GENERAL ELECTRIC REACTOR PROTECTION SYSTEM EXECUTIVE SUMMARY

This report documents an analysis of the safety-related performance of the reactor protection system (RPS) at U.S. General Electric commercial reactors during the period 1984 through 1995. Objectives of the study were the following: (1) to estimate RPS unavailability based on operational experience data and compare the results with models used in probabilistic risk assessments (PRAs) and individual plant examinations (IPEs), and (2) to review the operational data from an engineering perspective to determine trends and patterns, and to gain additional insights into RPS performance. The General Electric RPS designs covered in the unavailability estimation include those with relay-based trip systems. The fault tree developed for this design assumed a BWR/4 plant.

General Electric RPS operational data were collected from Licensee Event Reports as reported in the Sequence Coding and Search System and the Nuclear Plant Reliability Data System. The period covered 1984 through 1995. Data from both sources were evaluated by engineers with operational experience at nuclear power plants. Approximately 7,000 events were evaluated for applicability to this study. Those data not excluded were further characterized as to the type of RPS component, type of failure, failure detection, status of the plant during the failure, etc. Characterized data include both independent component failures and common-cause failures (CCFs) of more than one component. The CCF data were classified as outlined in the report *Common-Cause Failure Data Collection and Analysis System* (NUREG/CR-6268). Component demand counts were obtained from plant reactor trip histories and component test frequency information.

The risk-based analysis of the RPS operational data focused on obtaining failure probabilities for component independent failure and CCF events in the RPS fault tree. The level of detail of the basic events includes the following: channel trip signal sensor/transmitters and associated bistables, process switches, and relays; hydraulic control units (solenoid- and air-operated valves and the scram accumulator); and control rod drives and control rods. CCF events were modeled for all redundant, similar types of components.

Data analysis and subsequent fault tree quantification resulted in an RPS mean unavailability (failure probability upon demand) of 5.8E-6 for the BWR/4 relay-based design. (This unavailability does not include any credit for operator action to actuate the manual scram switches.) An uncertainty analysis resulted in a 5th percentile value of 1.8E-6 and a 95th percentile value of 1.4E-5. Essentially 100% of this unavailability is from CCF events; the combinations of independent failures contribute less than 0.1%. Channel failures contribute 58% to the total unavailability, hydraulic control unit failures contribute 32%, trip system failures contribute 6%, and control rod and control rod drive failures contribute 4%.

CCF events involving the scram pilot solenoid-operated valves (SOVs) and backup scram SOVs contribute 29% to the overall RPS unavailability. The most significant historical event, involving the use of improper seating material and affecting all the scram pilot SOVs, occurred in 1984. Two similar types of SOV CCF events occurred in 1994 but did not affect as many of the components. In addition, problems with the use of liquid thread sealant resulted in several significant CCF events. It is believed that the requirement to test 10% of the control rods each four months helped discover these types of problems (developing over time) before they developed to catastrophic failures.

The backup scram portion of the RPS may be an important contributor to low RPS unavailability, based on the sensitivity study discussed in Appendix G of this report and uncertainties associated with the SOV failure characteristics. (Without the backup scram logic, only two of eight trip system relay failures are needed to fail the RPS, rather than four of eight if the backup scram system is modeled.) The backup scram SOVs are classified as non-safety-related and these valves are not part of the NPRDS reportable scope for the General Electric RPS. Therefore, no failure data were collected for these valves. In addition, it is not clear how often these valves are tested, and what their failure probabilities are. This study assumed these valves are tested every 18 months during shutdown, and that their failure characteristics are similar to the scram pilot SOVs. These assumptions should be verified.

There were significant scram discharge volume (SDV) problems in the early 1980s involving both drainage of SDVs and level instrumentation, dominated by the 1980 Browns Ferry Unit 3 failure of 76 of 185 control rods to insert. Data collected during the period 1984 through 1995 indicate that SDV instrumentation failure probabilities are similar to other RPS trip instrumentation. In addition, only one inadvertent filling of the SDV while a plant was at power was identified during the period. Finally, the RPS fault tree quantification indicates that SDV events leading to failure of the RPS contribute less than 1% to the overall RPS unavailability. Therefore, early SDV-related problems in General Electric RPSs are no longer dominant contributors to RPS unavailability.

The RPS fault tree was also quantified allowing credit for manual scram by the operator (with a failure probability of 0.01). The resulting RPS unavailability is 2.6E-6. Operator action reduces the RPS unavailability by approximately 55%. This reduction is limited because a dominant contributor to RPS unavailability is the scram pilot SOV CCF event, which is unaffected by the operator action. In addition, the manual scram signal must still pass through the channel and trip system relays, for the configuration analyzed. RPS hydraulic control unit failures (SOVs) contribute 71% to the total unavailability, trip system failures contribute 14%, control rod and control rod drive failures contribute 10%, and channel failures contribute 5%.

The unavailability estimate of 5.8E-6 (allowing no credit for manual scram by the operator) is lower than typically used in the past. Past estimates typically ranged from 1.0E-5 to 3.0E-5 and were usually based on information in NUREG-0460, published in 1978. The individual component failure probabilities per demand, derived from the 1984 through 1995 data, are generally comparable to failure probability estimates listed in previous reports. Therefore, the low RPS unavailability estimate is mostly attributable to lower failure probabilities for the CCF events. The General Electric RPS CCF events collected for this project, covering the period 1984 through 1995, contain few events involving complete failures of many redundant components. Correspondingly, the CCF calculations result in low CCF failure probabilities.

The trends in component failure probabilities and numbers of CCF events are generally flat over the period 1984 through 1995. Therefore, existing RPS surveillance and maintenance practices and industry lessons learned programs have been effective in preventing increasing failure probabilities.