1. GENERAL ELECTRIC RPS SYSTEM DESCRIPTION

1.1 System Operation

The General Electric RPS is a complex control system comprising numerous electronic components that combine to provide the ability to produce an automatic or manual rapid shutdown of the nuclear reactor, known as a reactor trip or scram. In spite of its complexity, the General Electric RPS components can be roughly divided into four segments—channels, trip systems, hydraulic control units (HCUs), and rods—as shown in Figure 1. The rod segment includes the control rods and associated control rod drives (CRDs). General Electric RPSs typically have 120 to 190 control rods and associated CRDs. The HCU segment includes the HCU components: scram pilot solenoid-operated valves or SOVs, scram inlet and outlet air-operated valves or AOVs, and scram accumulator. There is one HCU for each CRD. Also included in the HCU segment are the scram discharge volume (SDV) and two backup scram SOVs controlling instrument air to the scram air header. Some GE plants have a single, dual-coil SOV rather than two single-coil scram pilot SOVs, and the number of SDVs can be one or two. For the trip system segment, all but one of the GE plants have relay-based trip systems. Clinton, a BWR6 design, is the only GE plant to have a solid-state trip system. (The Clinton RPS design is not covered in this report.)

The analysis of the General Electric RPS is based on a BWR/4 design, with Peach Bottom Unit 2 chosen as the reference plant. This configuration, termed the relay-based RPS, has been used in a General Electric generic analysis of RPSs as representative of BWR RPS designs except for the Clinton solid-state design. A representative integrated system diagram of the RPS is shown in Figure 2. Simplified diagrams of the design, constructed to more clearly show the breakdown of the RPS into segments, are presented in Figures 3 through 6. Note that the relay numbers in Figures 3 through 6 have been chosen to be consistent with the NPRDS GE RPS diagrams.

As shown in Figures 3 through 6, there are two RPS trip systems, A and B. These trip systems receive trip signals from the channels, process the signals, and then open the HCU scram pilot SOVs given appropriate combinations of signals from the channels. Opening the scram pilot SOVs bleeds the

RPS Segments			
Channel	Trip System	HCUs and Related	Rods
4 channels (A – D, sometimes termed A1, A2, B1, and B2)	2 trip systems (A, B); scram logic and backup scram logic	120 to 190 HCUs; 1 or 2 SDVs	120 to 190 CRDs and associated control rods

Figure 1. Segments of General Electric RPS.

