HIGH-PRESSURE COOLANT INJECTION EXECUTIVE SUMMARY

This report presents a performance evaluation of the High-Pressure Coolant Injection (HPCI) systems at 24 United States commercial boiling-water reactors (BWRs). The evaluation is based on the operating experience from 1987 through 1998, as reported in Licensee Event Reports (LERs). This report updates a previous analysis of the HPCI system for the same twenty-four BWRs based on the operating experience from 1987 through 1993. The primary objectives of the study are to: (1) estimate the system unreliability based on 1987–1998 operating experience; (2) compare these estimates to estimates derived by using the failure probabilities used in probabilistic risk assessments and individual plant examinations (PRA/IPEs); (3) determine if there are trends and patterns in the HPCI system operating experience; (4) provide an engineering analysis of the factors affecting HPCI system unreliability; and (5) determine if the HPCI system unreliability from this updated study is changing in comparison to the original study results based on the 1987–1993 operating experience.

This study used as its source data the operating experience from 1987 through 1998 as reported in LERs. The Sequence Coding and Search System (SCSS) database was used to identify LERs that reported unplanned demands and inoperabilities of the HPCI system. The full text of each LER was reviewed from a risk and reliability perspective by at least two engineers with commercial nuclear power plant experience.

The HPCI system unreliability was estimated using a fault tree model to associate event occurrences with broadly defined failure modes such as failure to start or failure to run. The probabilities for the failure modes were calculated by reviewing the failure information, categorizing each event by failure mode, and estimating the corresponding number of demands (both successes and failures). Sixteen plant risk reports (i.e., PRAs, IPEs, and NUREGs) were used for comparison to the HPCI reliability results calculated in this study. These reports document HPCI system information for twenty-four BWR plants.

Major Findings–Reliability Analysis

HPCI system unreliability for a short-term mission based on the 1987–1998 operating experience has increased slightly compared to the earlier estimate presented in the original report. The unreliability estimated based on original 1987–1993 operating experience and the1987–1998 operating experience are 5.6E-2 and 6.6E-2, respectively. The small increase in the HPCI system unreliability estimate based on the 1987–1998 operating experience is primarily due to modeling failure of the injection valve to reopen in the unreliability calculation. Since this failure mode, although identified in the original report, was not included in the system unreliability estimate calculated in the original report, the difference between the two estimates cannot be regarded as being real.

The major findings from the update analysis are summarized below.

Overall unreliability. The industry-wide unreliability of the HPCI system calculated from the 1987–1998 operating experience for a short-term mission is 6.6E-02 per demand. If the probability of operator recovery from failure is ignored, the industry-wide mean is 8.1E-02. The unreliability estimates are based on failures that occurred during unplanned demands, and cyclic and quarterly surveillance tests.

Failure of the injection valve to reopen (cycling the injection valve for subsequent reactor pressure vessel water level control) and failure to start of the system other than the injection valve are the leading contributors to HPCI system unreliability, 33% and 26%, respectively.

Plant-specific results. Individual plant results vary from about 5.5E-02 to 9.1E-02, or less than a factor of two. The estimates of HPCI system unreliability using operating experience from LERs and

fault tree analyses are plotted in Figure ES-1. The differences among plants are small and are not considered risk significant. Details are provided in Section 3.2 of the report.

Comparisons to PRA/IPEs. A second fault tree was developed to compare HPCI system unreliabilities based on PRA/IPE data and data from the 1987–1998 operating experience. The industry-wide average of HPCI system unreliability calculated using data (e.g., component failure probabilities, maintenance unavailability) extracted from PRA/IPEs is about a factor of three lower than the industry-wide estimate, based on the 1987–1998 experience. However, this comparison is based on data from the original IPE submittals. The data used in the IPEs were based on the experience from the decade of the 1980s, and therefore the IPE failure rates may not represent the system failures modeled in this report but may represent a subset of the 1987–1998 experience. A plot of these estimates is shown in Figure ES-2. Some plant-specific results displayed in Figure ES-2 consists of a single point (the mean value) since no uncertainty parameters for the component failure probabilities were available in the IPE. Section 3.3 provides the results and insights for comparison with PRA/IPE results.

