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10.3 ENGINEERED SAFETY FEATURES ACTUATION SYSTEM

Learning Objectives:

1. State the purposes of the engineered safety features actuation systems (ESFAS).
2. List the inputs, actuation systems, and examples of components that are actuated by the ESFAS.
3. Explain the ESFAS logic.
4. Describe the sequence of events (flow path), beginning at the sensor up to and including the start of an ESF component, which occurs when an accident condition is sensed.
5. Explain how the ESF actuation system(s) is/are designed with redundancy.
6. Explain how ESF systems are bypassed during a normal plant shutdown.
7. Explain how the operator can gain control (override) of an ESF component during an accident.

10.3.1 Introduction

The purpose of the ESFAS is to sense accident related parameters and to actuate equipment that will mitigate the consequences of the accidents. Included in this broad statement is the actuation of equipment that removes core decay heat, provides for long term core cooling, terminates steam line breaks, and protects the containment building fission product barrier.

The ESFAS receives inputs from:

1. Pressurizer pressure,
2. Containment pressure,
3. Containment radiation,
4. Steam generator pressure,
5. Steam generator level,
6. 4160 Vac ESF bus voltage, and
7. Refueling water tank (RWT) level.

The first four input parameters can be used to signal that a loss of coolant accident or steam line break has occurred. The steam generator level input actuates the auxiliary feedwater system (AFW). The 4160 Vac ESF bus voltage input is used to sequence loads onto the diesel generator during accident conditions. Finally, the RWT level input is used to switch the emergency core cooling equipment to the long term core cooling mode of operation.

The input signals are used to actuate eight separate ESF actuation systems as listed below:

1. Safety injection actuation signal (SIAS),
2. Containment spray actuation signal (CSAS),
3. Containment isolation signal (CIS),
4. Recirculation actuation signal (RAS),
5. Containment radiation signal (CRS),

6. Steam generator isolation signal (SGIS),
7. Auxiliary feedwater actuation signal (AFAS), and
8. EDG Sequencing Signal.

10.3.2 System Description

The ESFAS consists of four sensor subsystems that monitor redundant and independent process measurements and generate trip signals when the process variable reaches an unsatisfactory level (set point). Table 10.3-1 lists the setpoints for the various ESFAS parameters. Each subsystem receives one pressurizer pressure input, one containment radiation input, two steam generator pressure inputs (one for each steam generator), two steam generator level inputs (one for each steam generator), one RWT level input, one bus under voltage input, and three containment building pressure inputs.

Each input is monitored by one or, in some cases, two bistables. The bistables provide a trip signal when the input reaches a preset level. When tripped, the bistables provide logic outputs to the actuation subsystems.

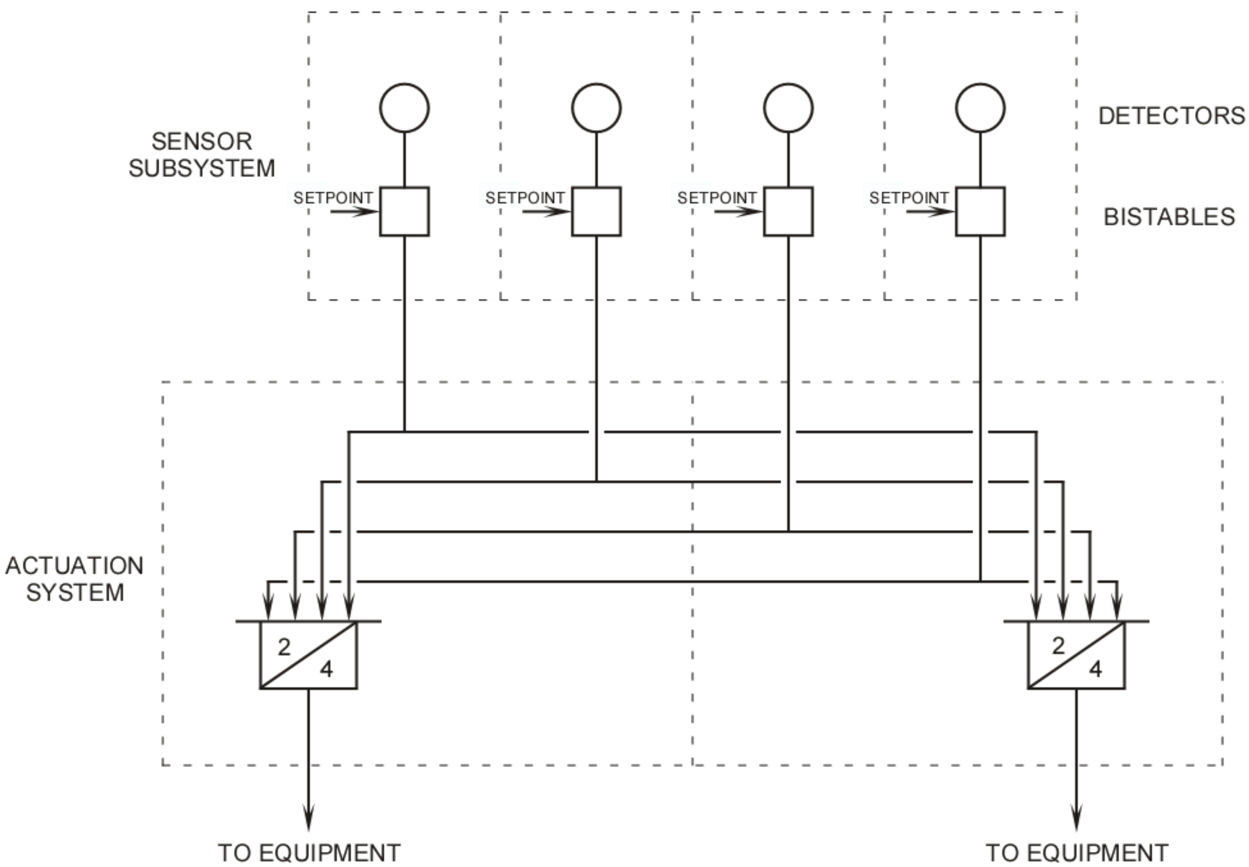

Figure 10.3-1 ESF Organization

The two redundant and independent actuation subsystems monitor the sensor subsystem bistables for trip conditions. If the proper coincidence logic exists, the ESF equipment will be actuated by the actuation subsystems. Figure 10.3-1 shows the general layout of the ESFAS system. As shown in the drawing, the input of the ESF parameter is supplied by a detector to a bistable. The bistable determines if the

parameter has exceeded the allowable value and sends an output to the actuation subsystems.

In the actuation subsystem, a determination of proper logic is made. If at least two of the four detectors (as determined by bistable output) have sensed a need for ESF actuation, then each actuation subassembly will actuate ESF equipment. One actuation subassembly activates train “A” equipment, and the other subassembly actuates train “B” equipment.

To illustrate the operation of the sensor and actuation subsystems, assume that the four detectors shown on Figure 10.3-1 are pressurizer pressure detectors. When a loss of coolant accident occurs, pressurizer pressure decreases. When pressure drops to the SIAS set point (1740 psia), the bistables in the sensor subassemblies will sense that an accident is taking place. The bistables will send a signal to the redundant actuation subassemblies. When the actuation subassemblies sense that at least two of the four bistables have actuated, the actuation subassemblies will actuate the ESF equipment. A typical component that is actuated by the SIAS is a high pressure safety injection (HPSI) pump. One of the actuation subsystems (train A) will actuate the 11 HPSI pump, and the redundant actuation subsystem (train B) will actuate the 13 HPSI pump.

The sensor subsystems bistables turn off (de-energize) when an actuation set point is reached. The logic modules in the actuation subsystems turn on (energize) actuating relays when the proper two-out-of-four logic is sensed. The turn off-turn on characteristic of the bistables affects the operation of the systems when power is lost. If power is lost to a sensor subsystem, all of the bistables in the subsystem will de-energize. This will result in one input to each of the actuation subsystems. Since the subsystems require a two-out-of-four logic, no ESF equipment will actuate. If power is lost to an actuation subsystem, all ESF actuation signals to the equipment in one train would be lost; however, the redundant train equipment would be available for plant protection. In addition, the operator would be able to manually actuate ESF equipment from its normal control station.

10.3.3 Detailed Description

10.3.3.1 Safety Injection Actuation Signal (SIAS)

The SIAS initiates operation of equipment that is necessary for core cooling and to ensure adequate shutdown of the reactor in the event of a LOCA, a main steam line break, or a main feedwater line break inside of the containment. In order to provide protection for these accidents, the SIAS monitors pressurizer and containment building pressures.

