Pressurized Water Reactor
B&W Technology
Crosstraining Course Manual

Chapter 10.1

Reactor Protection System

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10.1 REACTOR PROTECTION SYSTEM

Learning Objectives:

1. State the purpose of the reactor protection system (RPS).

2. Explain how the following design features are incorporated into the RPS:

    a. Single failure criterion
    b. Testability
    c. Equipment qualification (environment, power, etc.)
    d. Independence
    e. Redundancy

3. Given a list of reactor trip signals, explain the basis for each.

4. Describe the sequence of events that occur during a reactor trip from the sensor to the trip breaker, including the normal RPS logic.

5. Explain when the channel bypass and shutdown bypass features are used and what effects each have on the RPS, including any changes in the RPS logic.

6. Describe the trip circuit breaker logic used to interrupt power to the control rod drive mechanisms, and explain why failures in the rod control system do not affect the reactor trip capability.

10.1.1 Introduction

The purpose of the RPS is to protect the barriers that prevent the release of radioactive fission products to the general public during anticipated operational occurrences (General Design Criterion 20). The barriers protected by the RPS are the fuel cladding and reactor coolant pressure boundary. Anticipated operational occurrences are defined (10 CFR 50, Appendix A) as events that are expected to occur during the design lifetime (40 years) of the plant and include such events as a loss of reactor coolant flow, loss of main feedwater, and reactivity excursions.

Barrier protection during anticipated operational occurrences can be ensured by placing limits on reactor coolant system (RCS) pressure, fuel centerline temperature, and departure from nucleate boiling ratio (DNBR), and by ensuring that these limits are not violated. Maximum values of system pressure and fuel centerline temperature and a minimum value for DNBR are provided as safety limits plant technical specifications. The RPS ensures that these safety limits are not exceeded.

The safety limit for reactor coolant pressure ensures that the integrity of the RCS is maintained. The safety limit associated with fuel centerline temperature prevents fuel melting, which could lead to the destruction of the fuel cladding. The minimum DNBR limit ensures that departure from nucleate boiling will not occur. This limit protects the cladding from high-temperature induced failures resulting from the large reduction in cladding to water heat transfer, which occurs at the onset of departure from nucleate boiling.

The RPS prevents any of the above limits from being exceeded by interrupting power to the control rod drives, allowing the control rods (groups 1 through 7) to drop into the core and shut down the reactor. The system consists of four independent and redundant channels that receive the necessary inputs to ensure that safety limits are not exceeded. The inputs to the RPS are neutron power, axial power imbalance, hot leg temperature, RCS pressure, reactor coolant flow, reactor building pressure, reactor coolant pump (RCP) status, main turbine status, and main feedwater pump status. Separate sensors for each of the four channels sense that an input parameter has exceeded its setpoint, power will be interrupted to the control rods. This interruption of power to the control rods is defined as a reactor trip. The logic used is that whenever any two out of four channels agree that a safe operating condition limit has been exceeded, a signal is processed to open the reactor trip breakers.

B&W plants have been provided with two different RPS designs. The initial design is the one used by most of the plants and is the one discussed in this section. The latest design (RPS-II) was incorporated for later 177 (Davis Besse, Midland 1&2) and the 205 fuel assembly (F/A) plants. The major differences are briefly addressed. The trip functions remain the same, except that RPS-II incorporates optical isolation, solid state devices in the channel trip logic, and a calculating module (digital) to compute certain reactor trip functions. The optical isolation is performed by use of photo-transmitters, photo-receivers, and fiber optic cables, which serve to separate non-class 1E signal paths from the class 1E signals. Relays in the trip logic have been replaced by solid state devices. A calculating module (for DNBR, pump status, and offset trips) has replaced the overpower trip (based on flow and axial imbalance), the power/pumps trip, and variable low pressure trip. The later design was developed to allow computation of more complex protection system functions and to provide the flexibility associated with a programmable digital computer. Channel bistables and reactor trip module relays have been replaced with solid state devices to extend the capability of the RPS by raising the system's immunity to seismic disturbances and to provide faster response times to action signals. In addition, the solid state devices eliminate the moving parts found in relay applications.

10.1.2 System Design Criteria

Since the RPS protects the core from damage, the design criteria applied are extensive and restrictive to guarantee reliable operation. The entire system is designed to meet or exceed the requirements set forth in IEEE 279, "Criteria for Nuclear Power Plant Protection Systems."

1. Single Failure: No single failure shall prevent a protective system from fulfilling its protective functions when action is required (General Design Criteria 21 and 23). In addition, although not required by IEEE 279, the system must meet the plant reliability criterion that no single failure shall initiate unnecessary protective system action whenever implementation does not conflict with the single failure criterion of IEEE 279.

2. Redundancy: All RPS functions are implemented by redundant sensors, measuring channels, logic, and action devices.

3. Independence: Redundant RPS channels are electrically independent and packaged to provide physical separation per General Design Criterion 22 (including separation from control systems per General Design Criterion 24). The use of buffer assemblies (or optical isolators) affords the required separation between class 1E and non-class 1E systems.

4. Testability: Manual test facilities shall be built into the RPS (General Design Criterion 21) and its inputs and outputs to provide for pre-operational testing to give assurance that the system can fulfill its required protective functions. The RPS must also provide on-line testing to prove operability and demonstrate reliability without interfering with normal reactor or plant operation or trip functions.

5. Equipment Qualification: A wide range of environmental qualification tests, performance tests, etc. are employed to ensure equipment survivability under accident (loss-of-coolant accident [LOCA]) environments. The test results demonstrate that the equipment meets General Design Criterion 22. Protection system sensor equipment within the reactor building but outside the primary shield shall be designed for continuous operation. This equipment must also withstand the superimposed accident dose with the associated environment for the length of time the equipment is required to operate following a LOCA or steamline break (including instrument errors).

10.1.3 Reactor Trips

The RPS generates the following reactor trips:

1. high reactor power,
2. nuclear overpower based on RCS flow and axial imbalance,
3. power to pumps,
4. high T_h,
5. high RCS pressure,
6. low RCS pressure,
7. variable low RCS pressure,
8. high reactor building pressure,
9. loss of main feedwater, and
10. turbine trip.

The protection provided by each of these trips is discussed in this section.

10.1.3.1 High Reactor Power Trip

The high reactor power trip functions to prevent core damage during reactivity excursions that occur too rapidly to provide protection by sensing a change in RCS pressure or temperature. A rod ejection, a multiple group rod withdrawal accident, and an end-of-life steamline break are examples of reactivity excursions for which the high reactor power trip is the primary protection.

The high power trip also establishes an upper power bound for flux/delta flux/flow protection and for design calculations for DNBR considerations. The high power trip signal is based on heat balance corrected excore nuclear flux indication. When measured reactor power exceeds the setpoint (105.5%), a trip signal is generated.

10.1.3.2 Nuclear Overpower Trip Based on RCS Flow and Axial Imbalance (Flux/Delta Flux/Flow)

The purpose of the flux to delta flux to flow ($\phi/\Delta\phi$/flow) trip is to prevent exceeding either kw/ft limits (excessive kw/ft generation from a fuel rod can result in high fuel centerline temperatures and fuel melting) or departure from nuclear boiling ratio (DNBR) limits. This trip can be thought of as a high power trip with its setpoint being reduced by RCS flow and/or axial imbalance (top power - bottom power). Figure 10.1-1 shows the typical trip envelope that is generated by the $\phi/\Delta\phi$/flow trip circuitry. Those combinations of power (ϕ), imbalance ($\Delta\phi$), and flow that lie outside the envelope will produce a reactor trip signal. This trip is replaced with the DNBR and offset trips in the 205 F/A RPS.

10.1.3.3 Power to Pumps Trip

This trip prevents DNBR from dropping below 1.30 by tripping the reactor when pumping power is lost. In addition, this trip limits power production if a reactor coolant pump is operating in each loop and prevents single loop operation. The setpoints for various pump combinations are listed in Table 10.1-1.

10.1.3.4 High Th Trip

The high hot leg temperature trip prevents the reactor from being operated above a fixed outlet temperature. The fixed temperature limit defines the effective range of the variable low RCS pressure trip. The high temperature trip setpoint is 644°F. The high temperature trip is not required as the primary protection for any transient, but it provides backup protection for overpower and high RCS pressure trips.

10.1.3.5 High RCS Pressure Trip

The function of the high RCS pressure trip is to ensure that the reactor coolant pressure safety limit is not exceeded (which helps provide pressure boundary protection). The high pressure trip provides primary protection for anticipated operational occurrences which provide slow reactivity insertions, such as single rod withdrawal accidents, boron dilution accidents, and under-cooling events. The high pressure trip setpoint of 2370 psig provides a margin between maximum operating RCS pressure and the set pressure of the pressurizer safety valves (2500 psig). In addition, the high pressure setpoint provides an upper pressure boundary for the calculation of DNBR.

10.1.3.6 Low RCS Pressure Trip

The function of the low RCS pressure trip is to prevent the departure from nucleate boiling and to mitigate the circumstances of pressure decreasing transients such as steam generator tube ruptures, steamline breaks, and loss-of-coolant accidents. The low RCS pressure trip helps to mitigate the consequences of the pressure decreasing transients by reducing power to decay heat levels through the reactor trip.

The low pressure trip setpoint of 2000 psig allows transients below normal operating pressure (2195 psig) without generation of unnecessary trips and provides a minimum margin above the ESFAS actuation setpoint of 1600 psig. This margin is required to provide a reasonable RCS pressure band below the low pressure trip setpoint in which the ESFAS can be bypassed when the plant is undergoing a controlled cooldown.

10.1.3.7 Variable Low RCS Pressure Trip

This trip provides DNB protection for the core. As shown in Figure 10.1-2, the trip provides a margin to DNB for a combination of pressures and temperatures that are not covered by the low RCS pressure or high T_h trip.

10.1.3.8 High Reactor Building Pressure Trip

This trip functions to ensure that the reactor is shut down in the event of a loss-of-coolant accident.