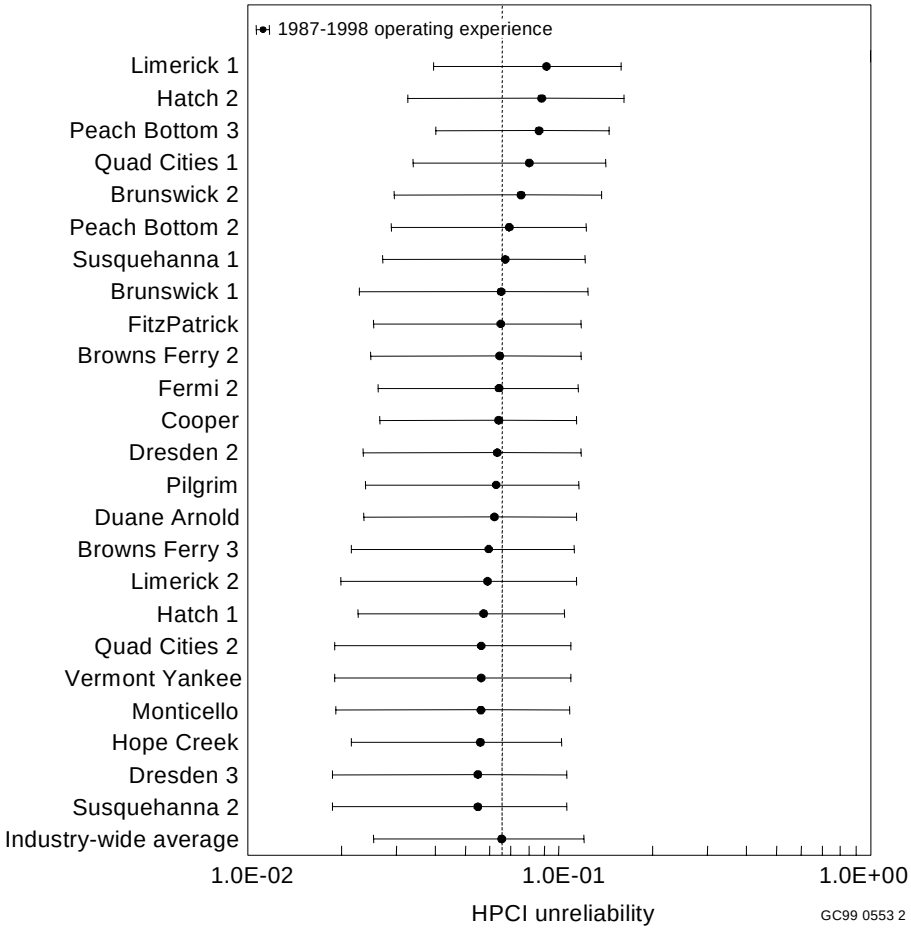

Figure ES-1. Plant-specific estimates of HPCI system unreliability for a short-term mission.

The leading contributors to HPCI system unreliability for a accident-postulated mission based on the fault tree developed for comparison to PRA/IPEs and using the 1987–1998 experience are the failure of the injection valve to reopen (cycling the injection valve for subsequent for reactor pressure vessel

water level control) and failure to run of the system other than suction transfer, 55% and 42%, respectively.