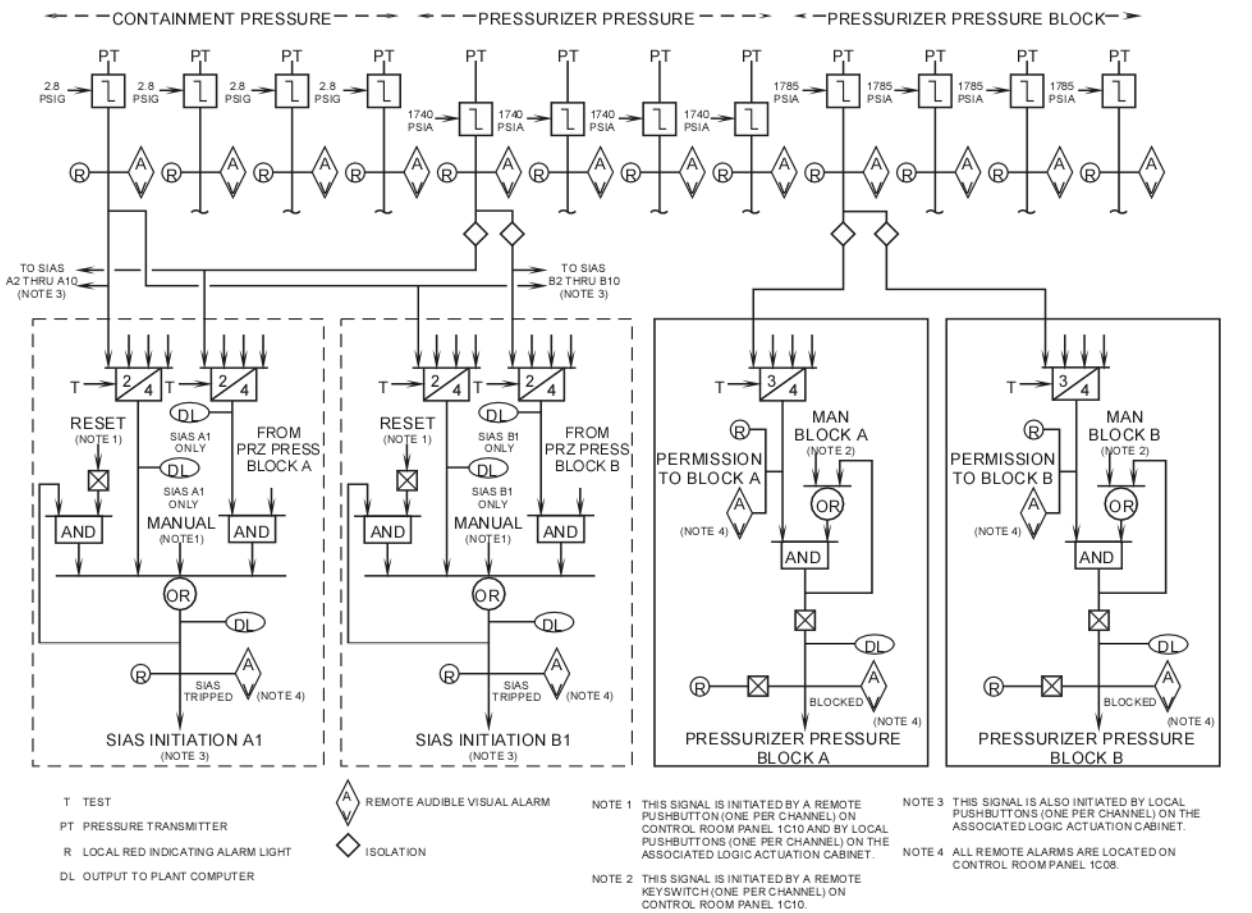

Figure 10.3-2 Safety Injection Actuation Signal Logic

Each of the four pressurizer pressure transmitter inputs (Figure 10.3-2) provides a signal to the Reactor Protection System (RPS) and the ESF actuation logic. In the ESF actuation logic, the pressurizer pressure signal is routed to two bistables. The first of these bistables compares the detector's signal with a set point of 1740 psia and is used to initiate the SIAS. The second bistable compares the detector's output with a set point of 1785 psia. The actuation signal flow path will be described first.

From the 1740 psia bistable, the signals are sent to the redundant actuation subsystems where the two-out-of-four logic is sensed. The output of the two-out-of-four logic circuits is routed to the SIAS initiation AND gate where it is combined with the pressurizer pressure block logic. The pressurizer pressure block must not be initiated for the signal to pass through the SIAS initiation AND gate. From the output of the SIAS initiation AND gate, the low pressurizer pressure signal is sent to the SIAS initiation OR gate where it is combined with the high containment building pressure signal. If either two-out-of-four low pressurizer pressure signals or two-out-of-four high containment building pressure signals are sensed, a SIAS signal will be generated. Once a SIAS signal is generated, it is sealed in by a loop from the output of the SIAS OR gate to its input via the SIAS reset circuitry.

The containment building pressure SIAS input is relatively simple in comparison to the pressurizer pressure input signal. Each of the four containment building pressure transmitters supplies a signal to the RPS and the ESF actuation logic. In the ESF logic, the signal is routed to a bistable where it is compared to a 2.8 psig set point. From that

bistable, the signal is sent to the redundant actuation subsystems where the two-out-of-four logic is sensed. The output of the two-out-of-four logic circuit is transmitted to the SIAS initiation OR gate. Again, if either two-out-of-four low pressurizer pressure signals or two-out-of-four high containment building pressure signals are sensed, an SIAS signal will be generated.

In addition to the pressurizer pressure and the containment building pressure inputs into the SIAS initiation OR gate, the OR gate also receives an input from a manual push-button. The manual push-button is installed to allow the operator to manually initiate SIAS if plant conditions warrant (pressurizer level is decreasing with all three charging pumps running, which is indicative of a LOCA and the operator needs to add inventory to the RCS) or if a failure of the automatic initiation circuitry occurs.

As previously discussed, once an SIAS signal is generated, it is sealed in. If the parameter(s) that caused the generation of the signal return to an untripped value (pressurizer pressure > 1740 psia or containment building pressure < 2.8 psig), the SIAS signal can be reset by depressing the SIAS reset push-button. When this push-button is actuated, the last of the remaining inputs to the SIAS initiation OR gate is removed. The equipment that received the SIAS signal can now be controlled normally.

The SIAS signal operates equipment to provide emergency core cooling, adds boric acid to the RCS, isolates RCS and containment penetrations, realigns cooling water systems, places the emergency diesels in a standby condition, and opens the containment spray header isolation valves.

The following is a list of SIAS actuated components:

1. Emergency Core Cooling Systems
   a. Starts two HPSI pumps,
   b. Opens eight (8) HPSI injection valves,
   c. Opens the HPSI auxiliary header isolation valve (if closed),
   d. Opens HPSI recirculation valves (if closed),
   e. Starts two LPSI pumps,
   f. Opens four LPSI injection valves, and
   g. Opens four SIT outlet isolation valves (if closed).
   h. Starts two Containment Spray Pumps

2. Boric Acid Addition
   a. Starts two boric acid pumps,
   b. Starts three charging pumps,
   c. Opens the gravity feed valves,
   d. Opens the boric acid addition motor-operated valve,
   e. Boric acid pump recirculation valves close and
   f. VCT outlet valves close.

3. RCS and containment penetrations
   a. Closes the letdown loop isolation valves,
   b. Closes the RCP controlled bleed off valves,
   c. Closes the RCDT containment isolation valve, and
   d. Closes the RCS sample valves.

4. Cooling water system realignments
    a. Starts two service water pumps,
    b. Isolates service water to the turbine building,
    c. Opens service water outlets (orifice bypasses) from the containment building cooling fans.
    d. Starts two component cooling water pumps,
    e. Opens the CCW supply to the shutdown cooling heat exchangers, and
    f. Starts two salt water pumps.
5. Containment Cooling Fans start in slow speed.
6. Emergency diesel generators are started.

When the plant is being cooled down, pressurizer pressure is decreased. To prevent unnecessary actuation of SIAS during a plant cool down, the low pressurizer pressure can be bypassed as shown in Figure 10.3-2. The pressurizer pressure transmitter supplies an input to a bistable with a set point of 1785 psia. From the bistable, the signal is routed to a three out of four logic circuit. The output of the three out of four logic circuit is supplied to the pressurizer pressure block AND gate, where it is combined with a key operated block switch. As the plant is intentionally depressurized, an alarm is received when at least three out of the four pressurizer pressure transmitters sense a pressure of less than 1785 psia. A key operated block switch is placed in the bypass position, satisfying both input conditions to the pressurizer pressure block AND gate. The output of pressurizer pressure block AND gate is sealed in, and the key may be removed from the block switch if desired. It should be noted that when pressurizer pressure exceeds 1785 psia, the three out of four input to the pressurizer pressure block AND gate will be lost, and the pressurizer pressure block will automatically be removed.

10.3.3.2 Containment Isolation Signal (CIS)

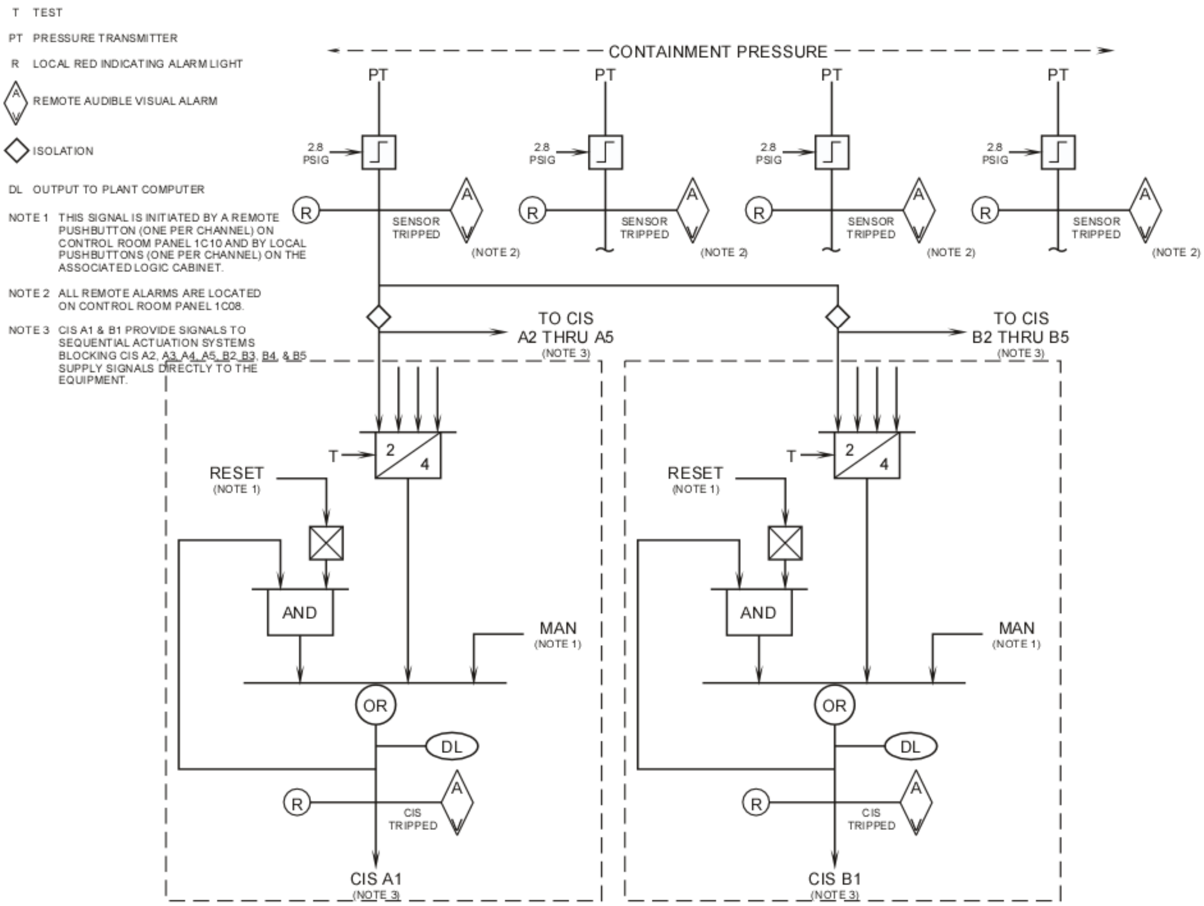

Figure 10.3-3 Containment Isolation Actuation Signal Logic

The isolation of containment during a loss of coolant accident minimizes the leakage paths for fission products through non-safety related penetrations. The containment isolation signal (CIS) is generated by high containment building pressure.