10.1.3.9 Anticipatory Loss of Main Feedwater Trip

This reactor trip was added to the 177 fuel assembly units following the accident at TMI-2. The purpose of this trip is to insure that the reactor is tripped when the ability to remove the heat from the reactor is reduced due to the loss of main feedwater flow. Before the inclusion of this anticipatory trip, the loss of main feedwater event was terminated by the high RCS pressure trip.

10.1.3.10 Reactor Trip on Turbine Trip

The reactor trip on turbine trip was the second trip that was added following the TMI-2 accident. This trip functions to shut down the reactor when its heat sink (turbine) is lost.

10.1.3.11 Manual Reactor Trip

A manual reactor trip pushbutton(s) is installed to allow the operator to trip the reactor. Plant procedures will allow this option if, in the opinion of the operator, an unsafe condition exists. A summary of RPS trips, setpoints, and purposes can be found in Table 10.1-1.

10.1.4 Reactor Trip Circuitry

10.1.4.1 Power Range Excore Nuclear Instrumentation

Each power range channel consists of two detectors (Figure 10.1-3), and each of these detectors provides an input into a linear amplifier. The outputs of the two linear amplifiers supply a summing amplifier and a difference amplifier. The summing amplifier's output supplies a signal to the $\phi/\Delta\phi$/flow trip circuitry. The output of the difference amplifier supplies a signal to a function generator, where it is combined with RCS flow. Function generator slope and breakpoint adjustments are provided to generate the trip envelope. The output of the function generator is compared with total power in the trip bistable and, if required, a trip signal will be generated.

In addition to the $\phi/\Delta\phi$/flow trip, the summing amplifier output signal supplies the high power trip and the power to pumps trip. The high flux trip bistable compares the total power input with a setpoint for the trip decision. In the power to pumps trip bistable, the total power signal is compared with a setpoint that is determined by the number of operating RCPs. If total power exceeds the setpoint, then a trip signal is generated.

10.1.4.2 Temperature and Pressure Inputs

Reactor coolant outlet temperature (T_h) is used in the generation of the high T_h trip (Figure 10.1-4) and the variable low pressure trip. Each RPS channel receives one T_h input. These signals originate from resistance temperature detectors (RTDs) that are mounted in wells in the RCS piping. Each RTD is wired into a bridge circuit located in an RPS cabinet. This cabinet is used to convert the change in RTD resistance to a voltage signal that is proportional to temperature. The T_h signal is compared with a setpoint to generate the high T_h trip. The output of the T_h signal converter is routed to the variable low pressure trip bistable for generation of this trip.

RCS pressure is sensed by pressure transmitters piped to taps on each reactor outlet line. Two transmitters tap into the A hot leg, and the remaining two transmitters tap into the B hot leg. Each of the four RPS channels supplies power to one pressure transmitter and in turn receives an input from that transmitter. The output of each pressure transmitter is

supplied to a buffer amplifier. The buffer amplifier receives, amplifies, and converts the 4- to 20 ma transmitter signal to a 0 – 10 vdc analog signal proportional to RCS pressure, with a scaled range from 1500 - 2500 psig. The voltage signal from the buffer amplifier supplies an input to the high pressure trip bistable, the low pressure trip bistable, the shutdown bypass trip bistable, and the variable low pressure trip bistable. In each of the bistables, a comparison is made between actual RCS pressure and a setpoint. If the setpoint is exceeded, a trip signal will be issued by the bistable.

10.1.4.3 Reactor Building Pressure Input

Reactor building (RB) pressure is compared with a setpoint in a bistable to generate a reactor trip signal. At some plants, the high RB pressure trip is generated by pressure switches located inside the reactor building.

10.1.4.4 Anticipatory Trip Circuitry

The loss of main feed pumps and turbine trips consist of contact inputs that are in series with the channel trip relay. Since the loss of feed pumps and turbine reactor trips are not in service at low power levels, parallel power range bistable contacts bypass these trips until power is above their setpoints. As shown in Figure 10.1-5, if both feed pump contacts open and reactor power is greater than 10% power, the channel trip relay will de-energize. The turbine trip works in a similar fashion at 40% power. It should be noted that the power contacts in parallel with the main feed pump contacts and the turbine trip contact bypass the anticipatory trips if power is less than their respective setpoints. In this case, the power contacts are closed and the opening of both main feed pump contacts or the turbine trip contact will not de-energize the channel trip relay. (Note that the setpoint values are plant specific.)

10.1.4.5 RCS Flow

RCS flow from each of the hot legs is transmitted to the RPS. In the RPS, the individual flow signals are summed, and the total flow signal is used in the generation of the $\phi/\Delta\phi$/flow trip.

10.1.5 RPS Channel Logic

The RPS trip scheme consists of series contacts that are operated by bistables. Refer to Figure 10.1-6, using RPS channel A as an example. During normal plant operations, all contacts are closed and the channel trip relay (KA) remains energized. However, if any trip parameter (in channel A) exceeds its setpoint, its associated contact opens and de-energizes the channel trip relay. When the channel trip relay de-energizes, several actions occur:

1. The KA relay de-energizes the four (4) output logic relays (KA1, KA2, KA3, and KA4). Each of these relays “informs” its associated RPS channel that a reactor trip signal has occurred in RPS channel A.

2. The KA1 contacts in the undervoltage (UV) coil circuitry powered by RPS channel A open, but the undervoltage coil remains energized through the closed KB1, KC1, and KD1 contacts. This condition exists in each RPS channel (except that the contact designations are different). Each RPS channel controls an undervoltage (UV) coil on a reactor trip circuit breaker.

3. The KA contact in parallel with the channel reset switch opens, and the trip is sealed in. The channel reset switch must be depressed, after the trip condition has cleared, to re-energize the channel trip relay and thus restore the RPS channel to its normal (non-tripped) configuration.

While the information presented is associated only with RPS channel A, it is applicable for any RPS channel. Also, even though channel A has sensed a reactor trip condition, the reactor has not tripped. When the second RPS channel senses a reactor trip condition, the following occurs:

1. The channel trip relay for that channel de-energizes.

2. The output logic relays for the second channel de-energize and open contacts that supply power to the reactor trip circuit breaker UV coils.

3. With contacts opened by two separate RPS channels, power is interrupted to the reactor trip circuit breaker UV coils and the breakers open. When the breakers open, the control rods fall into the core.

In the preceding discussion, two key points should be remembered. First, a minimum of two out of four channels must sense a trip condition to cause a reactor trip. This logic is satisfied by the eight series/parallel contacts in the reactor trip circuit breaker UV coil circuitry. Second, coincidence trip logic does not exist. Since the bistable relay contacts are in series with the channel trip relays, two unrelated channel trips can result in a reactor trip.

10.1.6 Reactor Trip Circuit Breaker Logic

Power is supplied to the control rods (Figure 10.1-7) from two separate plant sources through the AC trip circuit breakers. These breakers are designated A and B, and their undervoltage coils are powered by RPS channels A and B, respectively. From the circuit breakers, the control rod drive (CRD) power travels through voltage regulators and stepdown transformers. These devices, in turn, supply redundant busses that feed the DC power supplies for the safety rods and the regulating rod power supplies.

The DC power supplies rectify the AC input and supply power to hold the safety rods in their fully withdrawn position. One of the redundant power supplies powers phase A, and the other phase CC. Either phase being energized is sufficient to hold the rod. Two breakers are located on the output of each power supply. Each breaker controls power to two of the four safety rod groups. The undervoltage coils on the two circuit breakers on the output of one of the power supplies are controlled by RPS channel C, and the other two breakers are controlled by RPS channel D.

In addition to the DC power supplies, the redundant busses also supply power to the regulating and auxiliary power supplies. These power supplies consist of silicon control rectifiers (SCRs) that are gated on by the microcomputer (solid state system) or the programming lamps (optical disk system). (The SCRs as well as the programming lamps (if applicable) are redundant.) If power is removed from the gate drives (solid state system) or the programming lamps, gating power is lost to the SCRs, and they cease to supply power to the regulating rods. In the solid state system, power to the gate drives is controlled by contactors (E and F). In the optical disk system, the programming lamp power is controlled by contactors (E and F) which are controlled by RPS power. One of the redundant programming lamp supplies is controlled by RPS channel C, and the other supply is controlled by RPS channel D.

One AC breaker and two DC breakers are in series in one of the power supplies, and the redundant AC breaker and DC breakers are in series in the other power supply to the control rods. The logic required to cause a reactor trip is the opening of a circuit breaker in each of the redundant power supplies. (The two DC circuit breakers on the output of each power supply are treated as one breaker.) This is known as a one-out-of-two-used-twice logic. The following example illustrates the operation of the reactor trip circuit breakers:

If only the “B” AC breaker opens:

a. The input power to the associated DC power supply is lost and the “CC” phase to the safety rods de-energize.

b. The SCR supply from the secondary power source is lost and the secondary power supply to the regulating rods de-energize.

If only the “C” DC breaker(s) and E contactor open:

a. The output of the main DC power supply is lost and the “A” phase to the safety rods de-energize.

b. When the E contactor opens, gating power to the main SCRs is lost to the regulating rods.

The combination of the opening of the “B” AC breaker, the “C” DC breaker(s), and the E contactor causes a reactor trip. Any other combination of at least one circuit breaker opening in each power supply will cause a reactor trip.

To summarize the last two sections, assume that RPS channel B senses a low RCS pressure condition and RPS channel C senses a variable low RCS pressure condition. When the channel B bistable relay de-energizes, the channel trip relay de-energizes and opens its associated contacts. The same thing occurs in channel C, except that the variable low RCS pressure bistable relay de-energizes the C channel trip relay. When the output logic relays de-energize, the B and C contacts in the UV and E/F contactor circuits open. When the UV coils and E/F contactors de-energize, all circuit breakers open, and gating power to the SCRs is removed. All rods fall into the core, resulting in a reactor trip.

10.1.7 System Testing

To ensure the operability of the RPS, plant technical specifications require the monthly testing of each RPS channel. The analog trips in the RPS can be tested with an installed test power supply that is substituted for the detector output. The output of the test power supply is increased to the trip setpoint to verify the operability of the associated buffer amplifier(s) and bistable trip units. The test panel allows the testing of analog inputs (pressure, temperature, and power) and contact inputs (pump status monitor). Individual test modules can be operated without causing a channel trip, if the channel is in channel bypass (Section 10.1.8).

