.

12.3.6 Feedwater Isolation

12.3.6.1 Feedwater Isolation Actuation Signals

Main feedwater to the steam generators is automatically isolated by each of the following signals:

- Low T_{avg} (564°F) coincident with a reactor trip (permissive P-4),
- High steam generator water level (permissive P-14) in any generator, and
- SI actuation.

Isolating MFW in response to these signals provides the following benefits:

1. Overcooling of the reactor coolant by excessive MFW to the steam generators should be avoided. In response to the large prolonged “shrink” in steam generator levels following a reactor trip, the steam generator water level control system develops large feed flow demands; without MFW isolation the main feedwater regulating valves would supply relatively cold feedwater to the generators at a very high rate.

2. Completely filling the steam generators and introducing water into the steam piping should be avoided.

3. The non-Seismic Category I portion of the feedwater piping is isolated from seismically qualified equipment needed for decay heat removal during an accident.

The actuation signals are summarized in Table 12.3-1.

12.3.6.2 Feedwater Isolation Functions

Any feedwater isolation signal closes all four main feedwater regulating valves, all four bypass regulating valves, and all eight feedwater isolation valves. The high steam generator water level and SI actuation signals also directly trip the main feed pumps and the main turbine.

12.3.7 Auxiliary Feedwater Actuation

12.3.7.1 Auxiliary Feedwater Actuation Signals

The AFW system is automatically actuated by the following signals:

- SI actuation,
- Low-low steam generator water level in any generator,
- ESF bus undervoltage (train dependent - undervoltage on bus A1 starts the “A” train AFW pump; undervoltage on bus A2 starts the “B” train pump), and
- Trip of all main feed pumps.

(Note: Automatic AFW actuation by the ATWS mitigation system actuation circuitry is not listed here because that actuation signal is not generated by the RPS.) The above list indicates that the AFW system is actuated when the MFW system is not available or is not maintaining a sufficient heat sink, and to provide a safety-grade source of water for heat sink maintenance during an accident. The actuation signals are summarized in Table 12.3-1.

12.3.7.2 Auxiliary Feedwater Actuation Functions

An actuation signal to the “A” train (steam-driven) AFW pump opens all four steam supply valves (one from each main steam line) to the pump turbine and opens the turbine trip and throttle valve. An actuation signal to the “B” train (diesel-driven) pump starts the diesel engine and unisolates the service water line which provides cooling for several engine and pump heat loads. Any actuation signal to either AFW train closes all isolation valves in the steam generator blowdown and sampling lines.

12.3.8 Summary

The reactor protection system acts to limit the consequences of postulated accidents by actuating engineered safety features. These systems and components are actuated to place the plant in the most stable, safe shutdown condition possible following an accident. The ESF functions discussed in this section are safety injection actuation, containment spray actuation, containment isolation, steam line isolation, feedwater isolation, and AFW actuation.

TABLE 12.3-1
SUMMARY OF ENGINEERED SAFETY FEATURES ACTUATION SIGNALS

Signal	Coincidence	Setpoint	Interlocks	Accident/Condition
Safety Injection Actuation				
Low Pressurizer Pressure	2/3	1807 psig	Manual block; block enabled when pressurizer pressure < 1915 psig (P-11)	Loss-of-coolant accident (LOCA)
High Differential Pressure Between Steam lines	Any steam line 100 psi lower than at least two of the remaining three steam lines	100 psi ΔP	No Interlocks	Steam line break (SLB) upstream of the main steam line isolation valves (MSIVs)
High Steam Flow COINCIDENT WITH Low Steam Pressure OR Low-Low T_{avg}	1/2 flows on 2/4 steam lines 2/4 steam lines 2/4 RCS loops	Setpoint varies with turbine load (impulse pressure) 600 psig (Rate sensitive) 553°F	Manual block; block enabled when T_{avg} < 553°F (P-12)	SLB downstream of the MSIVs (common to all steam generators)
High Containment Pressure	2/3	3.5 psig	No Interlocks	High energy line break inside containment (LOCA or secondary pipe break)
Manual	1/2 actuation switches on main control board		No Interlocks	Operator backup to automatic actuation