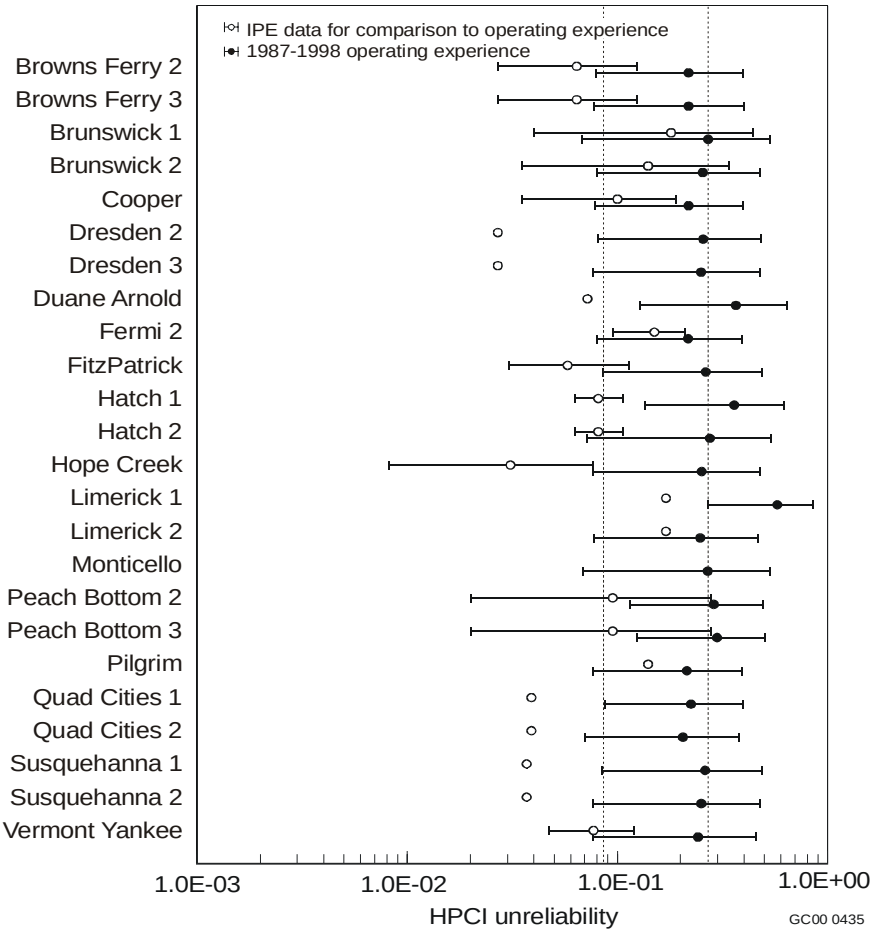

Figure ES-2. Plant-specific estimates of HPCI system unreliability (accident-postulated mission for PRA comparison purposes) based on the 1987–1998 operating experience and compared to estimates calculated using component failure probabilities found in the PRA/IPEs. (The dashed lines represent the corresponding industry-wide averages.)

Unreliability trend. Estimates of HPCI system unreliability (short-term mission) on a per calendar year basis identified no statistically significant decreasing trend within the industry estimates. Figure ES-3 displays the trend by calendar year of the unreliability calculated from the 1987–1998 experience.

Unplanned demand trend. Trends were identified in the frequency of HPCI unplanned demands (Figure ES-4). When modeled as a function of calendar year, the unplanned demand frequency exhibited a highly statistically significant decreasing trend.

Failure trend. The frequency of failure events observed by all detection methods was analyzed to determine trends. These detection methods include unplanned demands, cyclic and quarterly surveillance tests, as well as other detection methods, such as weekly tests and inspections. When modeled as a function of calendar year, a highly statistically significant decreasing trend was identified. The frequency of all HPCI system failures decreased by about a factor of four during the 1987–1998 period. Based on the end point of the trend line (calendar year 1998), this frequency is equivalent to an expectation across

the industry (24 plants) of about nine HPCI system failures per year. The fitted frequency is plotted against calendar year in Figure ES-5.