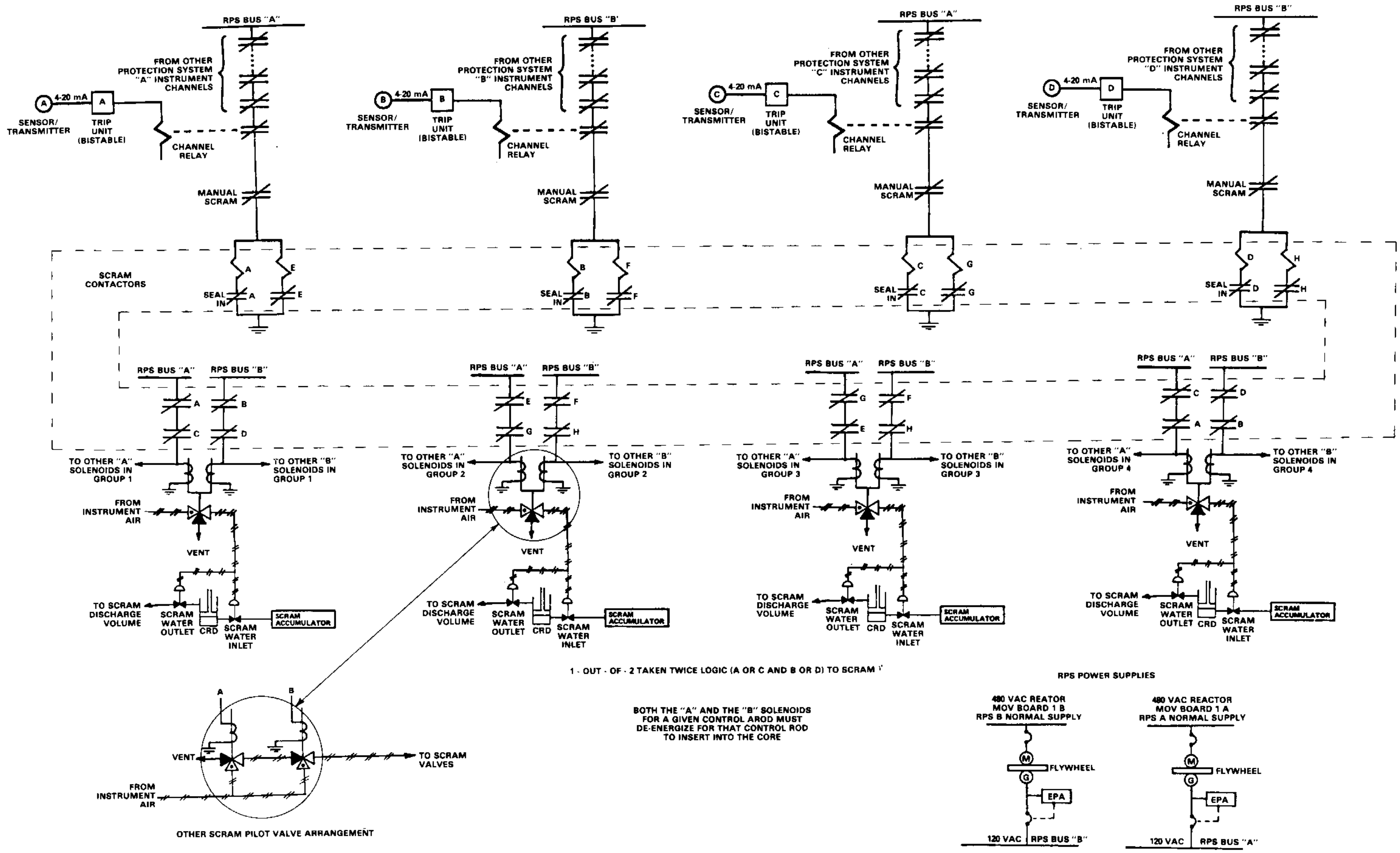

Figure 2. General Electric RPS integrated system diagram.