As shown in Figure 10.1-6, the primary sources of 120-vac power for the RPS are the four vital instrument buses. Each channel is powered from a different vital bus. Within the system cabinets, each RPS channel is powered by separate plus and minus 15-vdc channel power supplies. All trip devices operate in a normally energized state and go to a de-energized state to initiate trip action. Loss of power thus automatically forces the bistables into the tripped state. In addition, the loss of power to the channel trip relay would place it in a de-energized or tripped condition. Failure of a vital bus or a channel power supply causes the affected channel to trip.

The removal of any module required to perform a protective function initiates the trip normally associated with that portion of the system. For example, removal of a trip bistable trips the associated channel terminating device, and removal of a reactor trip module trips the associated CRD breaker. Removing a trip bistable breaks the trip chain leading to the channel trip relay, and a one-out-of-four trip input is sent to the other three channels.

10.1.7.1 Module Interlocks and Test Trip Relay

The entire RPS in simplified form is shown in Figure 10.1-6. In the preceding sections, each component element of the RPS has been discussed. The last remaining objective is to acquire an understanding of the module interlocks and test trip relay, identified for channel D. Each channel and each trip module is capable of being individually tested.

When a module is placed into the test mode, it causes the test trip relay to open the TT contact and to indicate an RPS channel trip. Under normal conditions the channel to be tested is placed in bypass before a module is tested.

The use of two-out-of-four logic between channels permits a channel to be tested on-line without initiating a reactor trip. Maintenance to the extent of removing and replacing any module within a channel may also be accomplished in the on-line state without a reactor trip. To prevent either on-line testing or maintenance features from creating a means for unintentionally negating protective action, a system of interlocks initiates a channel trip when a module is placed in the test mode or is removed from the system (unless the system is bypassed).

10.1.7.2 Bistable Modules

Bistable modules (Figure 10.1-8) are used to convert analog input signals to digital output signals in the form of relay contacts when setpoint values are reached. The bistable can be connected to trip on either an increasing or decreasing signal. An adjustable deadband, or hysteresis, is included to ensure positive switching action at the trip setpoint, even with noise or small variations present in the input signal. A memory circuit, which must be reset manually, is included to indicate whether the bistable module has been tripped or not. On the front plate are lights to indicate the trip state of the bistable and the state of the bistable memory. These indicating lamps are normally "dim" to reflect that power is available and that the bistable is in a normal or non-tripped condition. "Bright" indicating lamps signify that the bistable has been tripped. There are two momentary toggle switches for resetting the state and also the memory. Two potentiometers with turn counting dials are used for adjusting the setpoint of the bistable and the deadband. Test jacks are provided for measuring the input, setpoint, and deadband voltages.

The test scheme for the RPS is based on the use of comparative measurements between like variables in the four channels, and the substitution of externally introduced digital and analog signals as required, together with measurements of actual protective function trip setpoints. A digital voltmeter is provided for making accurate measurements of the trip setpoints and analog voltage signals. The test circuits allow the operator to test system channels from the input of any bistable up to the final actuating device at any time during reactor operation.

The bistable test consists of inserting an analog input from one of the channel test modules (Figure 10.1-9) and varying the input until the bistable setpoint is reached. The value of the inserted test signal, as monitored by the analog indicator as well as the digital voltmeter, represents the true value of the bistable setpoint. Thus, the test verifies not only that the bistable functions, but also that the setpoint is correctly set. During the test, satisfactory operation of the bistable can be observed by watching the trip status light in the reactor trip module (Figure 10.1-10). The reactor trip module two-out-of-four logic and the associated control rod drive breaker are tested by pressing various combinations of two logic test switches in the reactor trip module to simulate the six combinations of trips

inherent in a two-out-of-four coincidence logic. Satisfactory performance of the trip logic relays can be observed by watching the trip logic relay lights and the breaker trip lights on the reactor trip module. This test verifies not only all the combinations of the two-out-of-four logic, but also that the trip logic relays and the control rod breakers will trip.

The system test scheme includes frequent visual checks and comparisons within the system on a regular schedule in which all channels are checked at one time, together with less frequent electrical tests conducted on a rotational plan in which the tests are conducted on different channels at different times, as encouraged by the PRA to minimize common mode failure items.

10.1.8 RPS Bypasses

The two types of bypasses are RPS channel bypass and RPS shutdown bypass. Channel bypass provides a method of placing one RPS channel in a cannot trip condition, and shutdown bypass provides a method of leaving the safety rods withdrawn during testing or cooldown and heatup of the RCS. Each of these bypasses is discussed below.

10.1.8.1 Channel Bypass

A channel bypass (Figure 10.1-6) provision is provided to allow for maintenance and testing of the RPS. The use of channel bypass keeps the channel trip relay energized regardless of the status of the bistable relay contacts. To place a channel in channel bypass, the other three channels must not be in channel bypass. This is ensured by contacts from the other channels being in series with the channel bypass relay. If any contact is open, then the second channel cannot be bypassed. The second condition is the closing of the key switch on the reactor trip module (which is administratively controlled). When the bypass relay is energized, the bypass contact closes, maintaining the channel trip relay in an energized condition. All RPS trips are reduced to a 2-out-of-3 logic (of the remaining channels) when a channel is in channel bypass; this condition is continuously annunciated in the main control room. In channel bypass, the testing of trip bistables or repair of RPS modules can be performed without generating unnecessary trip signals from the affected channel.

10.1.8.2 Shutdown Bypass

During testing, plant cooldown, or plant heatup, it may be desirable to have safety rods withdrawn to provide rapid, additional shutdown capability in the event of unusual positive reactivity additions (moderator dilution, etc.). The Shutdown Bypass feature allows for withdrawing safety groups of rods when the RCS is below the normal RCS Low Pressure trip setpoint. This makes their negative reactivity available to terminate inadvertent reactivity excursions.

During a plant cooldown, the operators may want additional negative reactivity available by having safety rods withdrawn. To achieve this, the low RCS pressure trip

(2000 psig) would need to be bypassed in the reactor protection system. First, all of the rods would be fully inserted, then the RCS would be depressurized to less than 1820 psig, and finally each RPS channel would be placed in Shutdown Bypass. Placing the channels in Shutdown Bypass inserts a new high RCS pressure trip (1820 psig). The operators can now withdraw safety rods and continue with the plant cooldown.

In shutdown bypass (Figure 10.1-6), the normally closed SD contact in the bistable trip string opens and the key switch SD contact closes. This action bypasses the low RCS pressure trip, $\phi/\Delta\phi$/flow trip, power to pumps trip, and the variable low RCS pressure trip and inserts a new high RCS pressure (1820 psig) trip. The operator can now withdraw the safety rods for additional shutdown margin.

The insertion of the new high pressure trip bistable performs two functions. First, the trip setpoint of 1820 psig prevents operation at normal system pressure (2195 psig) with a portion of the RPS bypassed. The second function ensures that the bypass is removed prior to normal operation. During plant heatup and pressurization, safety rods are inserted before the RCS reaches 1820 psig. When the RPS is returned to normal by removing the shutdown bypass and RCS pressure is increased above the RCS low pressure trip setpoint, the safety rods are again fully withdrawn and the plant heatup can continue.

In addition to the shutdown bypass high RCS pressure trip, the high flux trip setpoint is administratively reduced to 5% while the RPS is in shutdown bypass. This provides a backup to the shutdown bypass high pressure trip, and allows low temperature physics testing while preventing the generation of any significant power.

10.1.9 PRA Insights

The major RPS PRA concern is an anticipated transient without scram (ATWS). According to the ANO-1 PRA, the ATWS has a core melt frequency contribution of 6%. The dominant accident sequence assumes that the transient starts with all the front line systems initially available and proceeds as follows:

1. A valid trip signal is received, and a double failure of the reactor trip circuit breakers occurs.

2. The main feedwater pumps trip or run back to a low feedwater flow condition.

3. The operator fails to initiate feed and bleed core cooling.

The risk reduction factor for the RPS is 1.06, and the risk achievement factor is 56,001. The large risk achievement factor is due to the small failure probability of the RPS that is assumed in the PRA. It should be noted that the PRA study was completed before the plant was required to add the shunt trip coils to the RPS circuitry.

NRC Generic Letter 83-28 required actions based on generic implications of the Salem ATWS events, which include automatic actuation of the shunt trip devices on the CRD breakers. Class 1 relays are installed within the CRD breaker cabinets to actuate the breakers by providing power to a shunt trip. One relay is placed in each channel and is connected in parallel with the undervoltage coil on the CRD breaker (Figure 10.1-11). Control power for the shunt trip will come through contacts actuated by the shunt relay. Upon de-energization of the undervoltage and shunt relays, power will be provided to the shunt trip relay, thereby tripping the CRD breaker.

10 CFR 50.62 requires additional safety improvements in the design and operation of light water cooled nuclear power reactors to minimize the probability of an ATWS event. The new requirements reduce the likelihood of failure of the reactor trip system to scram the reactor following an ATWS and reduce the consequences should failures occur. An anticipated transient and concurrent failure of the reactor trip system could lead to melting of reactor fuel and release of large amounts of radioactivity to the environment. The new requirements for pressurized water reactors are:

1. Additional equipment, independent of the reactor trip system, to automatically activate the auxiliary feedwater system and initiate a shutdown of the plant turbine under conditions indicative of an ATWS.

2. A diverse scram system independent of the existing reactor trip system (from sensor output to interruption of power to the control rods).

Functional diagrams of two diverse (or backup) scram systems (DSS) are shown in Figures 10.1-7 and 10.1-12. The DSS consists of two channels of instrumentation, each having a reactor coolant pressure input to the circuit with a trip setpoint of 2450 psig.

In Figure 10.1-7, the DSS contacts are in series with the E and F contactors. When the trip setpoint is reached, the DSS contacts open and remove gating power to the SCRs for Groups 5 - 7 and the auxiliary power supplies. This removes the power from the control rod drive mechanisms (CRDMs) and causing the control rods to drop into the core.