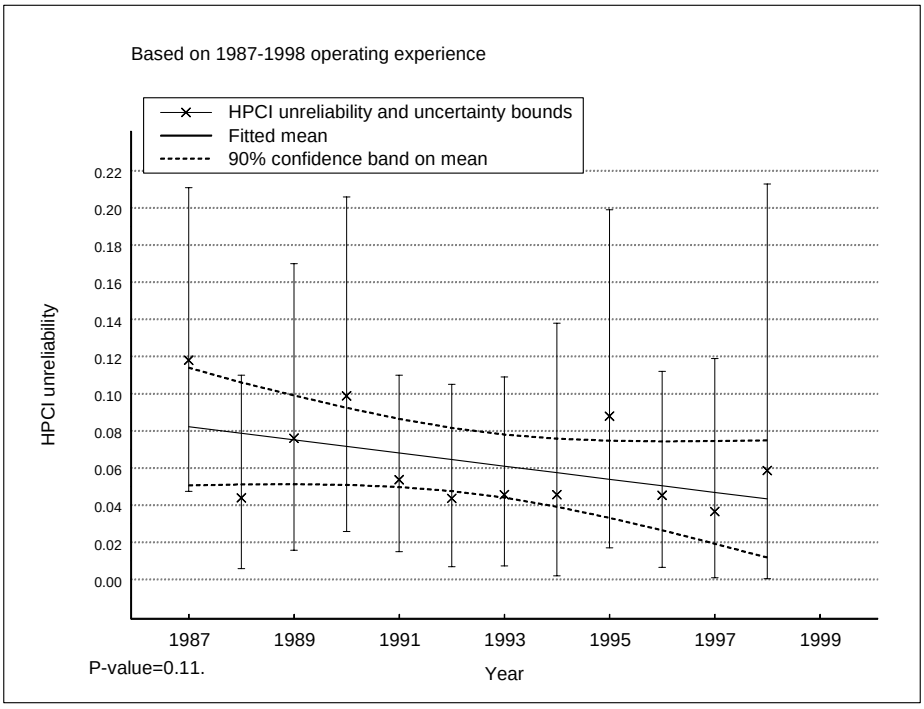

Figure ES-3. Trend of HPCI system unreliability (short-term mission), as a function of calendar year. The decreasing trend is not statistically significant.

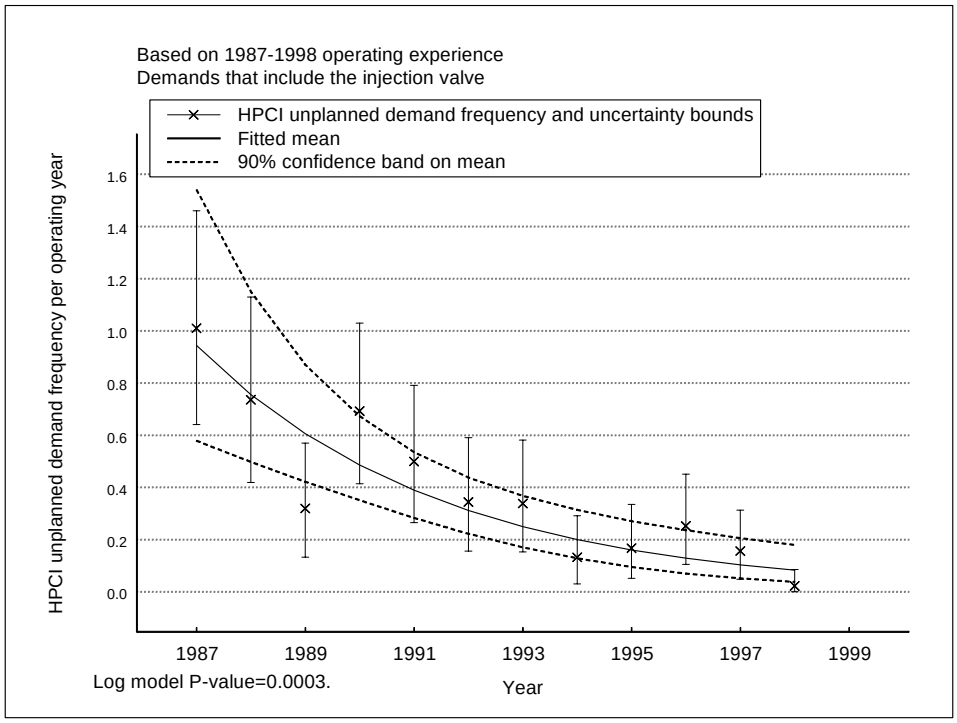

Figure ES-4. Frequency (events per operating year) of unplanned demands, as a function of calendar year. The decreasing trend is highly statistically significant.