TABLE 12.3-1 (cont'd)
SUMMARY OF ENGINEERED SAFETY FEATURES ACTUATION SIGNALS

Signal	Coincidence	Setpoint	Interlocks	Accident/Condition
Containment Spray Actuation				
High-High Containment Pressure	2/4	30 psig	No Interlocks	Large high energy line break inside containment (LOCA or secondary pipe break)
Manual	Simultaneous 2/2 actuation switches on main control board		No Interlocks	Operator backup to automatic actuation
Containment Isolation Phase A				
Any Safety Injection Actuation	Refer to Safety Injection Actuation portion of this table.			
Manual	1/2 actuation switches on main control board		No Interlocks	Operator backup to automatic actuation
Containment Isolation Phase B				
High-High Containment Pressure	2/4	30 psig	No Interlocks	Large high energy line break inside containment (LOCA or secondary pipe break)
Manual	Actuated with manual actuation of containment spray		No Interlocks	Operator backup to automatic actuation

TABLE 12.3-1 (cont'd)
SUMMARY OF ENGINEERED SAFETY FEATURES ACTUATION SIGNALS

Signal	Coincidence	Setpoint	Interlocks	Accident/Condition
Steam Line Isolation				
High-High containment pressure	2/4	30 psig	No Interlocks	Large high energy line break inside containment (LOCA or secondary pipe break)
High Steam Flow COINCIDENT WITH Low Steam Pressure OR Low-Low T_{avg}	1/2 flows on 2/4 steam lines 2/4 steam lines 2/4 RCS loops	Setpoint varies with turbine load (impulse pressure) 600 psig 553°F	No interlocks	SLB downstream of the MSIVs (common to all steam generators)
Feedwater Isolation				
Low T_{avg} COINCIDENT WITH Reactor Trip	2/4 RCS loops	564°F	P-4	Overcooling of reactor coolant following a reactor trip
High SG Water Level	2/3 levels on 1/4 SGs	69%	No Interlocks	SG overfill
Any Safety Injection Actuation	Refer to Safety Injection Actuation portion of this table.			
Auxiliary Feedwater Actuation				
Low-Low SG Water Level	2/3 levels on 1/4 SGs	11.5%	Can be defeated at RPS cabinets	Loss of heat sink
Trip of All Main Feed Pumps	2/2		Can be defeated using switches on main control board	Loss of heat sink
ESF Bus Undervoltage	1/2 taken twice on either ESF bus	2560 V with 1.1-sec delay	No Interlocks	Need for decay heat removal without offsite power
Any Safety Injection Actuation	Refer to Safety Injection Actuation portion of this table.			

