COMBUSTION ENGINEERING REACTOR PROTECTION SYSTEM EXECUTIVE SUMMARY

This report documents an analysis of the safety-related performance of the reactor protection system (RPS) at U.S. Combustion Engineering (CE) commercial nuclear reactors during the period 1984 through 1998. The objectives of the study were (1) to estimate RPS unavailability based on operational experience data and compare the results with models used in probabilistic risk assessments and individual plant examinations, 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 CE RPS designs covered in the unavailability estimation include four versions. Fault trees developed for this study were based on these four versions, which represent all CE plants.

Combustion Engineering RPS operational data were collected from Licensee Event Reports as recorded in the Sequence Coding and Search System and the Nuclear Plant Reliability Data System. The period covered 1984 through 1998. Data from both sources were evaluated by engineers with operational experience at nuclear power plants. Approximately 2400 events were evaluated for applicability to this study. 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 common-cause failure events in the RPS fault tree. The level of detail of the basic events includes channel trip signal sensor/transmitters and associated bistables, process switches and relays, and control rod drives and control rods. Common-cause failure events were modeled for all redundant, similar types of components.

Fault trees for each of the four designs of the CE RPS were developed and quantified using U.S. CE commercial nuclear reactor data from the period 1984 through 1998. All CE plants use the same channel through trip module design, except later plants use a digital core protection calculator. The Group 1 design uses trip contactors without any form of circuit breaker. The other three groups use either an eight-breaker design (Groups 2 and 3) or a four-breaker design (Group 4). Table ES-1 summarizes the RPS unavailability results of this study.

Table ES-1. Summary of Combustion Engineering RPS model results.

	5%	Mean	95%
Group 1 RPS Model			
No credit for manual trip by operator	1.2E-6	6.5E-6	1.8E-5
Credit for manual trip by operator	8.8E-7	5.7E-6	1.7E-5
Group 2 RPS Model			
No credit for manual trip by operator	1.9E-6	7.5E-6	1.9E-5
Credit for manual trip by operator	3.9E-7	1.9E-6	5.1E-6
Group 3 RPS Model			
No credit for manual trip by operator	1.9E-6	7.5E-6	1.9E-5
Credit for manual trip by operator	3.9E-7	1.9E-6	5.1E-6
Group 4 RPS Model			
No credit for manual trip by operator	1.6E-6	7.2E-6	1.9E-5
Credit for manual trip by operator	2.4E-7	1.6E-6	4.7E-6

The computed mean unavailabilities for the various CE design groups ranged from 6.5E-6 to 7.5E-6 (with no credit for manual trips). These are comparable to the values CE IPEs, which ranged from 3.7E-6 to 1.0E-5, and other reports. Common-cause failures contribute approximately 99 percent to the overall unavailability of the various designs. The individual component failure probabilities are generally comparable to failure probability estimates listed in previous reports.

The RPS fault tree was also quantified for manual trip by the operator (assuming an operator failure probability of 0.01). The mean unavailabilities improved 13 percent (Group 1) to 78 percent (Group 4), with a range of 1.6E-6 to 5.7E-6.

The study revealed several general insights:

- The dominant failure contribution to the Combustion Engineering RPS designs involve CCFs of the trip relays (K-1 through K-4, Groups 2, 3, and 4 or M-1 through M-4 Group 1) and the CCF of the mechanical portion of the trip breakers (except Group 1).

- Issues from the early 1980s that affected the performance of the reactor trip breakers (e.g., dirt, wear, lack of lubrication, and component failure) are not currently evident. Improved maintenance has resulted in improved performance of these components.

- Overall, the trends in unplanned trips, component failures, and CCF events decreased significantly over the time span of this study.

- The calculated unavailability of plants that have analog rather than digital core protection calculators shows no sensitivity to this design difference.

- The causes of the CE CCF events are similar to those of the rest of the industry. That is, over all RPS designs for all vendors for the components used in this study, the vast majority (80 percent) of RPS common-cause failure events can be attributed to either normal wear or out-of-specification conditions. These events are typically degraded states, rather than complete failures. Design and manufacturing causes led to the next highest category (7 percent) and human errors (operations, maintenance, and procedures) were the next highest category (6 percent). Environmental problems and the state of other components (e.g., power supplies) led to the remaining RPS common-cause failure events. No evidence was found that these proportions are changing over time.

- The principle method of detection of failures of components in this study was either by testing or by observation during routine plant tours. Only two failures were detected by actual trip demands, neither of which was a CCF. No change over time in the overall distribution of detection method is apparent.