As shown in Figure 10.3-3, four independent containment building pressure transmitters supply the CIS with inputs. Each transmitter supplies an input to a bistable in the sensor subsystem. If pressure equals or exceeds 2.8 psig, the bistable de-energizes and sends a signal to the two-out-of-four logic circuits in the actuation subassemblies. If at least two bistables de-energize, a CIS signal is generated. Once initiated, the CIS signal seals in via the CIS reset circuitry. CIS can also be manually initiated by the operator.

The CIS signal actuates the following equipment:

1. CCW is isolated to the RCPs,
2. Containment penetration room ventilation units start,
3. Containment iodine removal system is placed in service, and
4. Containment instrument air supply is isolated.
5. Isolates the containment purge system by stopping the purge supply and exhaust fans and closing the containment purge valves.

As previously discussed, once a CIS signal is generated, it is sealed in. If the parameter(s) that caused the generation of the signal return to an untripped value (containment building pressure < 2.8 psig), the CIS signal can be reset by depressing the CIS reset push-button. When this push-button is actuated, the last of the remaining inputs to the CIS initiation OR gate is removed. The equipment that received the CIS signal can now be controlled normally.

10.3.3.3 Containment Spray Actuation Signal (CSAS)

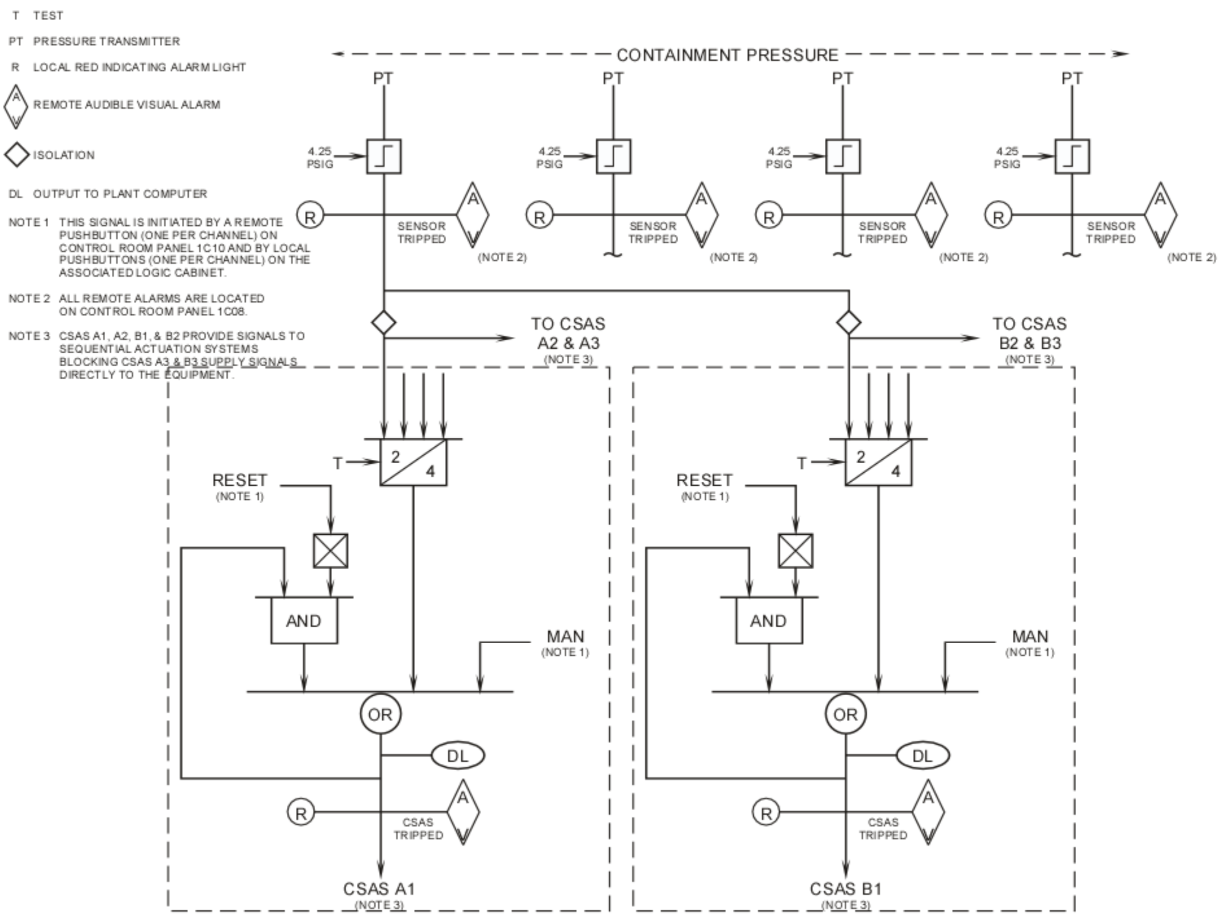

Figure 10.3-4 Containment Spray Actuation Signal Logic

Four independent containment building pressure transmitters (Figure 10.3-4) provide signal inputs to the CSAS. These pressure transmitters are separate from those used for SIAS and CIS. The actuation circuitry for CSAS is identical, with the exception of a 4.25 psig set point, to the circuitry for the CIS.

The CSAS automatically initiates operation of the equipment required to provide adequate containment cooling. Containment cooling reduces the pressure inside of the containment following an accident which minimizes the driving force for the leakage of fission products and reduces containment building stresses.

The CSAS signal actuates the following equipment:

1. Opens two containment spray header isolation valves,
2. Closes the main steam isolation valves (MSIVs) and main feedwater isolation valves (MFIVs), and

3. Trips the main feedwater pumps, the condensate booster pumps, and the heater drain pumps.

To prevent an inadvertent CSAS the containment spray pumps are started by SIAS.

10.3.3.4 Recirculation Actuation Signal (RAS)

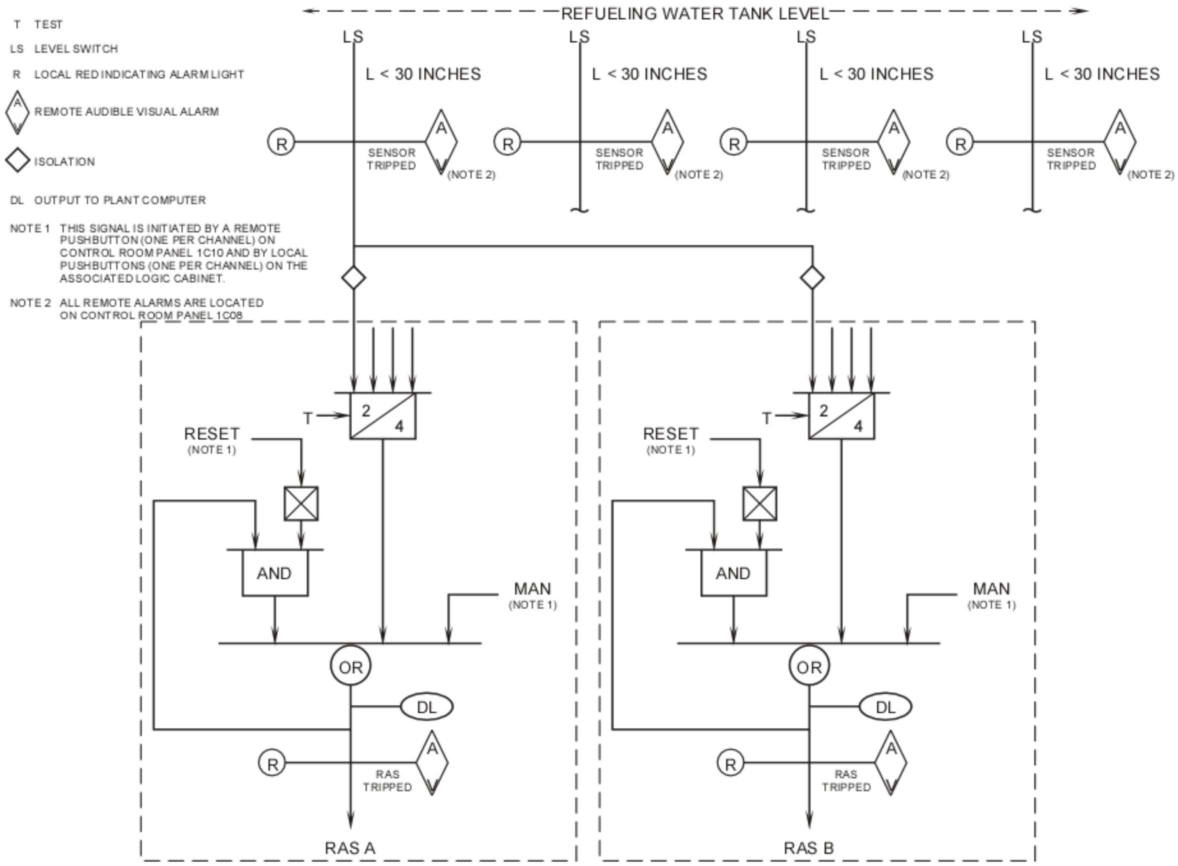

Figure 10.3-5 Recirculation Actuation Signal Logic

Four independent refueling water tank (RWT) level switches provide inputs to the RAS (Figure 10.3-5). Actuation of the RAS occurs automatically as a result of either two-out-of-four low RWT water level trip signals or from manual initiation. The operation of the circuitry is identical to the CIS circuitry.