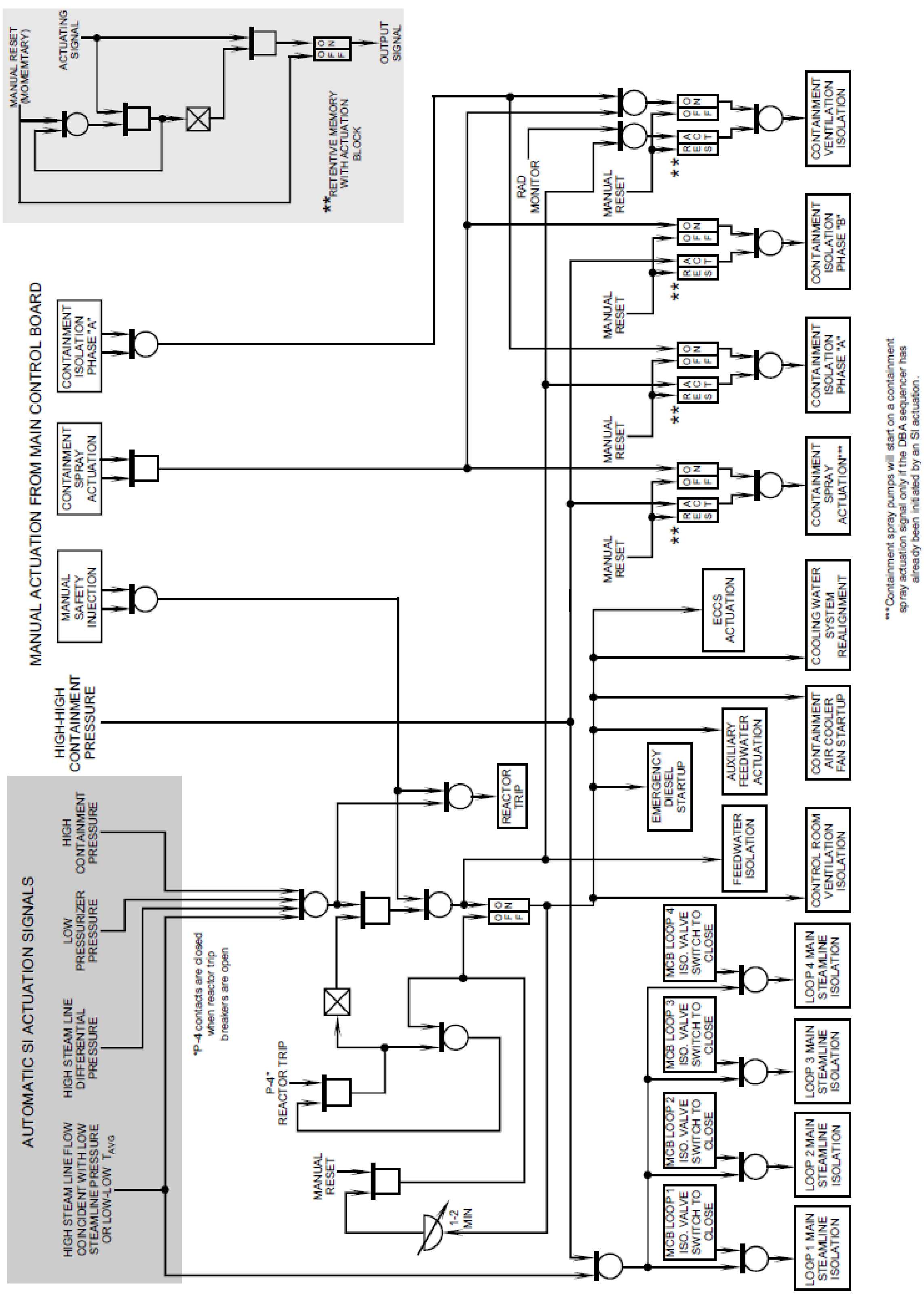


Figure 12.3-1 Engineered Safety Features Actuation Logic