In Figure 10.1-12, the bistable output will be a contact closure that energizes DSS relays in the control rod drive control system (CRDCS) cabinets. The DSS relay output will open programmer lamp circuits, causing de-gating of one group of SCRs. A coincident second DSS channel actuation will de-gate a second group of SCRs, thus removing the power from the CRDMs and causing the control rods to drop into the core. Both CRDCS groups' (channels A and B) SCRs must de-energize to release the control rods.

The system is designed to be testable with the reactor on-line. While one channel is being tested, a DSS bypass switch will be actuated to prevent an inadvertent reactor trip. A means to alert the operators that a DSS channel is in a bypass or tripped condition is provided. Inadvertent actuation of the DSS will be prevented by using a two-out-of-two channel logic to initiate a reactor trip.

10.1.10 Summary

The reactor protection system is designed to protect the fuel cladding boundary and the RCS pressure boundary from damage during anticipated operational occurrences. The system consists of four separate redundant channels that receive inputs of neutron flux, axial imbalance, RCS pressure, RCS flow, RCS temperature, RB pressure, RCP status, main feedwater pump status, and main turbine status.

These input signals are received by the trip circuitry. The RPS circuitry processes these inputs and compares these values to predetermined setpoints. If a setpoint is exceeded, a trip signal is generated. The generation of any trip signal in any two of the four RPS channels will result in the tripping of the reactor.

The reactor is tripped by the opening of circuit breakers that interrupt the power supply to the control rod drives. Six breakers are installed to increase reliability and allow testing of the trip system. A one-out-of-two-used-twice logic is used to interrupt power to the rods. The RPS has two bypasses: a shutdown bypass and a channel bypass. Shutdown bypass allows the withdrawal of safety rods for shutdown margin availability during plant cooldowns or heatups. Channel bypass is used for maintenance and testing. Test circuits in the analog and digital trip strings allow complete testing of all RPS trip functions.

TABLE 10.1-1 REACTOR TRIP SUMMARY		
Trip	Setpoint	Protection Afforded
High Reactor Power	105.5%	1. Rapid reactivity excursions. 2. Upper bound for DNBR calculations.
Flux / Delta Flux / Flow ($\Phi/\Delta\Phi$/Flow)	See Figure 10.1-1	1. DNBR 2. kw/ft
Reactor Power to Pumps	2/2 - >125% * 1/2 - >125% * 1/1 - 55% 0/2 - Automatic Trip 0/1 - Automatic Trip 0/0 - Automatic Trip (* Protection provided by Flux / Delta Flux / Flow trip)	1. DNBR 2. Prevents single loop operation
High T_h	644°F	Backup for High Rx Power and High RCS Pressure trips.
High RCS Pressure	2370 psig	RCS boundary protection.
Low RCS Pressure	2000 psig	DNBR
Variable Low RCS Pressure	$15.4T_h$ - 7718 psig (T_h in °F)	DNBR
High Reactor Building Pressure	4 psig	Ensures that the reactor is shut down during accidents.
Anticipatory Loss of Main Feedwater	Loss of both MFPs above 10%	1. Loss of heat sink. 2. TMI-2 requirement.
Reactor Trip on Turbine Trip	Turbine trip above 40%	1. Loss of heat sink. 2. TMI-2 requirement.

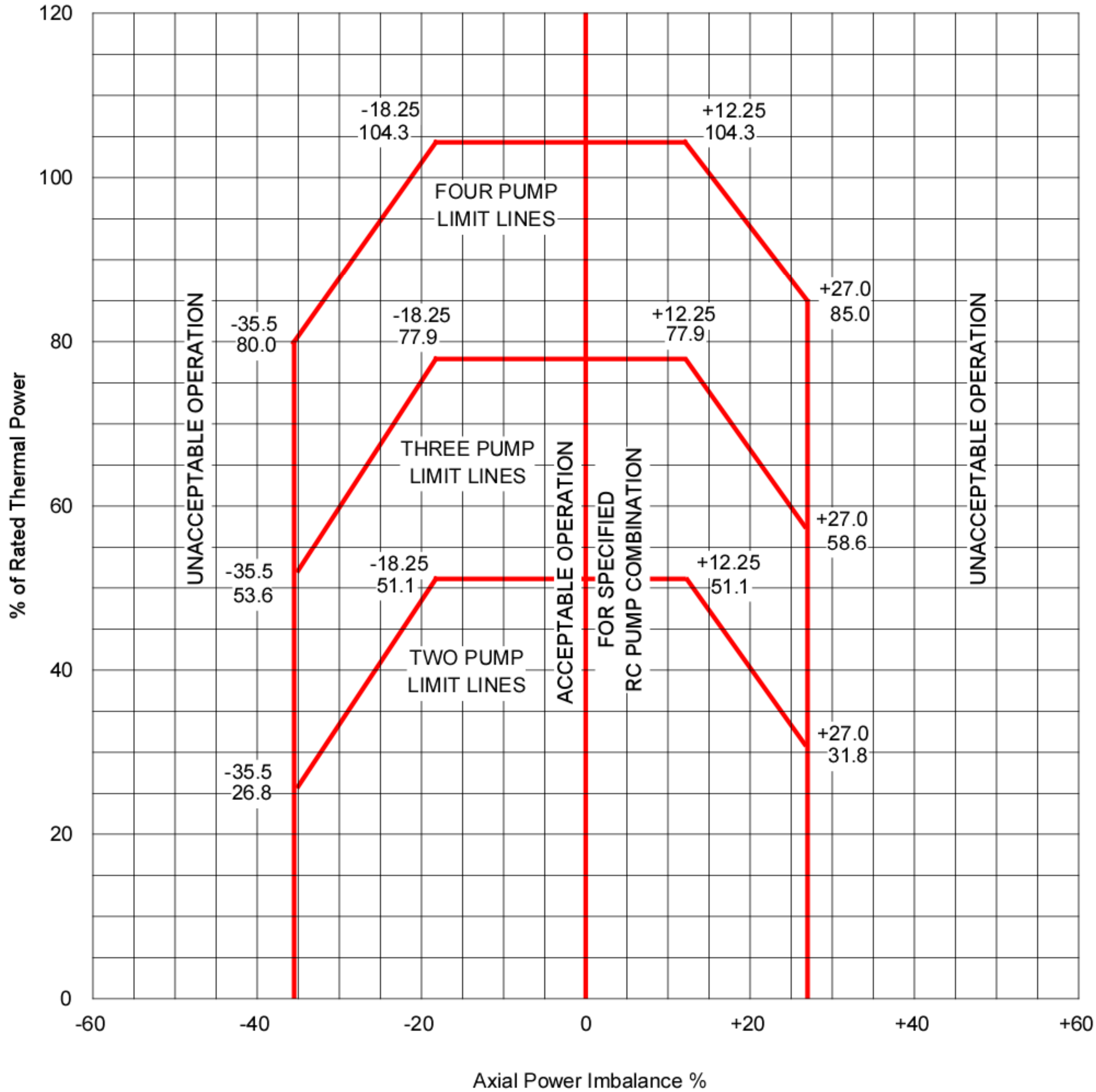

Figure 10.1-1 Flux / Delta Flux / Flow Trip Envelope

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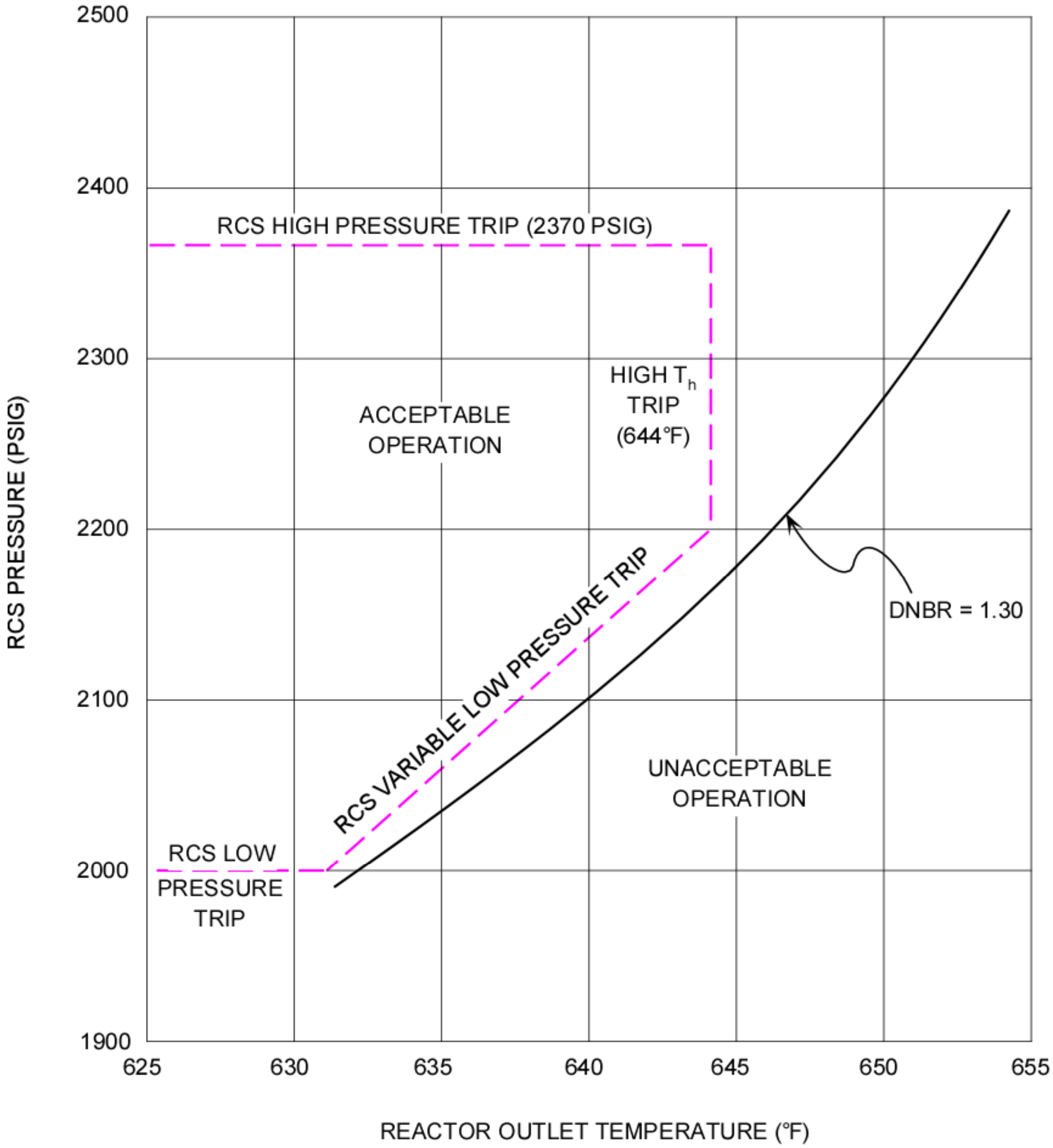