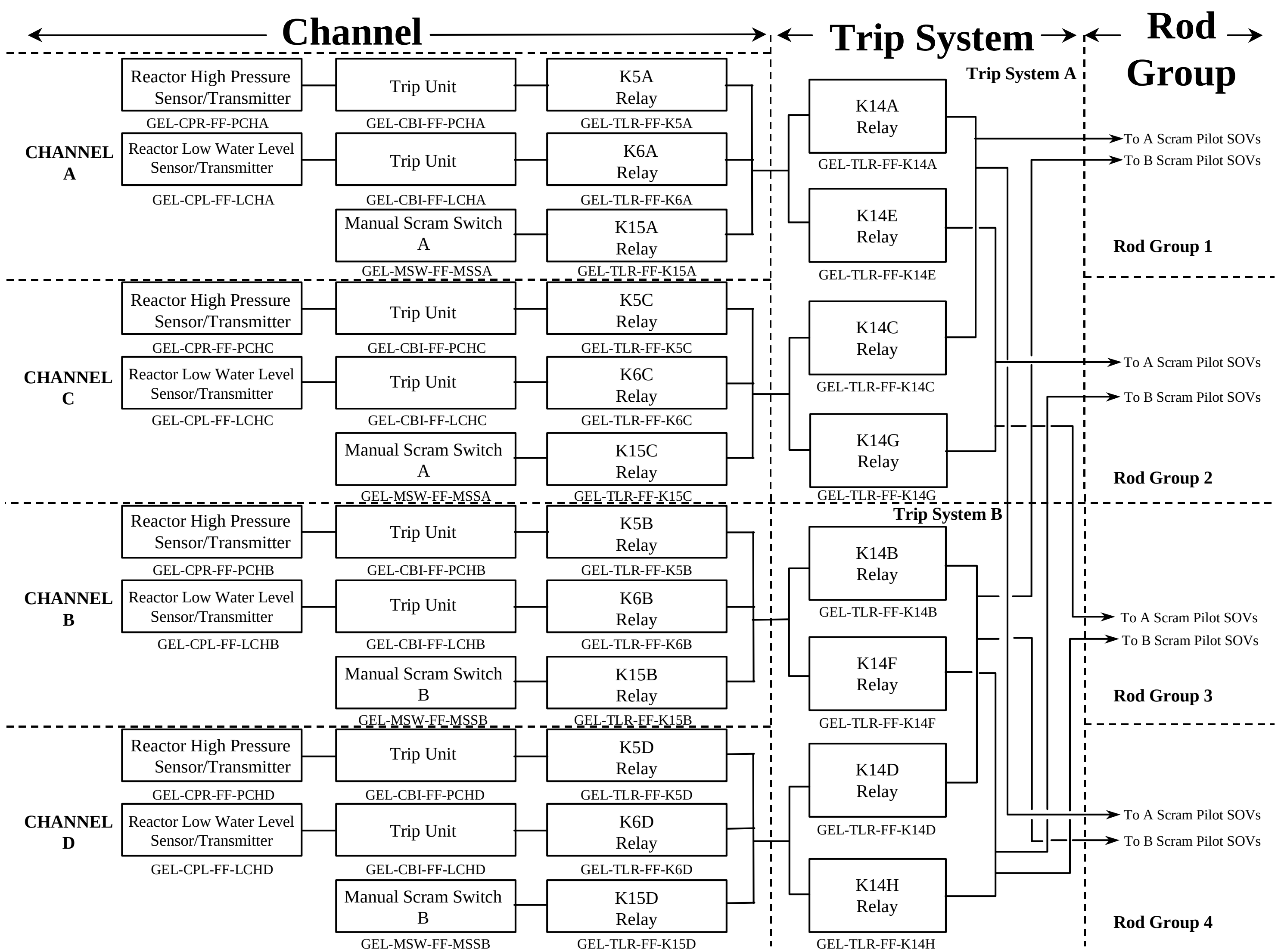

Figure 3. General Electric RPS simplified diagram (scram logic).