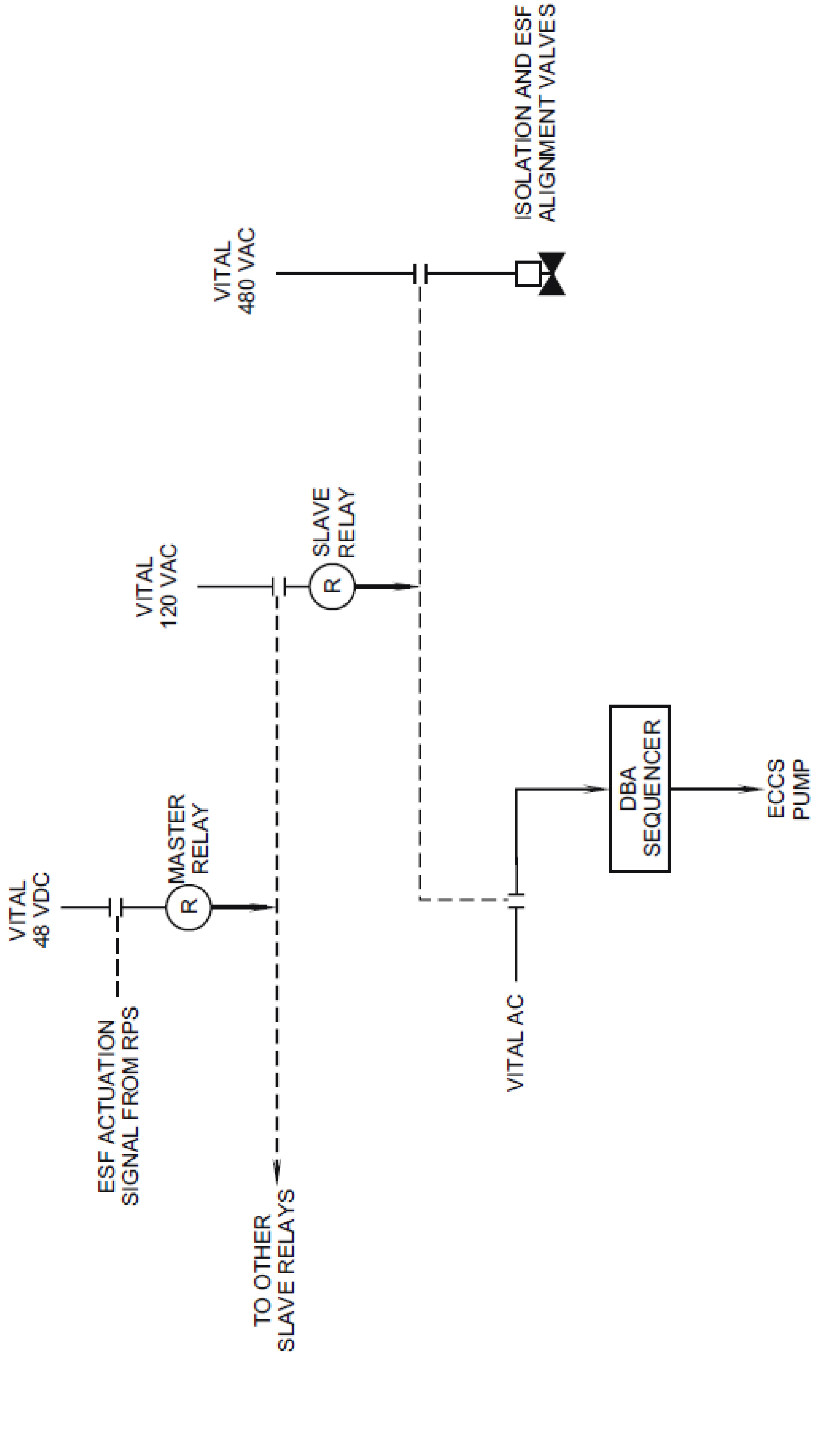


Figure 12.3-2 ESF Actuation Output Relay Operation