Figure 10.1-2 Pressure /Temperature Trip Envelope

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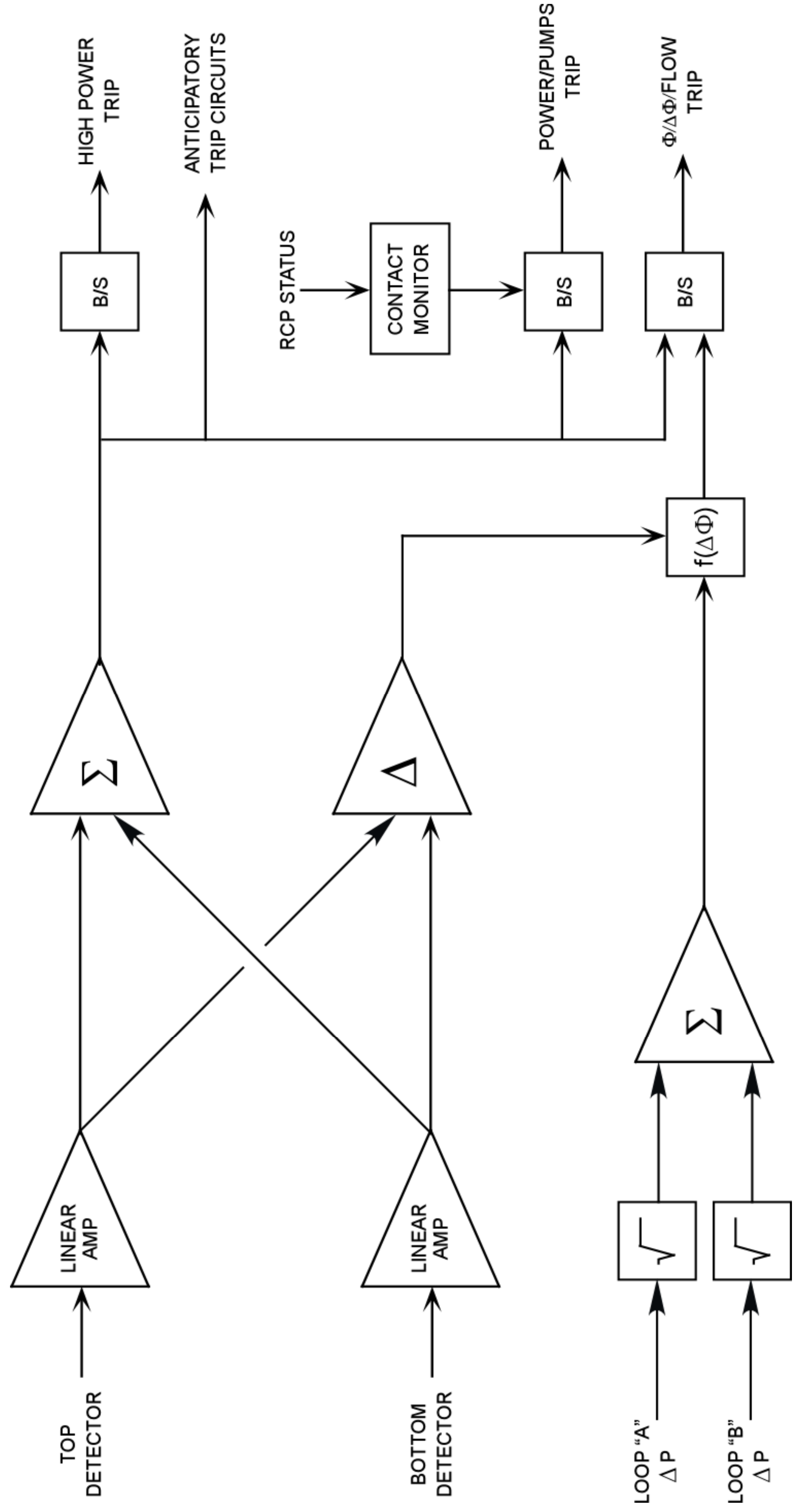

Figure 10.1-3 Excore Nuclear Instrumentation Inputs

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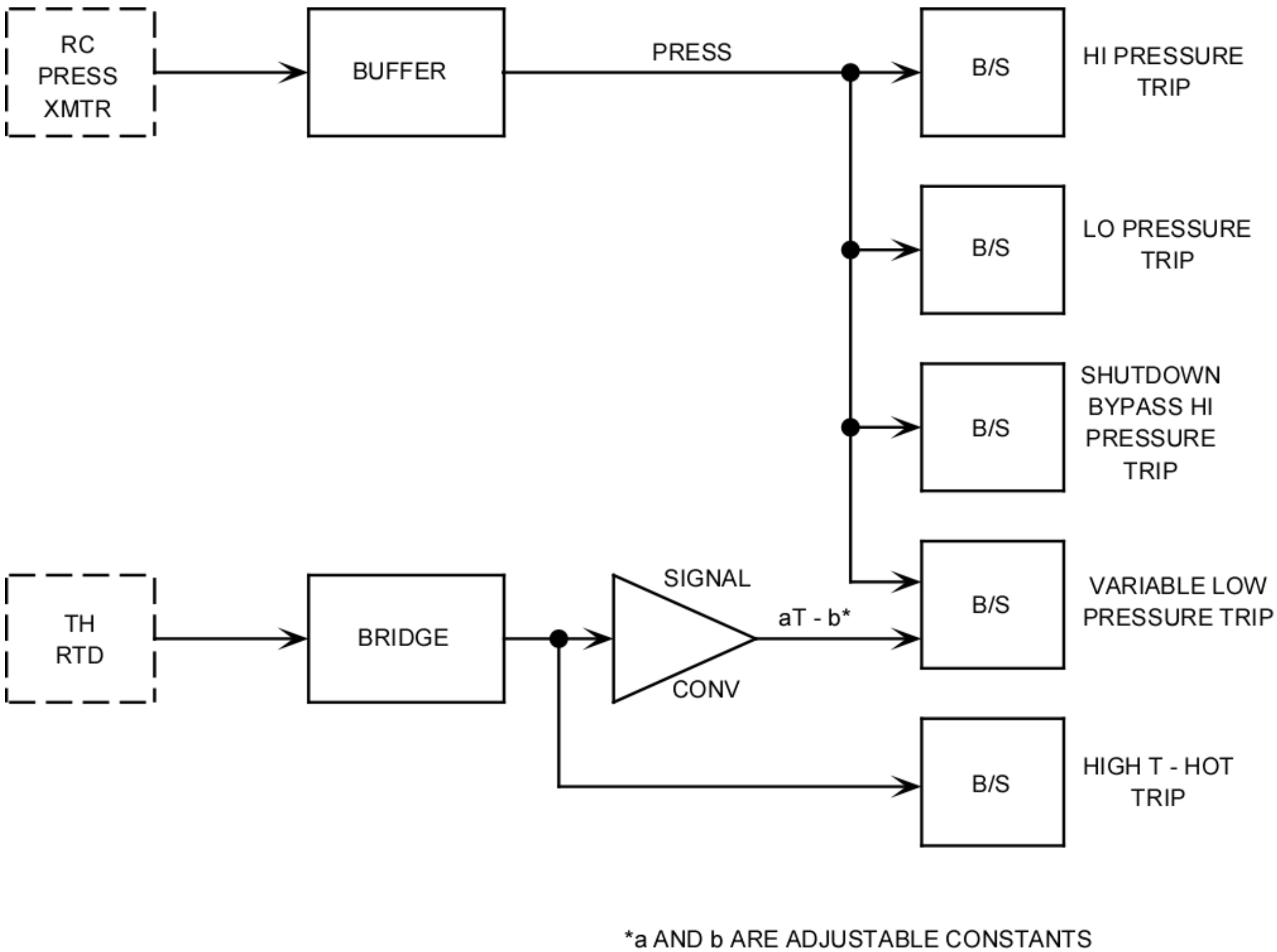