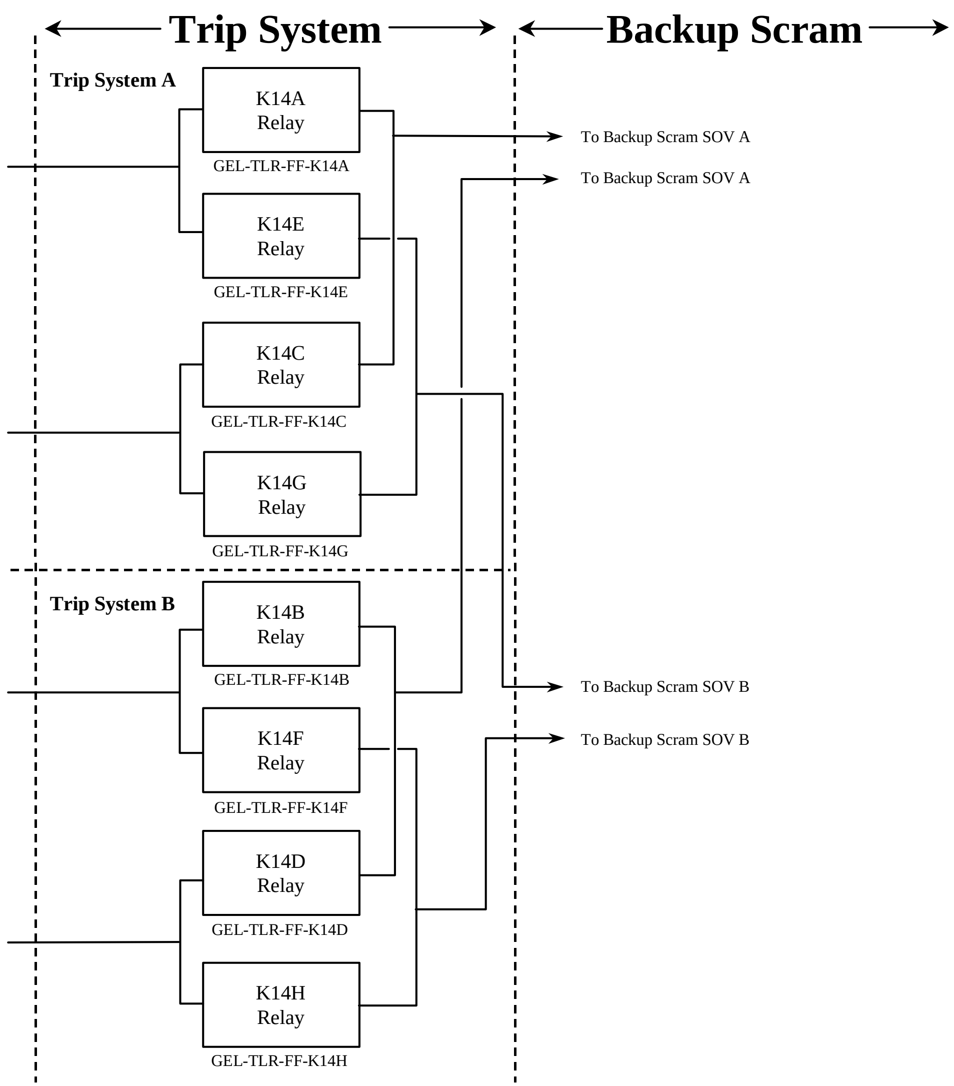

Figure 4. General Electric RPS simplified diagram (backup scram logic).