The RAS initiates operation of the equipment necessary to provide a continuous source of water for decay heat removal and containment spray. The following list summarizes the actions that occur when a RAS is generated:

1. The containment sump suctions open,
2. The LPSI pumps are stopped,
3. The LPSI, HPSI, and containment spray pump minimum recirculation valves close, and
4. The CCW heat exchanger salt water valves open.

10.3.3.5 Containment Radiation Signal (CRS)

Four independent radiation detectors located within the containment building provide signal inputs to the CRS actuation circuitry. Actuation of CRS occurs automatically as a

result of either two-out-of-four high radiation detector channel trip signals or manual initiation.

A CRS automatically operates the equipment necessary to limit the release of fission products during refueling and maintenance periods when containment integrity is breached. The CRS isolates the containment purge system by stopping the purge supply and exhaust fans and closing the containment purge valves.

10.3.3.6 Steam Generator Isolation Signal (SGIS)

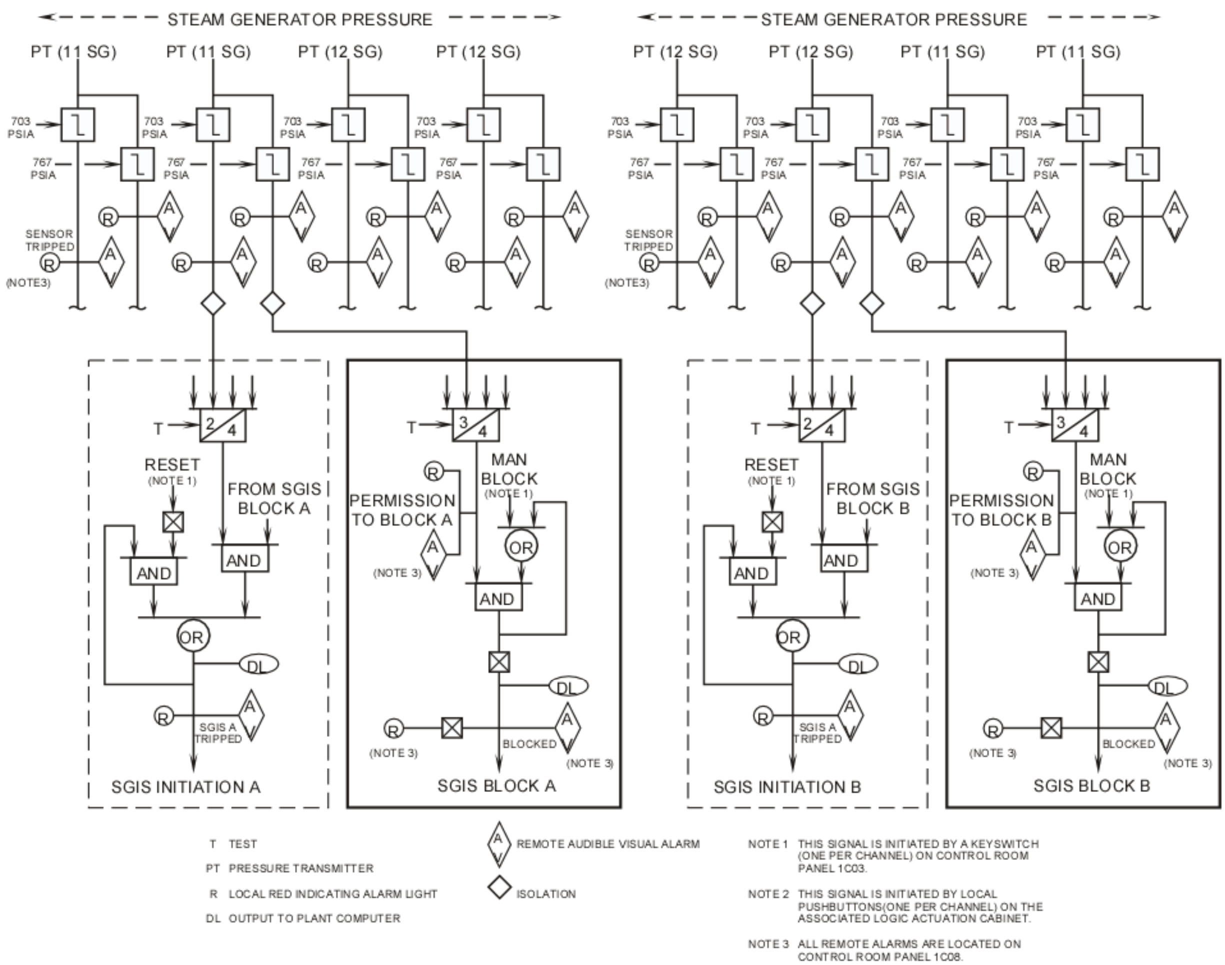

Figure 10.3-6   Steam Generator Isolation Signal Logic

Four independent steam generator pressure transmitters for each steam generator (Figure 10.3-6) provide inputs to the SGIS. Since the inputs for each steam generator are identical, only one of the steam generator inputs will be discussed. The steam generator pressure transmitter supplies an input to two bistables; a SGIS actuation bistable with a set point of 703 psia, and a SGIS block bistable with a set point of 767 psia.

From the 703 psia bistable, the signals are sent to the redundant actuation subsystems where the two-out-of-four logic is sensed. The output of the two-out-of-four logic circuits is routed to the SGIS initiation AND gate where it is combined with the steam generator pressure block logic. The steam generator pressure block must not initiated for the signal to pass through the SGIS initiation AND gate. From the output of the SGIS initiation AND gate, the low steam generator pressure signal is sent to the SGIS

initiation OR gate where it is combined with the manual push-button signal. If either two-out-of-four low steam generator pressure signals are sensed or the manual push-button is depressed, an SGIS signal will be generated. Once a SGIS signal is generated, it is sealed in by a loop from the output of the SGIS initiation OR gate to its input via the SGIS reset circuitry.

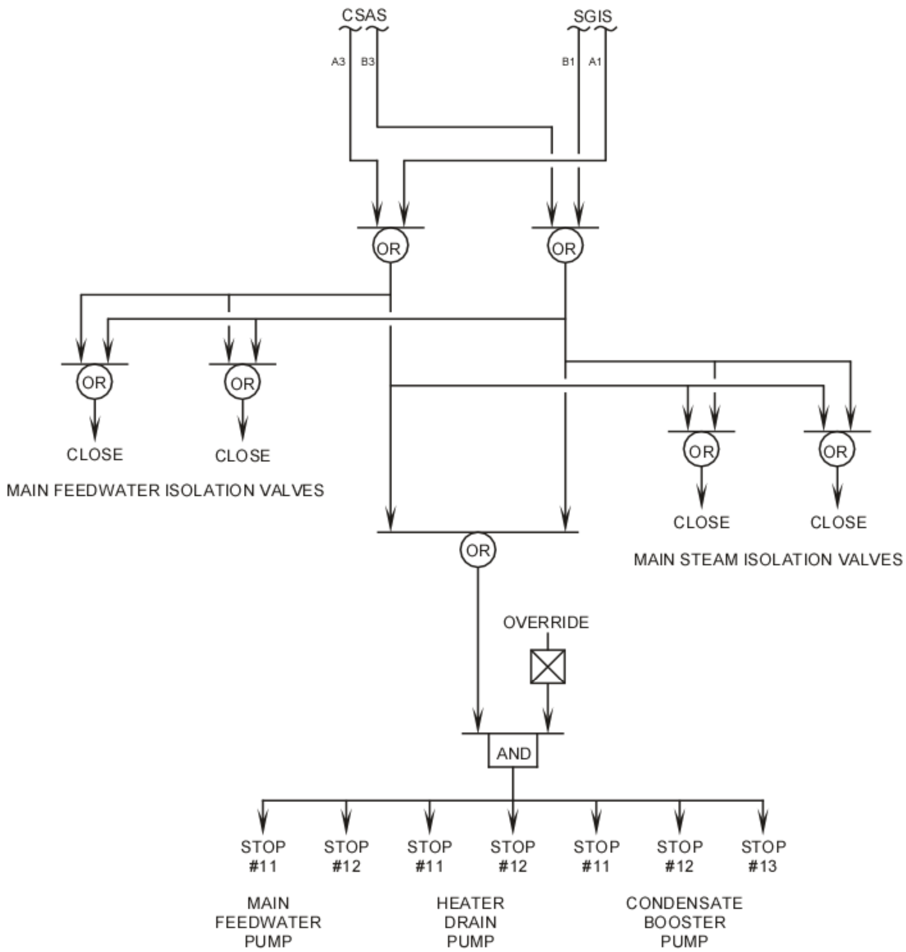

Figure 10.3-7 Steam Generator Isolation Actuation: Main Steam and Feedwater

The equipment that is operated by the SGIS and its interface with the CSAS is shown in Figure 10.3-7.