Figure 10.1-4   RPS Temperature and Pressure Inputs

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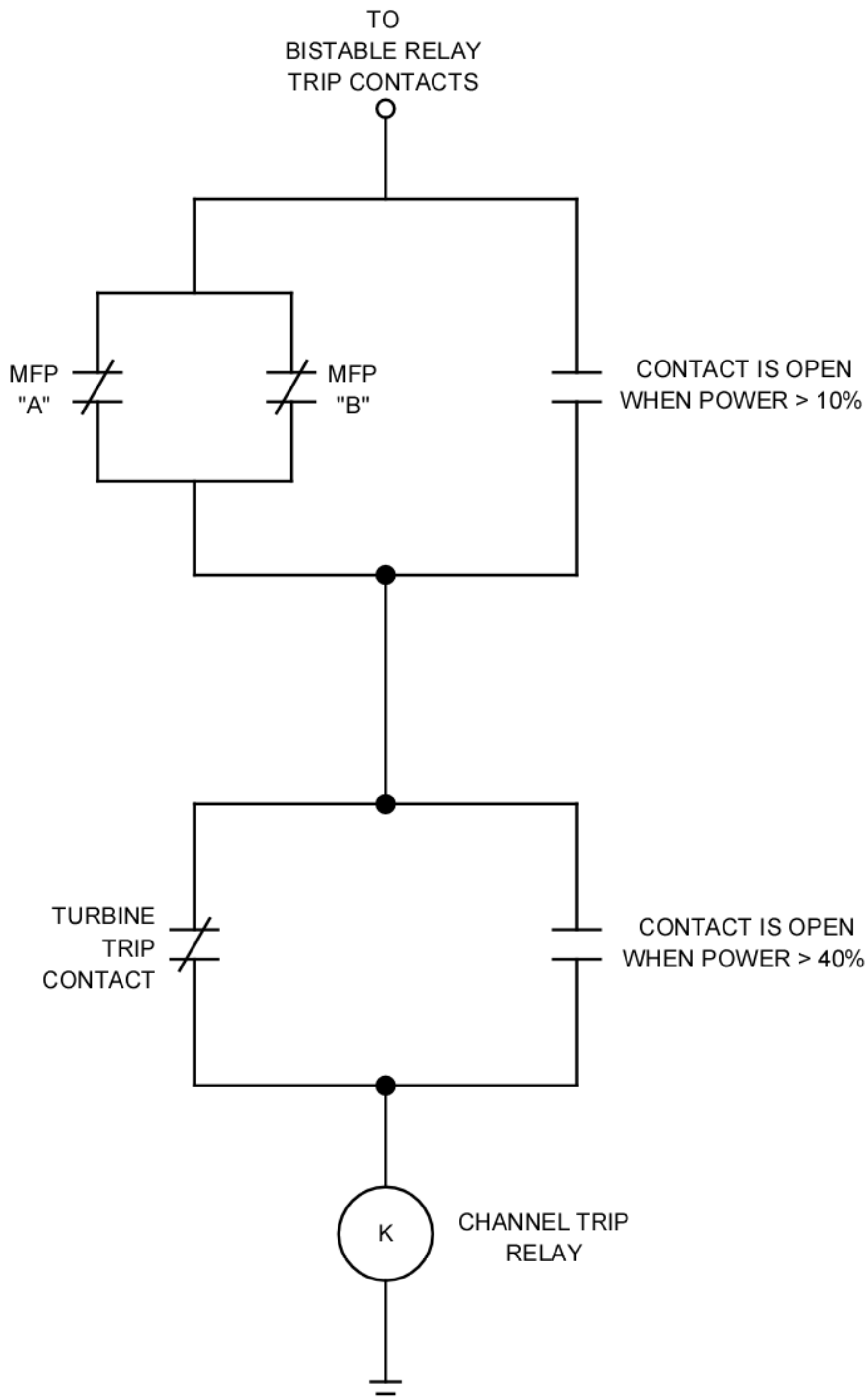

Figure 10.1-5 Anticipatory Trips Circuitry

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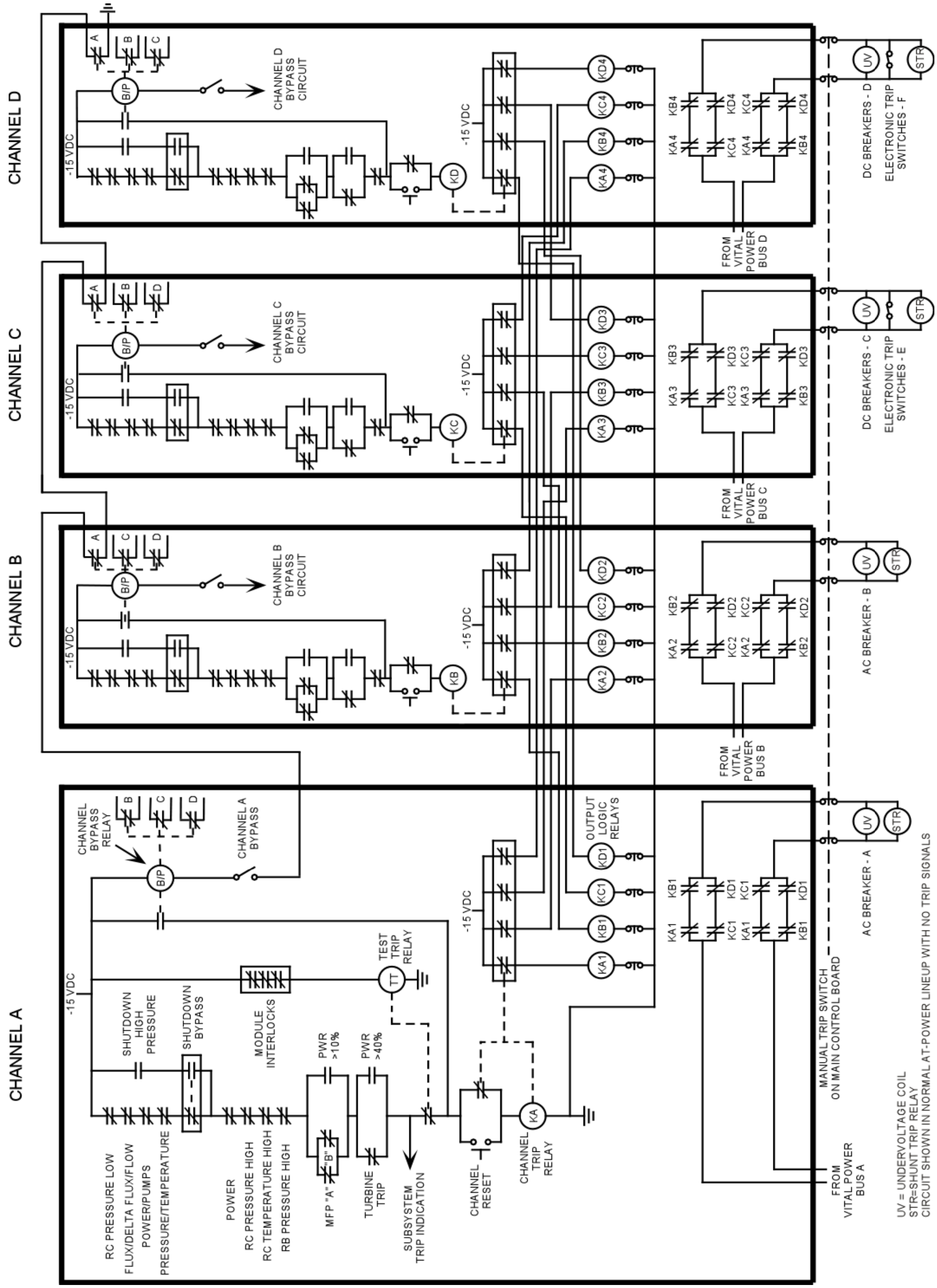

Figure 10.1-6 Reactor Protection System Channel Logic

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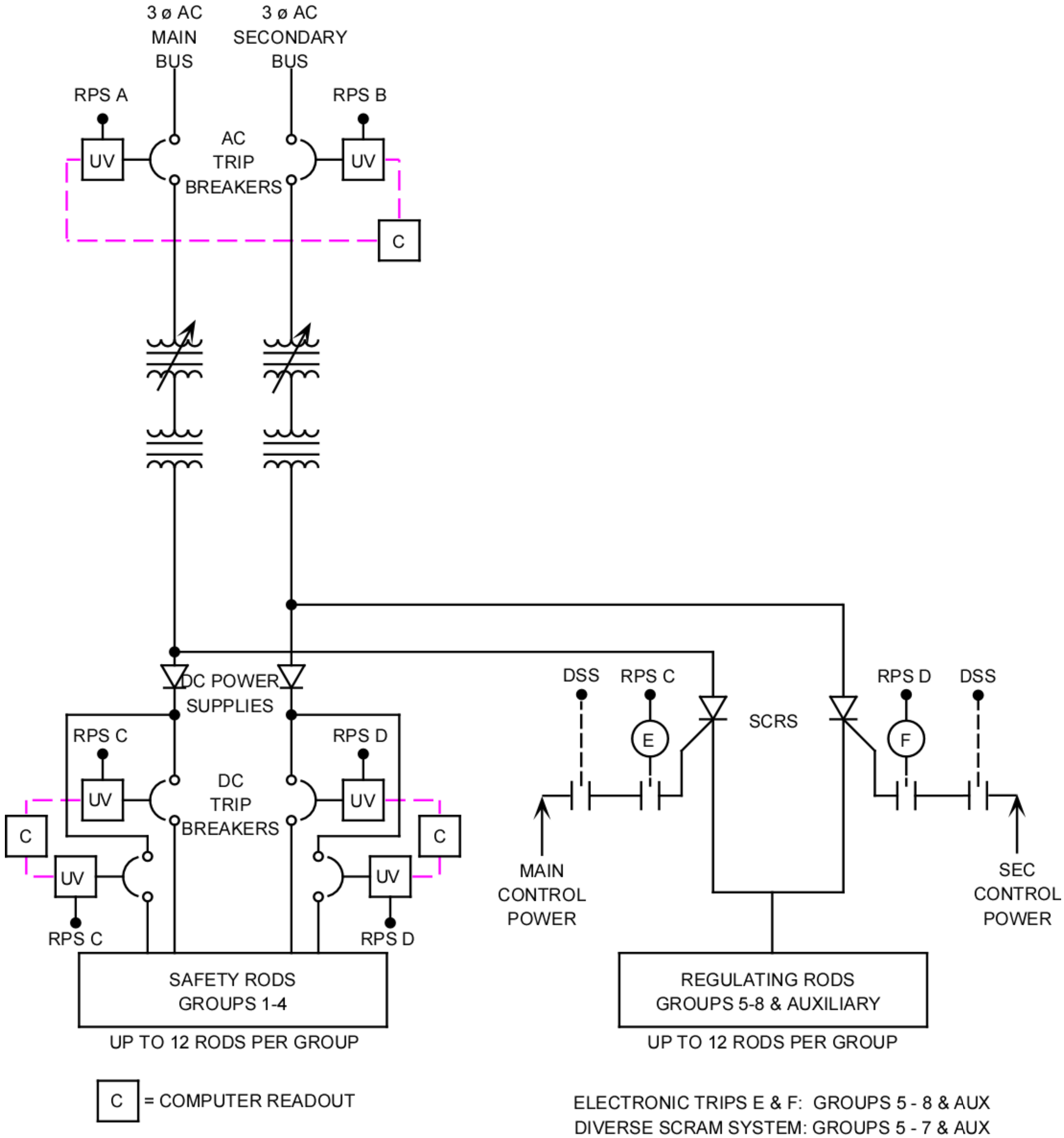