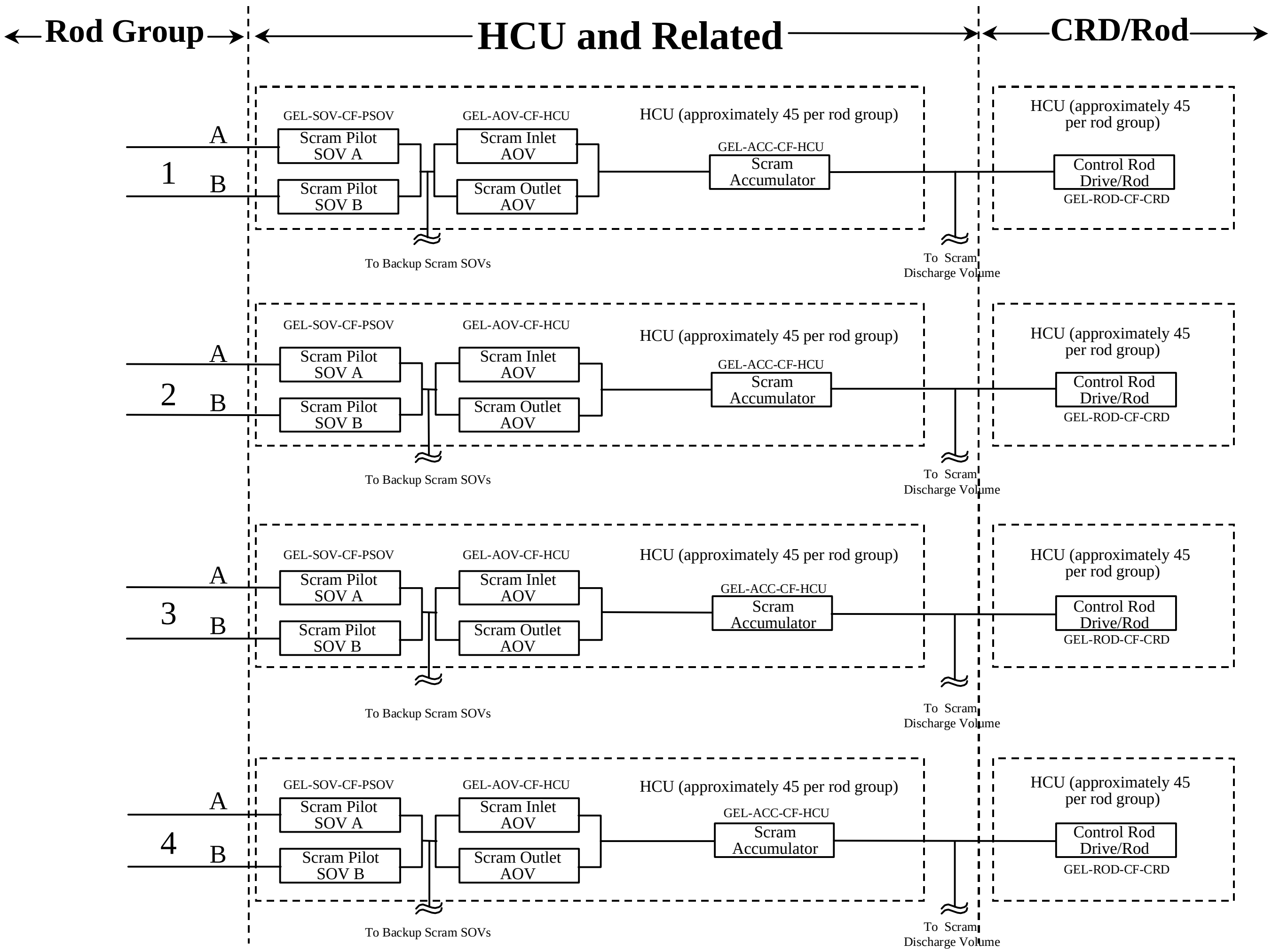

Figure 5. General Electric RPS simplified diagram (mechanical).