When the plant is being intentionally cooled down, steam generator pressure will decrease as RCS temperature is decreased. To prevent unnecessary actuation of SGIS during a plant cool down, a method of bypassing the low steam generator pressure condition is incorporated in the design of the ESFAS. As shown in Figure 10.3-6, the steam generator pressure transmitter supplies an input to a bistable with a set point of 767 psia. From the bistable, the signal is routed to a three out of four logic circuit. The output of the three-out-of-four logic circuit is supplied to the steam generator pressure block AND gate where it is combined with a key operated block switch. As the plant is intentionally cooled down, the operator receives an alarm when at least three out of the four steam generator pressure transmitters sense a pressure of less than 767 psia. The operator places the key operated block switch in the bypass position, and both input conditions to the steam generator pressure block AND gate are

satisfied. The output of the steam generator pressure block AND gate is sealed in, and the operator may remove the key from the block switch if desired. It should be noted that when steam generator pressure exceeds 767 psia, the three out of four input to the steam generator pressure block AND gate will be lost, and the steam generator pressure block will automatically be removed.

10.3.3.7 Diesel Generator Sequencing Signal

The diesel generator sequencing signal functions to provide an emergency source of power for the operation of the 4160 Vac distribution system through the application of load shedding and sequential reloading. The sequencing circuitry also prevents overloading of the diesel generators by the sequencing of heavy electrical loads.

The sequencing circuit is supplied with inputs that sense under voltage (UV) conditions on the 4160 Vac ESF busses. As in all ESF systems, the circuitry uses a two-out-of-four coincidence logic; however, the output of this ESF circuitry is dependent upon plant conditions.

If a loss of power occurs without a coincident SIAS signal, the sequencer automatically energizes selected essential loads at five second intervals. The selected loads include the service water pumps, the salt water pumps, and the instrument air compressors. If a loss of power and a SIAS is sensed at the same time, the load sequencing of the diesel generators will include safety related pumps such as the HPSI and LPSI pumps.

10.3.3.8 Auxiliary Feedwater Actuation System (AFAS)

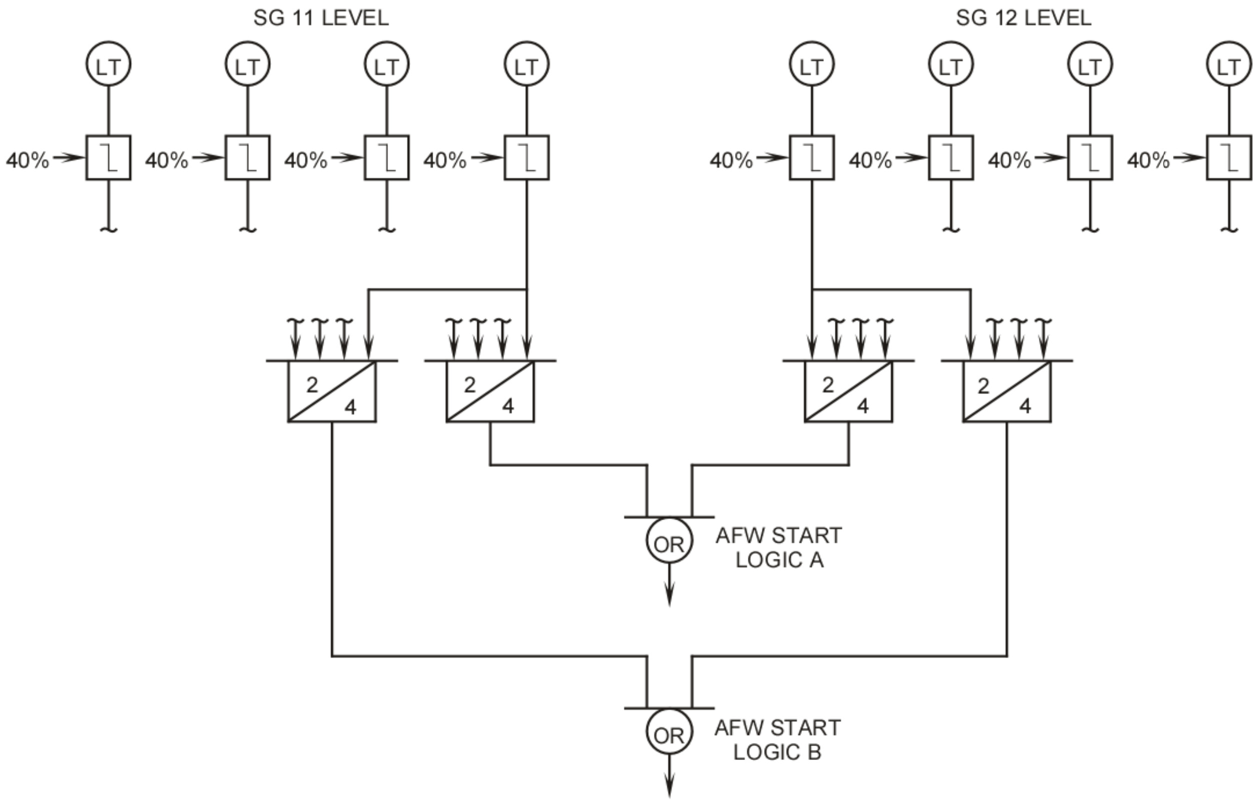

Figure 10.3-8 AFW Actuation Signal Logic

The actuation of auxiliary feedwater (AFW) by the AFAS ensures that the steam generators will be available as a RCS heat sink. The ability to transfer decay heat to the steam generators is important for anticipated operational occurrences such as a loss of main feed and for small break loss of coolant accidents.

The AFAS receives inputs from four channels of level indication from each steam generator (Figure 10.3-8). Each transmitter signal feeds a low level bistable where it is compared with a fixed set point of 40% wide range. If actual steam generator level drops to the setpoint, the bistable will trip. The output of the bistable is supplied to two two-out-of-four logics.

There are two two-out-of-four logics associated with each steam generator. Each of the logics receives four low level inputs from its associated steam generator. If at least two level transmitters sense that the steam generator level has dropped to the actuation set point, the two-out-of-four logic will have an output. The output signal from the four two-out-of-four logics enter two AFW start OR gates. The OR gates provide redundant actuation signals to start the AFW system. Each AFW start logic may be manually initiated and manually reset when level returns to set point. Figure 10.3-8 omits these features for simplicity.

10.3.3.9 Diverse Scram System (DSS)

Over the years, new safety issues have surfaced and these issues have required ESF system modifications. One such issue is the anticipated transient without a scram

(ATWS). Combustion Engineering designed plants were required to backfit a DSS to provide protection for the ATWS. Calvert Cliffs utilized the ESF narrow range pressurizer pressure input to actuate the DSS on high RCS pressure.

10.3.4 Engineered Safety Features Actuation System Design Basis

The ESFAS conforms to the provisions of the Institute of Electrical & Electronic Engineers (IEEE) 279 "Criteria for the Protection for Nuclear Power Generating Stations". Consideration was given to the following criteria:

Single Failure - No single fault in the components, modules, channels, or sensors of the ESFAS prevents engineered safety features operation. The wiring is installed so that no single fault or failure, including either an open or shorted circuit, negates minimum engineered safety features operations. Wiring for redundant circuits is protected and routed so that damage to any one path does not prevent minimum engineered safety features action. The sensors are piped so that blockage or failure of any one connection does not prevent engineered safety features operation.

Quality of components and modules - Components and modules must exhibit a quality consistent with the nuclear power plant 40 year design life objective, with minimum maintenance requirements and low failure rates.

Channel independence - Independence is provided between redundant subsystems (sensor and actuation) or channels to accomplish separation of the effect of unsafe environmental factors, reduce the likelihood of interactions between channels during maintenance operations or in the event of channel malfunction. Independence is obtained by electrical isolation, physical separation, and system repair.

Electrical isolation is provided between redundant channels, between sensor and actuation subsystems, and between the ESFAS and auxiliary equipment. Electrical isolation ensures that an electrical fault does not inhibit a protective action as a result of a redundant system.

Physical separation is maintained between redundant sensor subsystems, between sensor and actuation subsystems, and between redundant subsystems. This is accomplished by the use of separate and isolated cabinets for each of the four sensor subsystems and each of the two actuation subsystems.

With regard to system repair, the ESFAS is designed such that routine servicing and maintenance is performed without interfering with plant operation and without loss of the ESFAS function. Performance of maintenance and testing will not result in simultaneous availability of both actuation subsystems.

For further protection and reliability, the ESFAS modules are standardized and interchangeable, and have a minimum number of interconnections and interwiring. Withdrawal of or loss of power to a sensor module results in a trip signal to its associated two-out-of-four logic. Withdrawal of two sensor modules of a common actuation signal results in a trip of the associated actuation channel. Withdrawal of an actuation logic module does not result in a trip of that channel.

The ESFAS has also been designed to satisfy seismic and environmental requirements. The system is seismic Class I and is designed to withstand all simultaneous horizontal

and vertical accelerations resulting from the design basis earthquake without loss of functions. All components required to operate in a loss of coolant accident environment are tested at the expected temperature, pressure, and humidity conditions.

10.3.5 Summary

The engineered safety features actuation system is designed to monitor plant parameters and conditions, and to effect and maintain reliable and rapid safety equipment operation if any one or combination of conditions deviates from a preselected setpoint. Proper operation of the ESFAS protects the public from the accidental release of radioactive fission products in the event of a loss of coolant accident, steam line break, or feedwater line break.

TABLE 10.3-1

ESF SETPOINT SUMMARY

System	Setpoint	Bypass Setpoint
Safety Injection Actuation Signal		
Pressurizer Pressure	1740 psia	1785 psia
Containment Pressure	2.8 psig	None
Containment Isolation Signal		
Containment Pressure	2.8 psig	None
Containment Spray Actuation Signal		
Containment Pressure[1]	4.25 psig	None
Recirculation Actuation Signal		
RWT Level	30 inches	None
Steam Generator Isolation Signal		
Steam Generator Pressure[1]	703 psia	767 psia
Auxiliary Feedwater Actuation Signal		
Wide Range Steam Generator Level	40%	None

Notes:

[1]Will also close the MSIVs and MFIVs. In addition, the MFPs, heater drain pumps, and the condensate booster pumps are tripped.