Figure 10.1-7 Reactor Trip Circuit breakers

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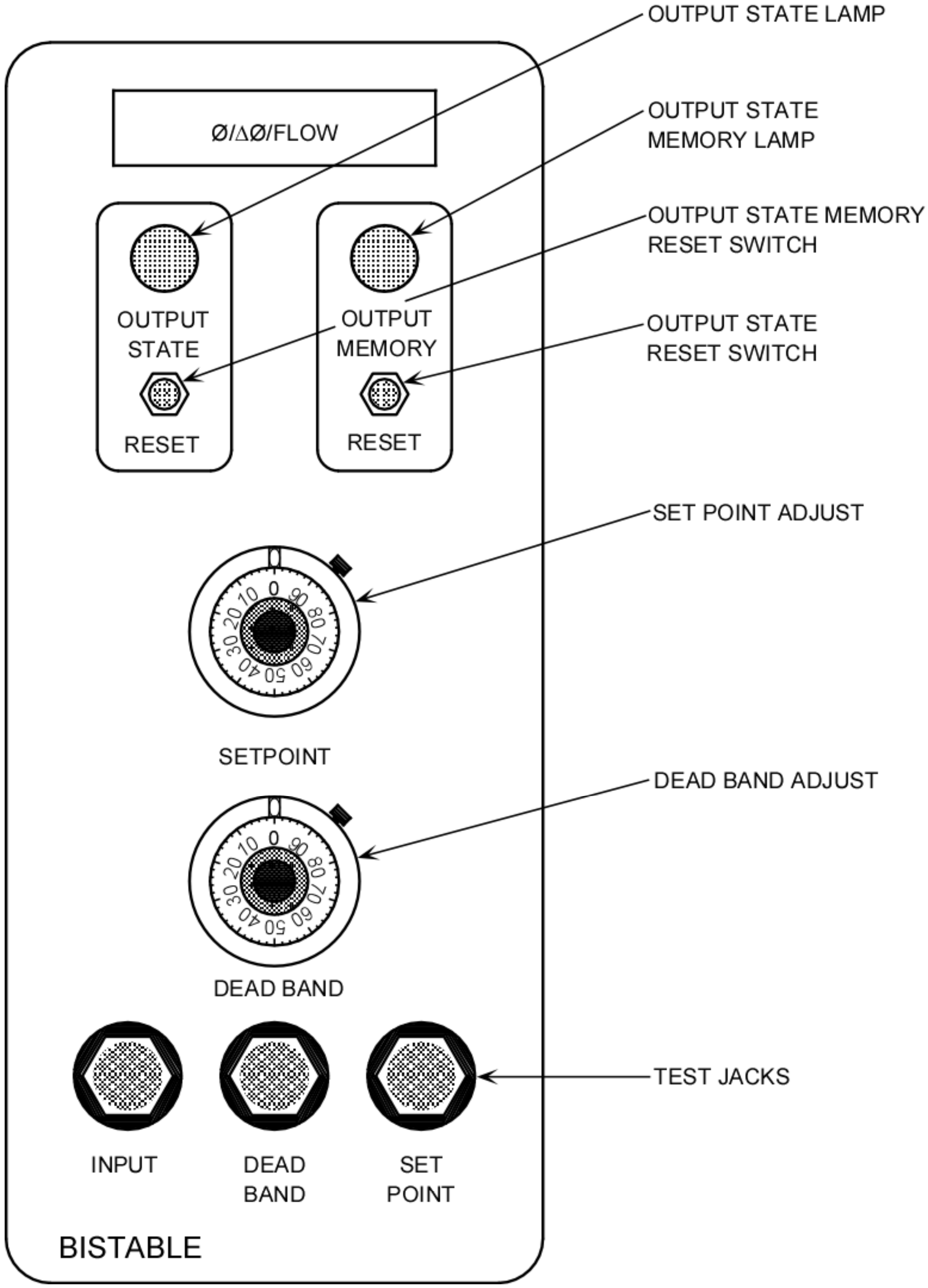

Figure 10.1-8 Bistable Module

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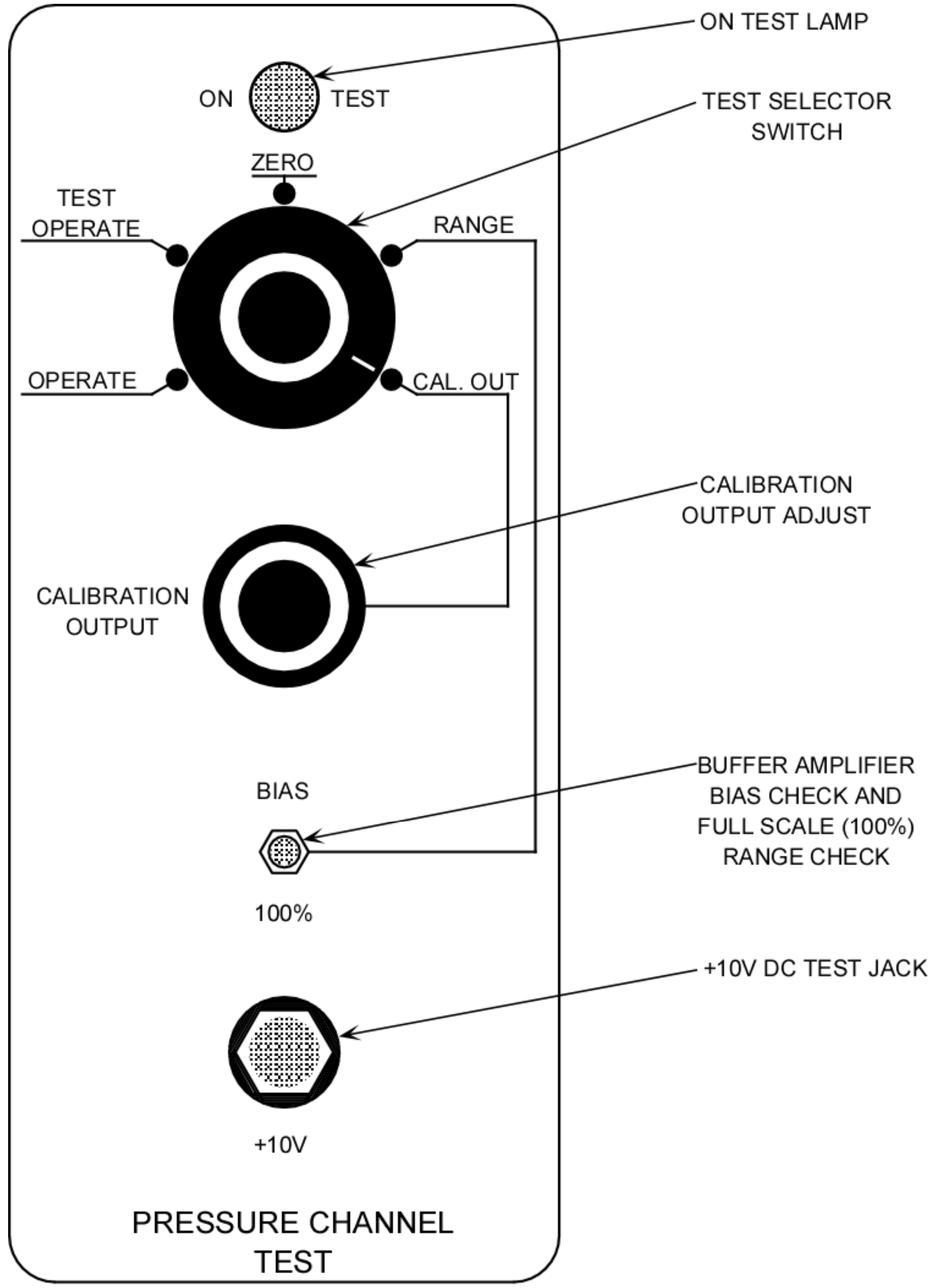