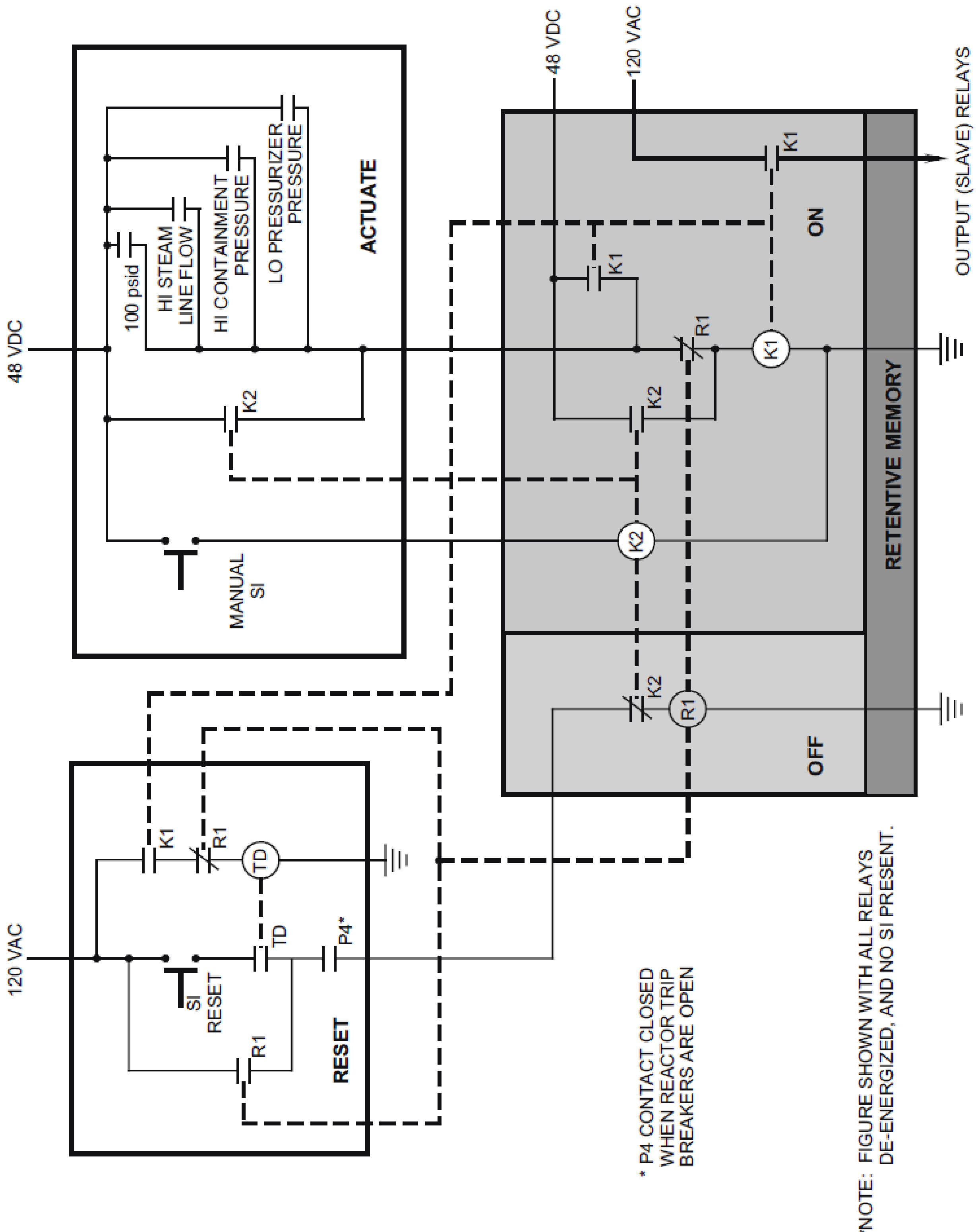


Figure 12.3-3 Safety Injection Actuation Retentive Memory and