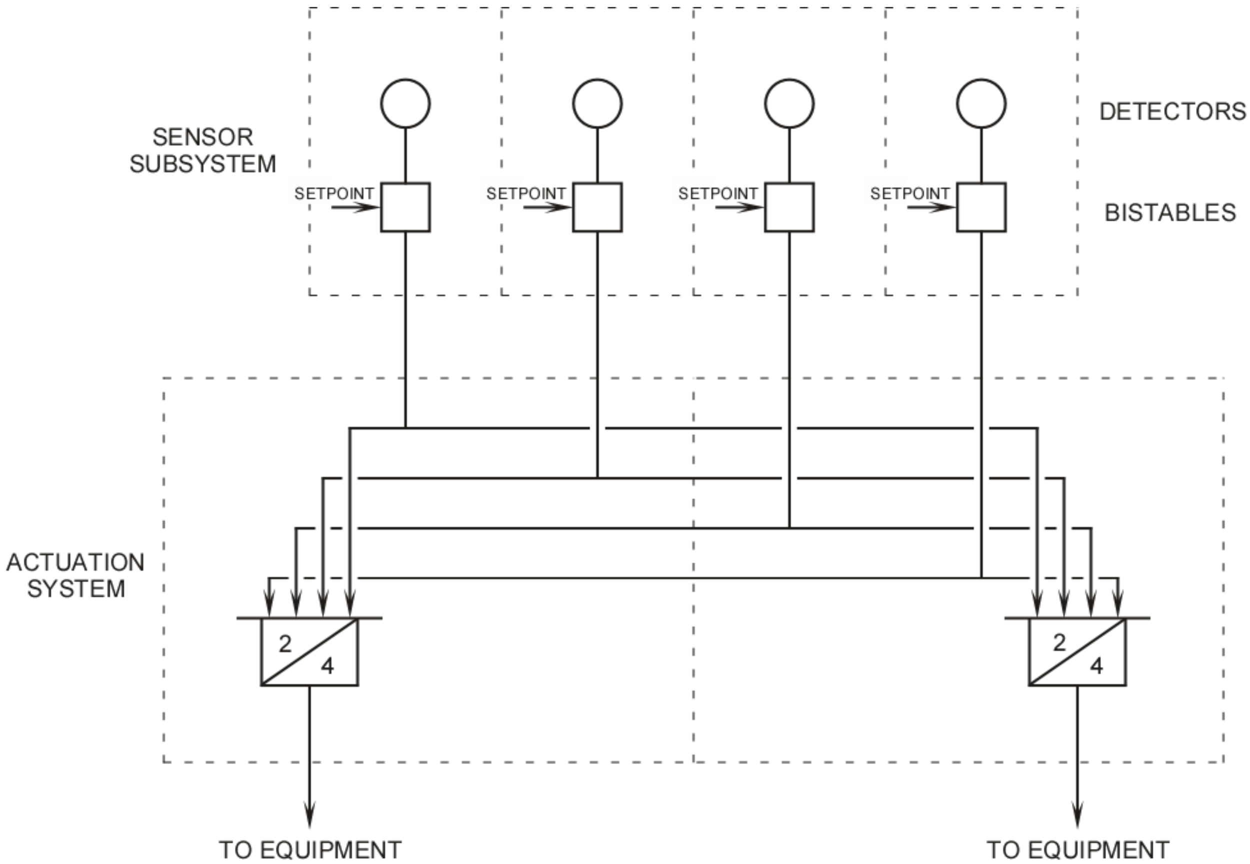

Figure 10.3-1 ESF Organization

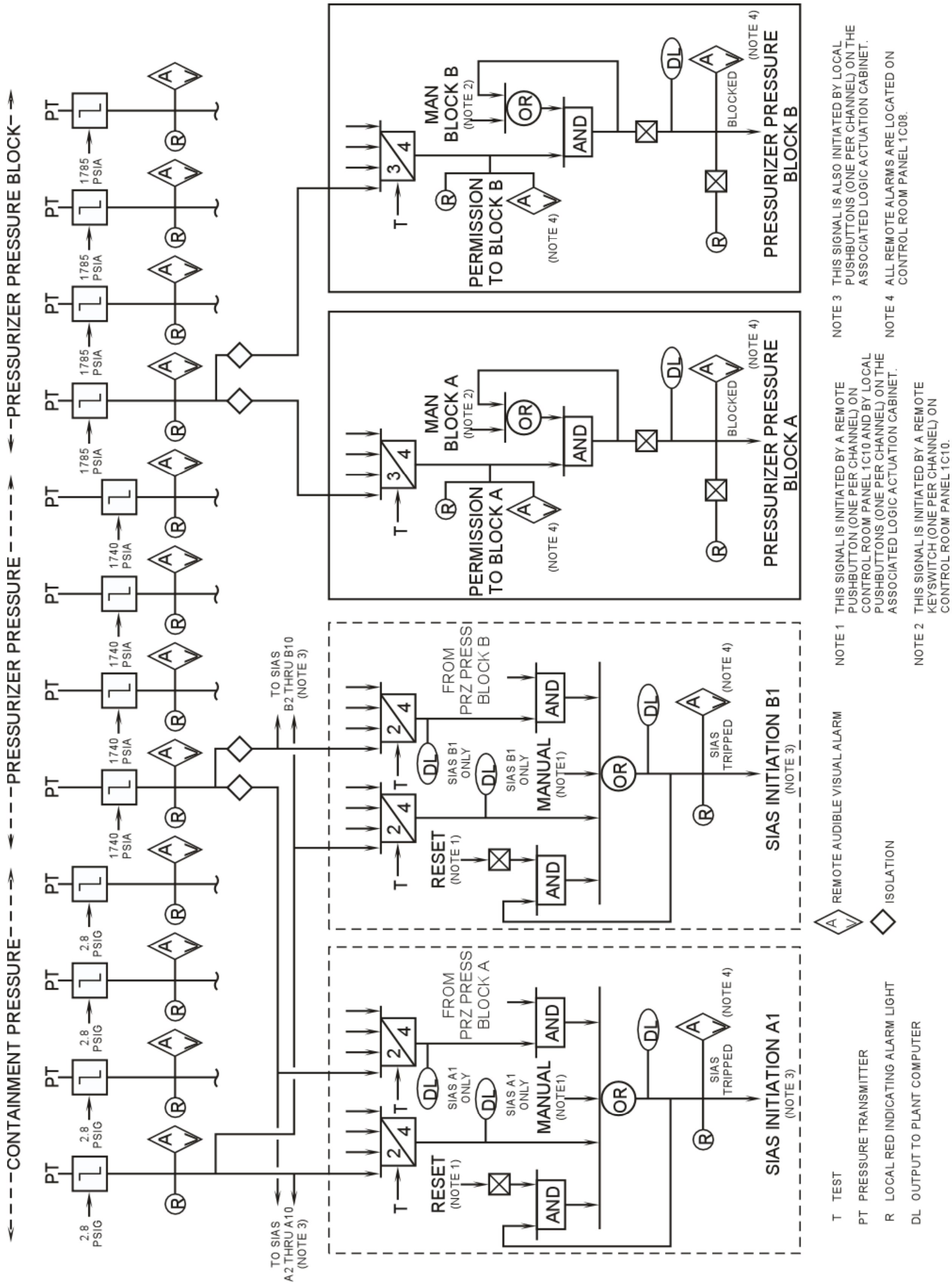

Figure 10.3-2 Safety Injection Actuation Logic

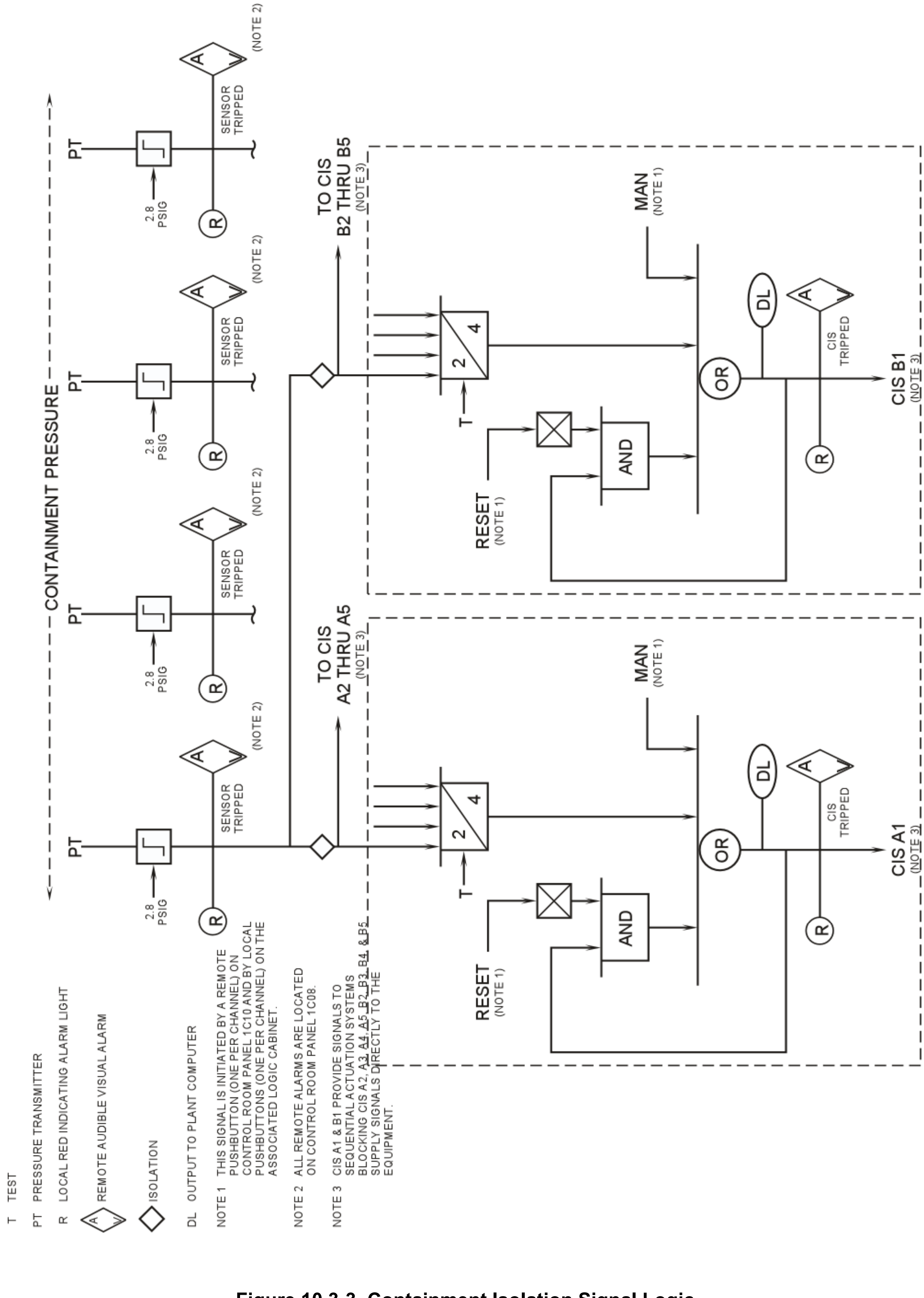

Figure 10.3-3 Containment Isolation Signal Logic