Figure 10.1-9 Channel Test Module

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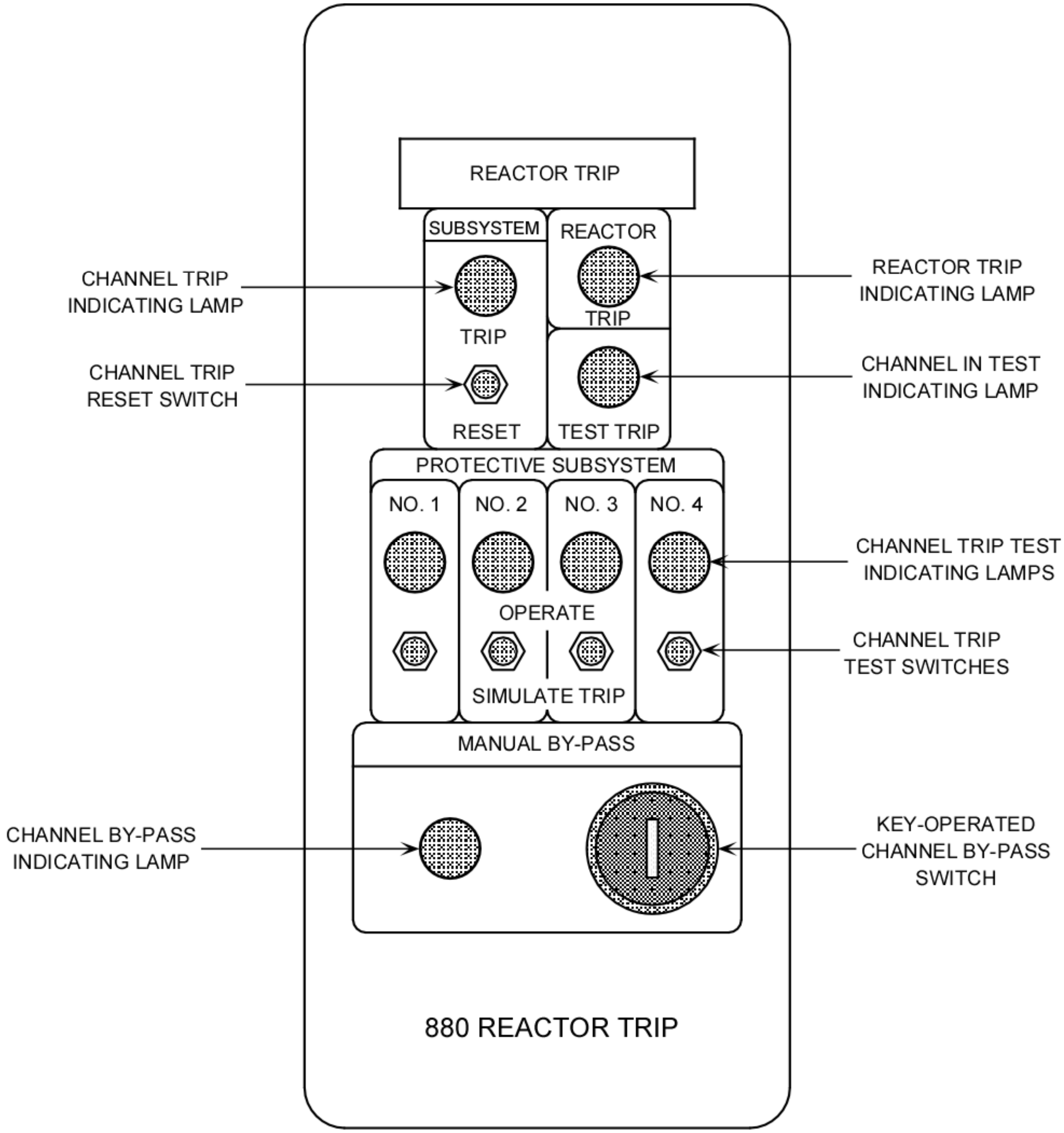

Figure 10.1-10 Reactor Trip Module

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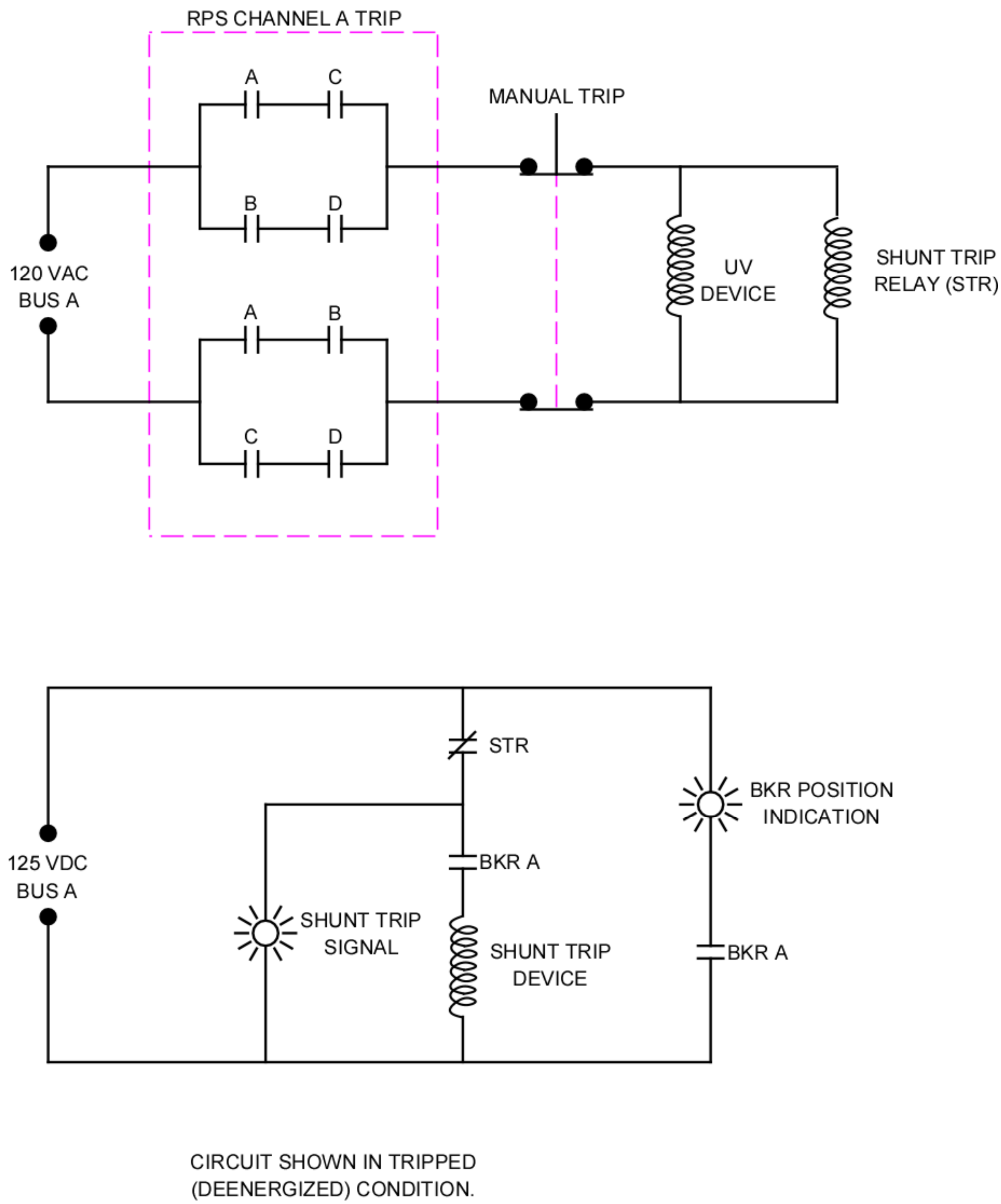

Figure 10.1-11 Shunt Trip Circuitry

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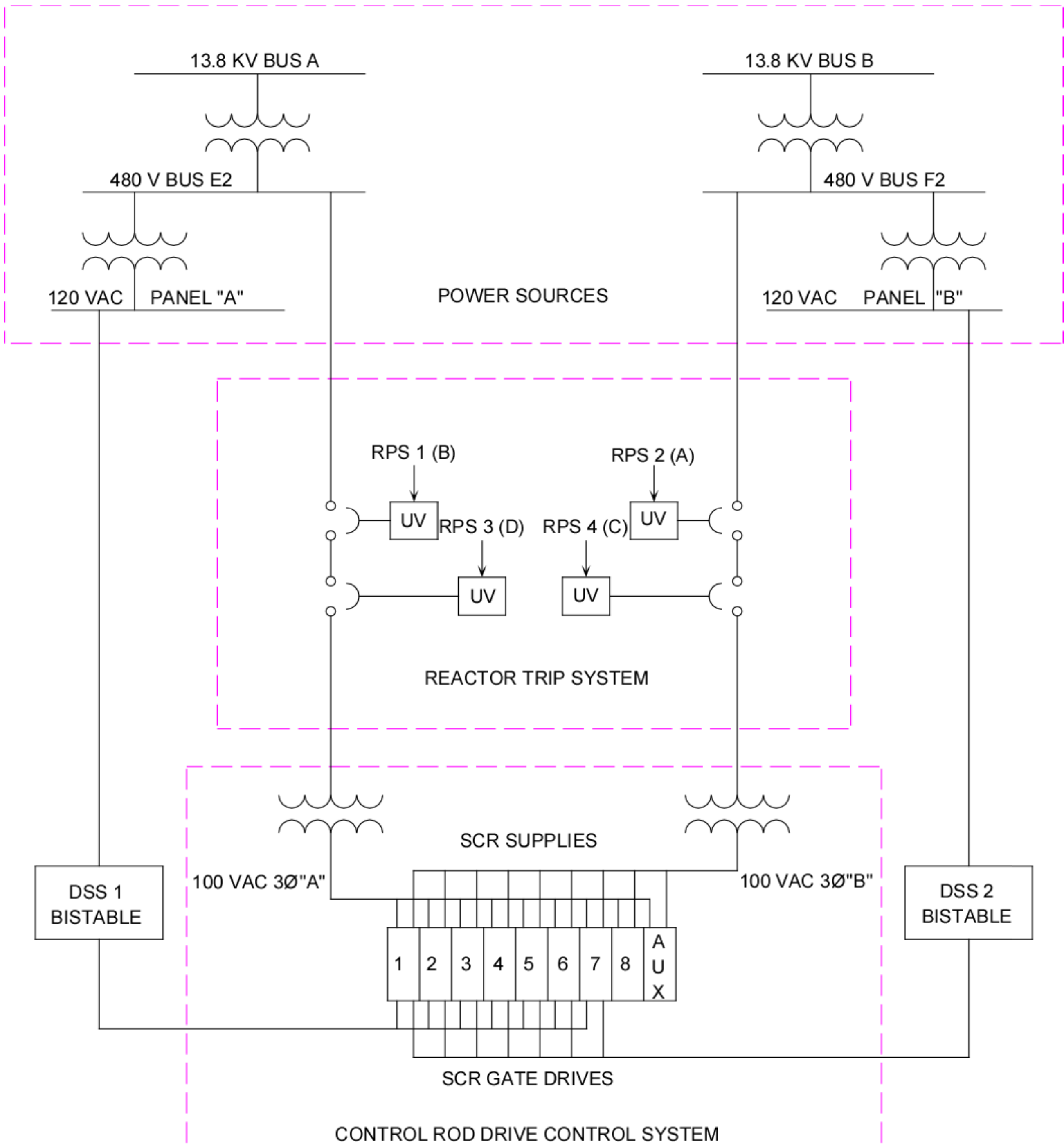

Figure 10.1-12 Backup (Diverse) Scram System (Davis-Besse)

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