Reset Circuit

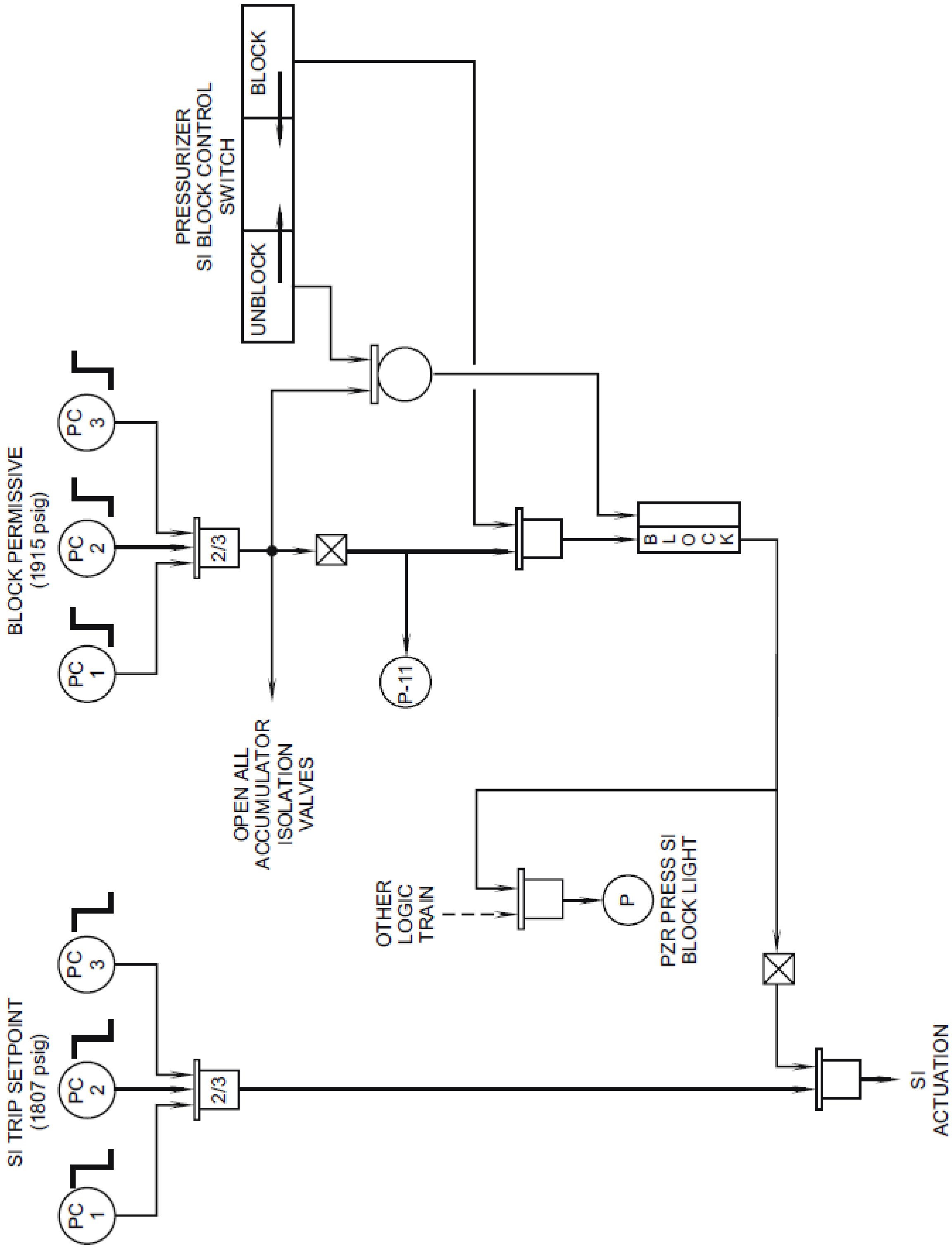
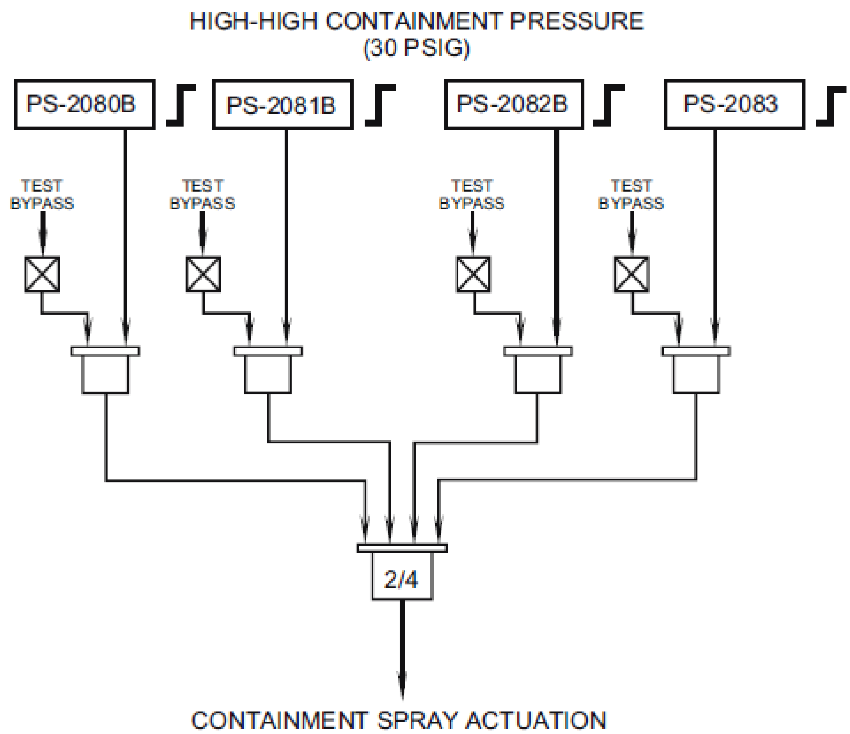