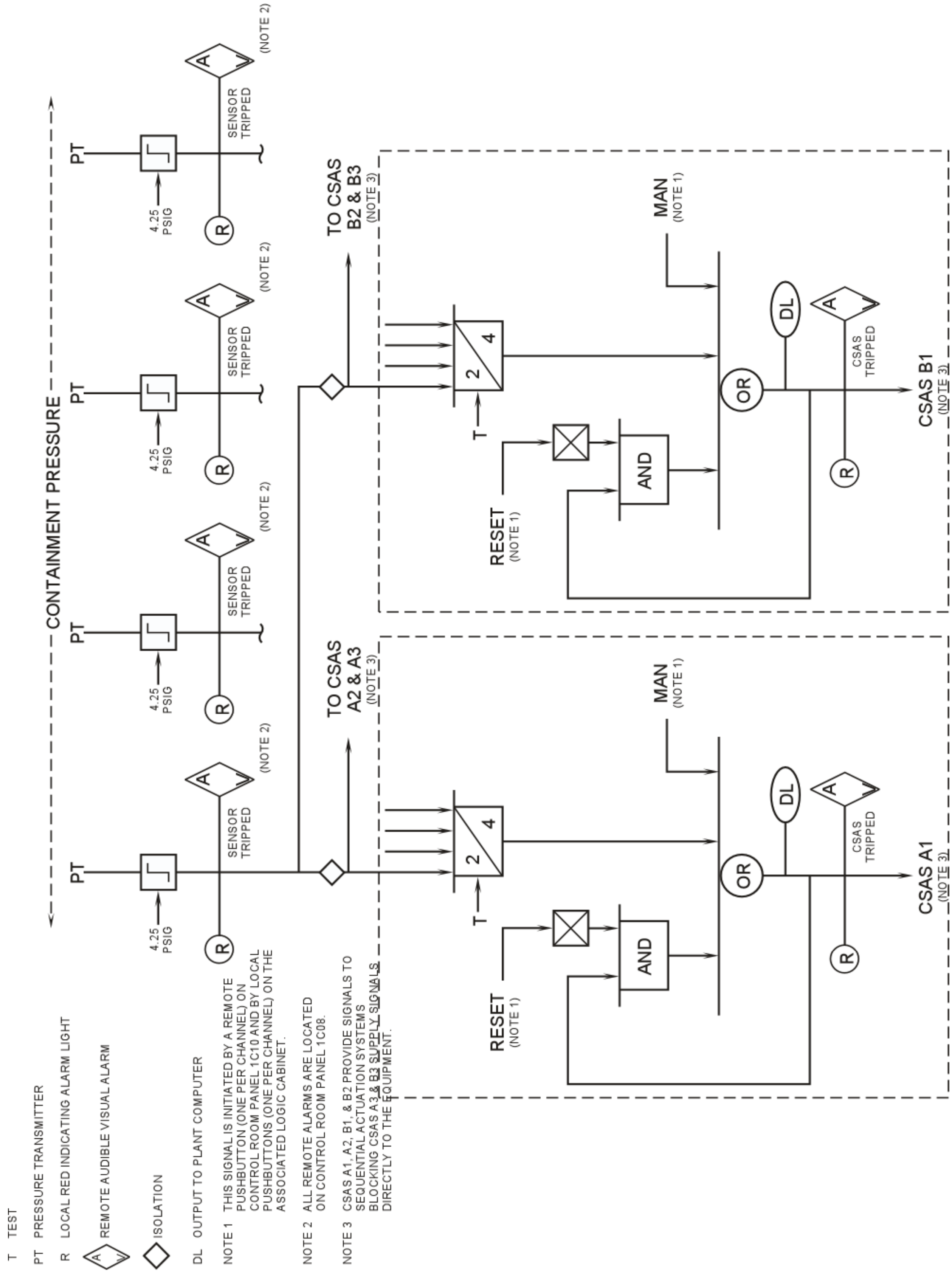

Figure 10.3-4 Containment Spray Actuation Signal

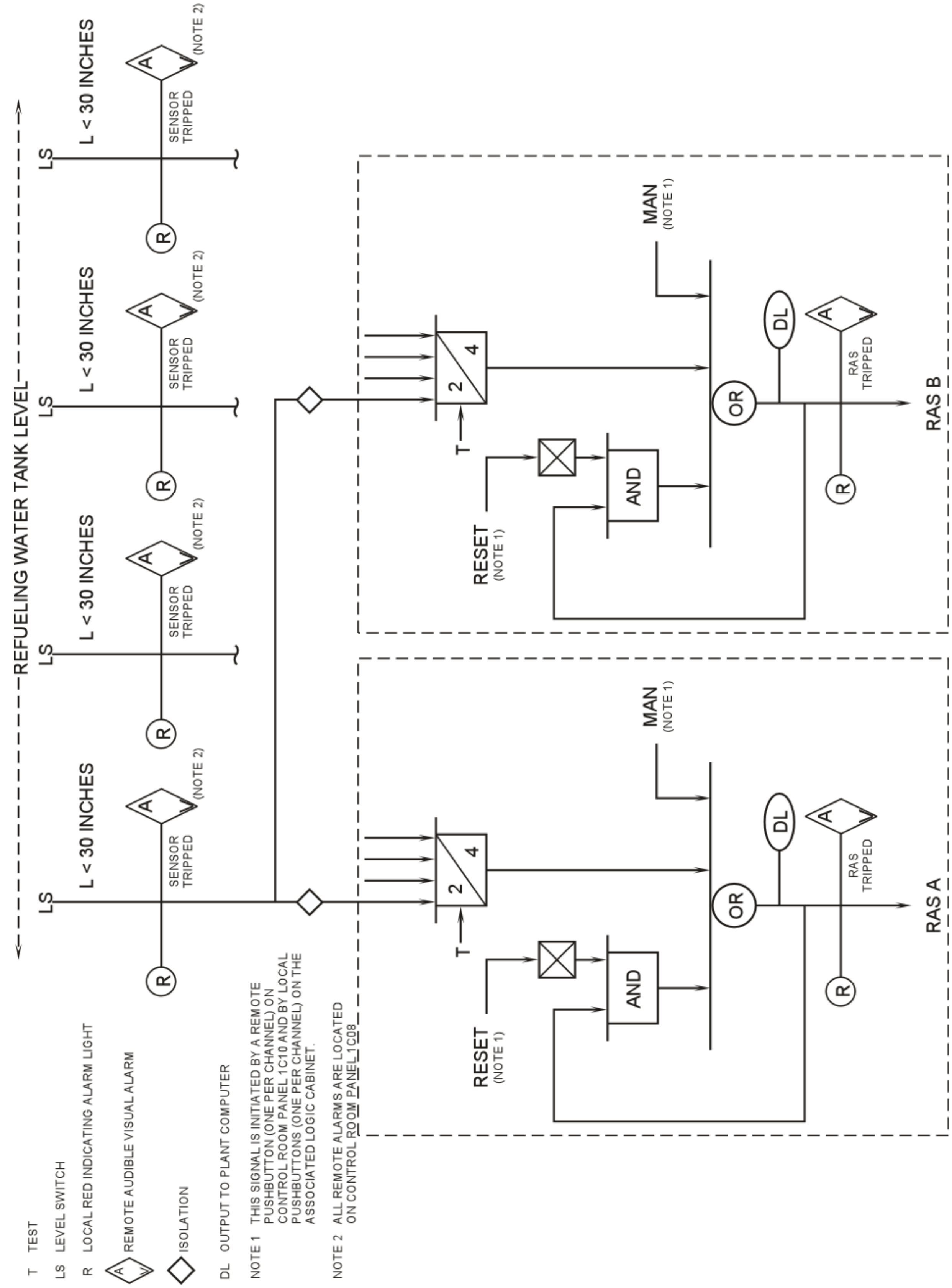

Figure 10.3-5 Recirculation Actuation Signal Logic

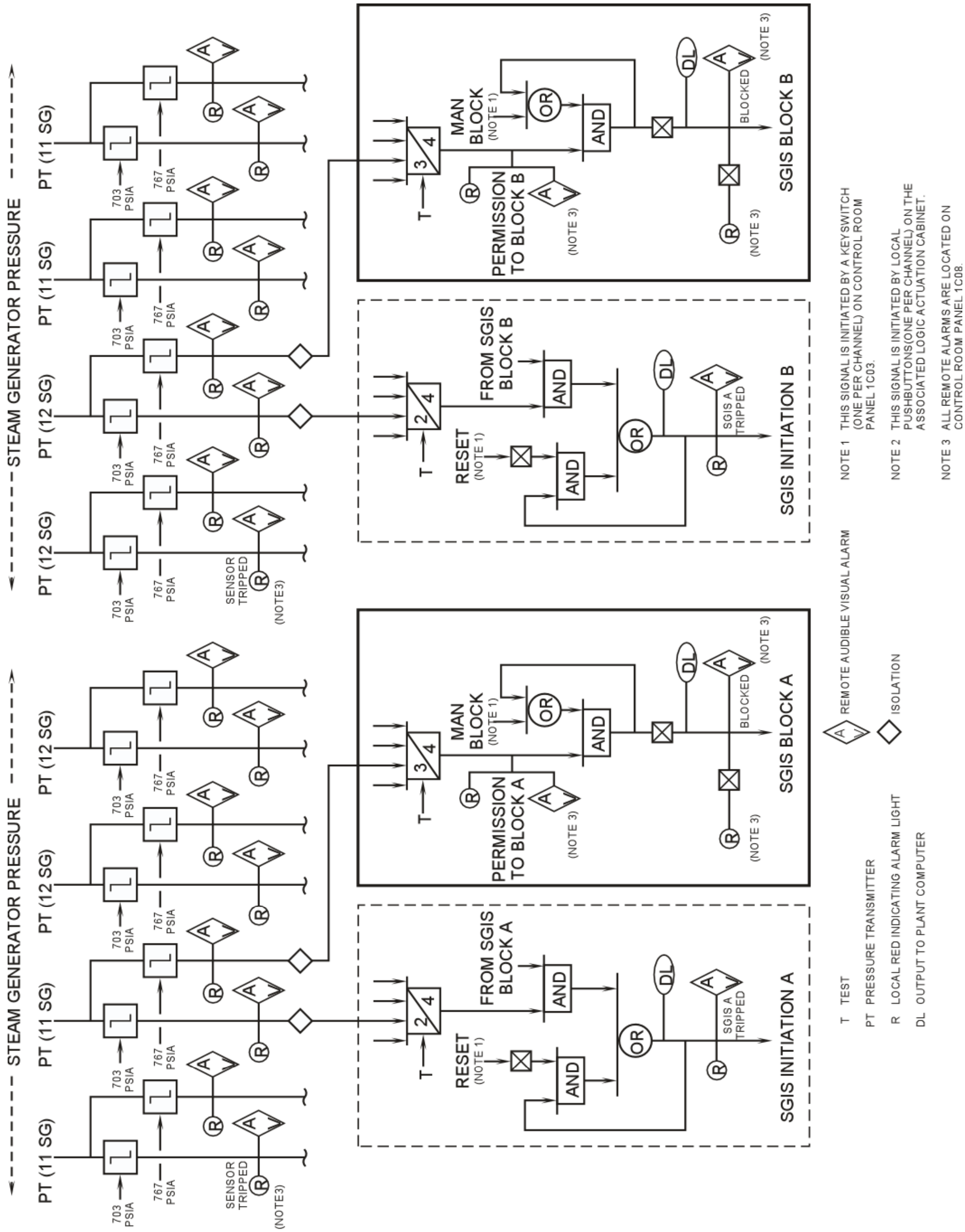