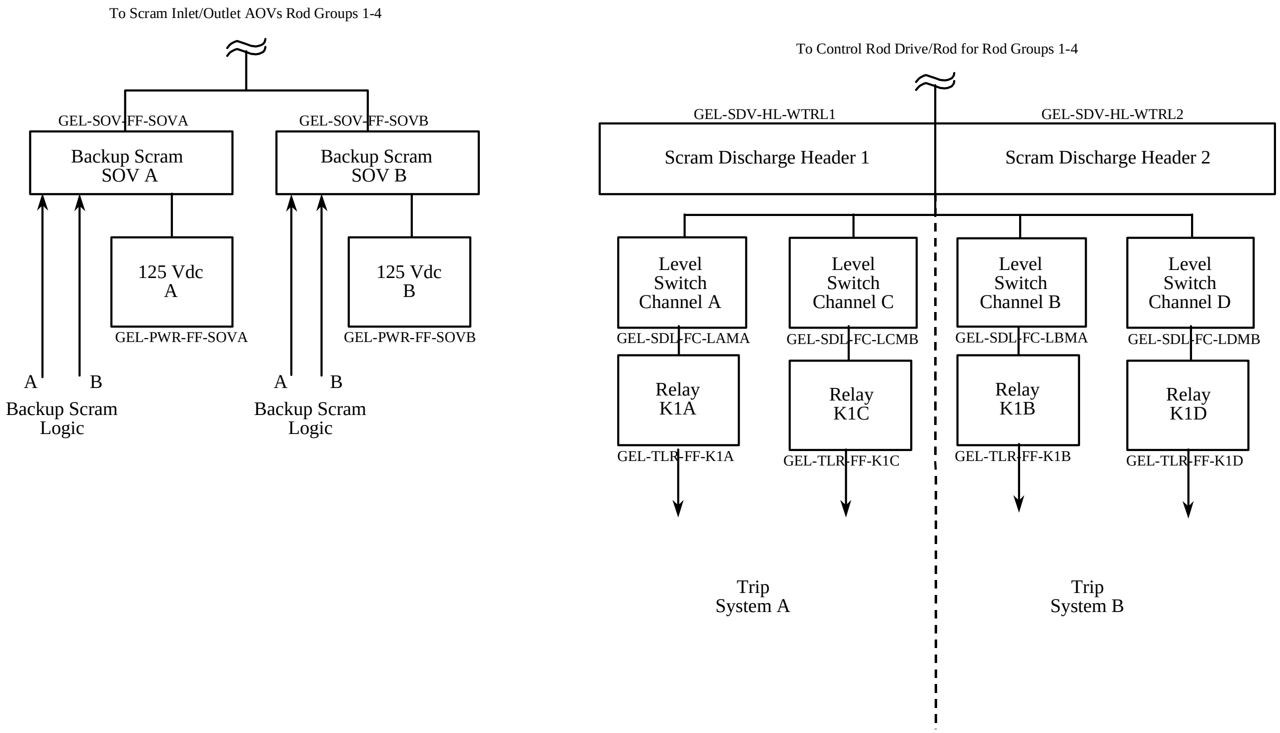

Figure 6. General Electric RPS simplified diagram (SDV and backup scram SOVs).

air from the scram inlet and outlet AOVs, allowing them to open and create a flow path for accumulator water to push the control rods up into the core.

The channel portion of the RPS, channels A through D, includes many different types of trip signals, as shown in Table 1. The trip signals include various neutron flux indications, reactor pressure and level, primary containment pressure, and others. Most of the signals involve four sensor/transmitters (or process switches), with a trip signal being generated if at least one of two measurements associated with each of the two trip systems exceeds a setpoint. This is termed a one-out-of-two-twice logic. Shown in the simplified RPS diagram in Figure 3 are sensor/transmitters and trip units associated with the reactor vessel high pressure and low water level trip signals. (These two signals, along with others, are appropriate for several plant upset conditions, such as main steam line isolation valve or MSIV closure, loss of feedwater, and various losses of electrical loads.) If a trip parameter reaches the trip setting, the trip unit de-energizes the associated relay (shown as relays K5 and K6 in Figure 3). Also shown in the figure are the manual scram switches and associated relays. The sensor/transmitter and trip unit components are located throughout the plant, while the relays are located in the two RPS cabinets in the control room. A loss of electrical power to a sensor/transmitter or trip unit would result in a trip signal.

The trip system portion of the RPS (Figures 3 and 4) includes two systems or trains, A and B. Channels A and C feed into trip system A, and channels B and D feed into trip system B. De-energizing relay K5A or K6A (or the manual scram relay K15A) in channel A results in de-energizing of contactor relays K14A and K14E. The logic is similar for the other three channel inputs to the trip systems. The scram logic (Figure 3) is arranged such that contactor relay K14A or K14C de-energizes the A scram pilot SOVs in rod groups 1 and 4, while contactor relay K14E or K14G de-energizes the A scram pilot SOVs in rod groups 2 and 3. Therefore, trip system A controls all of the A scram pilot SOVs. Similarly, trip system B controls all of the B scram pilot SOVs. Because both A and B scram pilot SOVs in an HCU must de-energize to result in control rod insertion, the main scram logic is one-out-of-two-twice. For example, a reactor vessel high-pressure signal in channel A and a reactor vessel high-pressure signal in channel B would generate a full reactor trip. However high pressure signals in only channels A and C would generate a half trip (only the A scram pilot SOVs would be de-energized). The trip systems are located in the two RPS cabinets in the control room. A loss of electrical power results in a trip signal from the affected trip system.

Figure 3 also shows four rod group circuits. Each rod group circuit controls one-fourth of the control rods. No RPS components are shown as part of the rod group circuits in the simplified diagram. The rod groups are presented to help illustrate how the rod group success criterion (assumed to be three of four) is associated with the scram logic.

Figure 4 shows the backup scram logic of the trip systems. In contrast to the scram logic, which individually controls the scram air supply inside each HCU, the backup scram controls the instrument air supply to the scram air header feeding all of the HCUs. The scram logic and the backup scram logic both utilize the eight K14 contactor relays. However, the backup scram logic uses different contacts in the relays. De-energizing contactor relay K14A or K14C and contactor relay K14B or K14D energizes backup scram SOV A, which cuts off instrument air supply to the scram air header and bleeds off the header air. Similar logic energizes backup scram SOV B, which also performs the same function. If the scram air header is bled off, then all of the HCUs lose air pressure and the control rods insert. Loss of electrical power to the backup scram SOVs results in failure of the backup scram system.