Figure 12.3-4 Low Pressurizer Pressure SI Actuation Logic



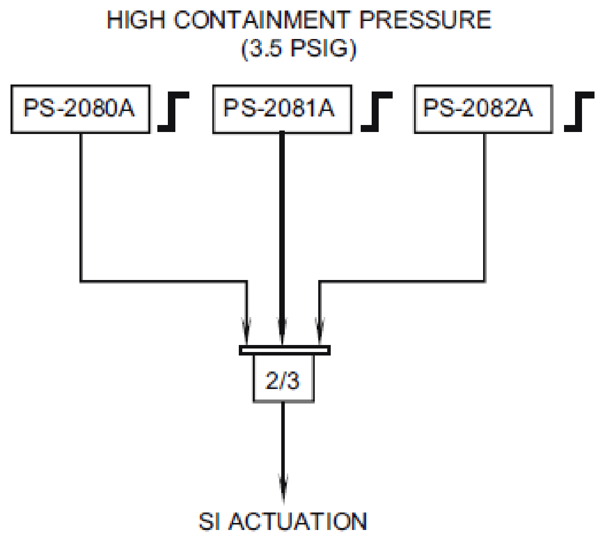


Figure 12.3-5 Containment Pressure ESF Actuation Logic

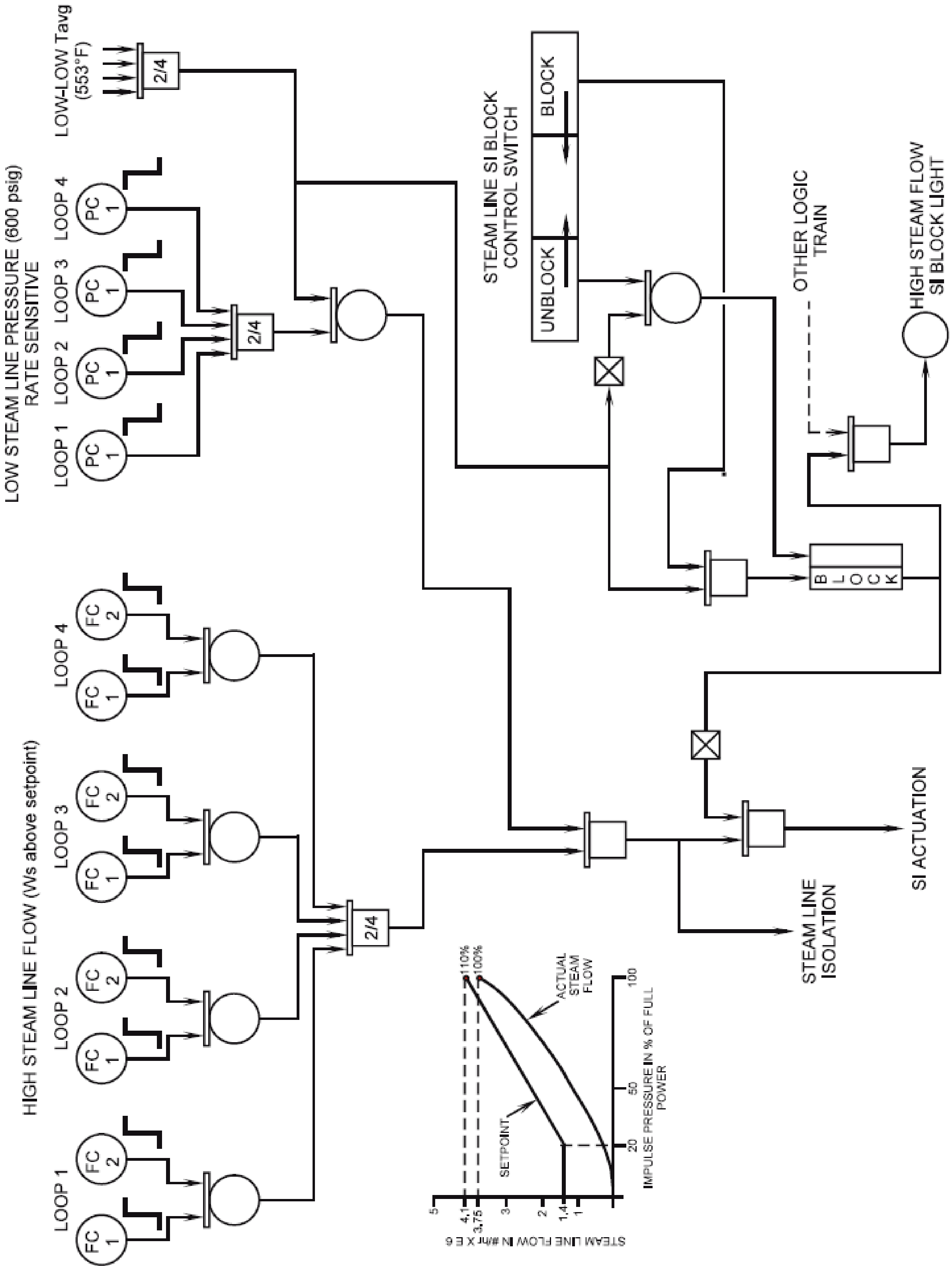