Figure 10.3-6 Steam Generator Isolation Signal Logic

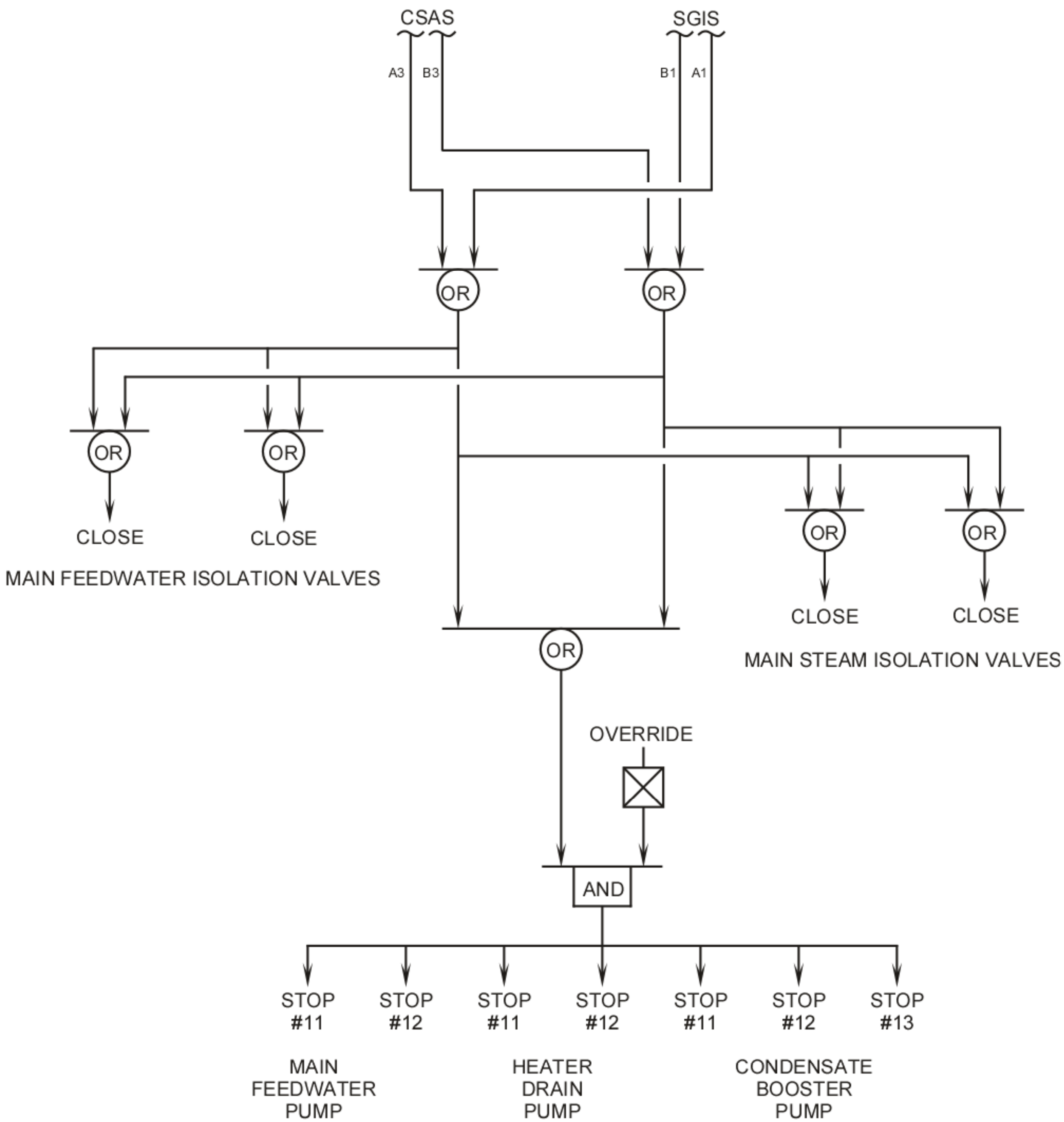

Figure 10.3-7 Steam Generator Isolation Actuation: Main Steam and Feedwater

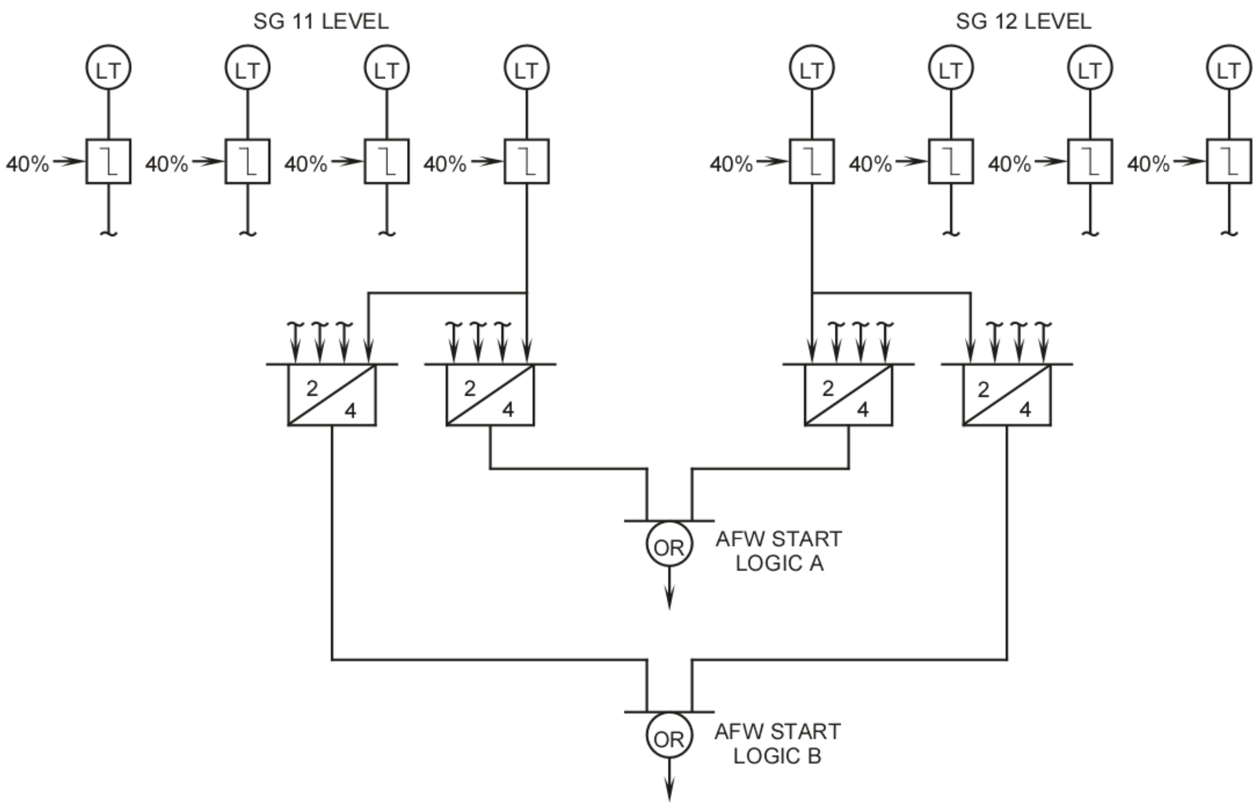

Figure 10.3-8 AFW Actuation Logic