Figure 5 shows most of the mechanical portion of the General Electric RPS. Within each of the 185 HCUs in the Peach Bottom Unit 2 reference plant, there are two scram pilot SOVs, two scram inlet/outlet AOVs, a scram accumulator, and various other components. If both of the scram pilot SOVs in an HCU are de-energized, then the air supply to the AOVs is bled off. Given loss of air, both the scram

Table 1. Peach Bottom Unit 2 RPS trip signals.

Trip Signal	Trip Logic	Purpose of Trip
1. Intermediate range high neutron flux	1 of 2 twice	Prevent an inadvertent power increase at low power
2. Average power range high neutron flux	1 of 2 twice (6 average power range monitors or APRMs, each with 14 to 22 sensors)	Prevent an inadvertent power increase while at power
3. Nuclear system high pressure [a]	1 of 2 twice	Protect the integrity of the reactor vessel and prevent the addition of significant positive reactivity to the core from steam void collapse
4. Primary containment high pressure	1 of 2 twice	Minimize fuel damage and reduce the addition of energy from the core to the coolant (loss-of-coolant accidents)
5. Reactor vessel low water level [a]	1 of 2 twice	Assure there is sufficient water above the reactor core
6. Turbine stop valve closure	1 of 2 twice (3 of 4 valves must close 15% or more)	Anticipate nuclear system high pressure
7. Turbine control valve fast closure	1 of 2 twice (pressure switches in hydraulic control system)	Anticipate nuclear system high pressure
8. Main steam line isolation	1 of 2 twice (3 of 4 steam lines must have a valve close 15% or more)	Anticipate reactor vessel low water level
9. Scram discharge volume high water level [b]	1 of 2 twice	Ensure the scram discharge volume has sufficient capacity to accommodate CRD water discharge resulting from a scram
10. Main steam line high radiation (disabled in some plants)	1 of 2 twice	Limit the fission products released from the core from gross fuel failure
11. Main condenser low vacuum (not in all plants)	1 of 2 twice	Anticipate turbine stop valve closure; protect main condenser from overpressure
12. Manual scram	2 of 2 switches	Provide the operators with a means to quickly shut down the reactor

a. These two signals are modeled in the RPS fault tree used for this study.

b. The scram discharge volume high water level trip signal is included in the fault tree model only as part of a precursor or conditioning event (undetected high scram discharge volume water level when an unrelated demand for the RPS occurs). This trip signal is not included as a third trip signal for the unrelated demand being modeled.

inlet and outlet AOVs open, allowing a path for scram accumulator water to flow to the CRD (forcing the control rod into the core) and CRD water to drain to the SDV. As a sensitivity case, opening of only the scram outlet AOV was analyzed. In such a case, reactor vessel water pressure (rather than accumulator water pressure) forces the control rod into the core. However, the rod insertion time is longer for this type of operation.

Finally, Figure 6 shows the SDV and associated level instrumentation and the backup scram SOVs. As discussed previously, either of the two backup scram SOVs can cut off the instrument air supply to the scram air header and bleed off the header. These SOVs require electrical power to energize to accomplish this.

The CRD water above the hydraulic piston is exhausted to the SDV. All of the 185 CRDs exhaust to this volume. During normal operation, the SDV drain valves are open and the volume contains no water. However, if for some reason, during normal full-power operation, the drain valves were to close and the SDV started to fill with water, level switches (one-out-of-two-twice logic) trip the reactor before enough water collects to impact the CRDs. (If the SDV were full of water before a reactor scram, then none of the CRDs could exhaust water above the hydraulic pistons, and none of the control rods would insert.)

Finally, the CRDs are hydraulic pistons connected to the bottom of the control rods. There is one HCU for each CRD/control rod.