Figure 12.3-6 High Steam Line Flow ESF Actuation Logic

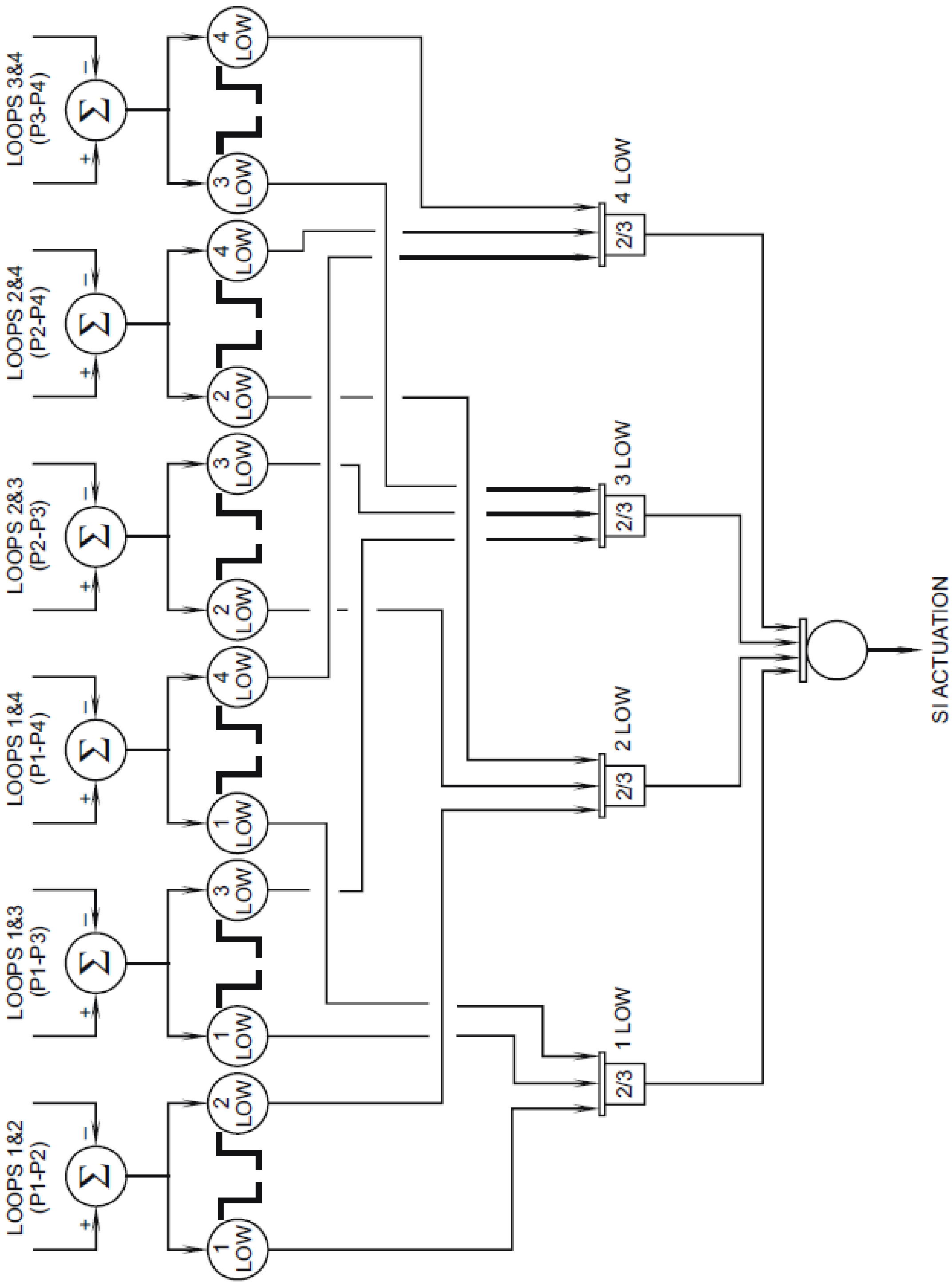


Figure 12.3-7 High Steam Line Differential Pressure SI Actuation Logic