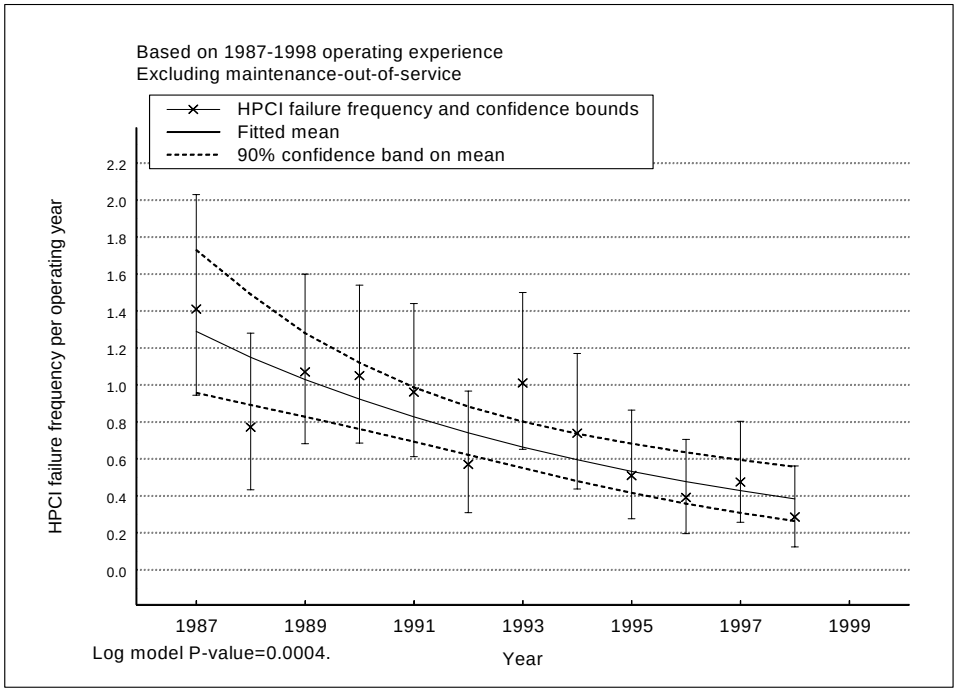

Figure ES-5. Frequency (events per operating year) of failures, as a function of calendar year. The decreasing trend is highly statistically significant.

Major Findings–Engineering Analysis

The HPCI system failures were reviewed several ways to identify the factors affecting overall system unreliability and the effectiveness of surveillance tests to detect these failures. The forty-six system failures used in the unreliability calculation were reviewed for insights into the cause of failure, component failed, and the HPCI system mode of failure. In addition, the remaining 116 failures were used to assist in developing insights into the reliability performance of the HPCI system.

Major contributor to system unreliability. As presented earlier, the leading contributor to HPCI system short-term unreliability is the failure of the injection valve to reopen for subsequent reactor pressure vessel water level control. Based on the limited unplanned demand data (79 demands), there is a 0.6% probability of the injection valve failing to initially open compared to 20% probability that the injection valve will fail to reopen if needed later during plant recovery. Since testing of the injection valve involves only a single-stroke test, the failure probability of the injection valve to reopen is based on two failure events that occurred during twelve unplanned demands (1987–1998 operating experience) where the valve was being cycled for reactor water level control.

Effectiveness of various detection methods. Overall, testing of various types and frequencies was the most effective method in detecting failures. Testing identified about half of the HPCI system failures. Although quarterly and cyclic surveillance testing as required by plant technical specifications resulted in 26% of the HPCI system failures, approximately 24% of the HPCI system failures were discovered by other routine tests and checks (e.g., weekly and monthly tests, post maintenance tests, etc.).

The HPCI system injection valve is tested quarterly; however, the quarterly testing of this valve is done in an environment that does not produce the same stresses on the valve that the valve would encounter in an accident environment. In addition, the injection valve is not cycled repeatedly during the quarterly test.

Leading component failures. Two component groups contributed about two thirds of all HPCI system failures: instrumentation and control (electronic) components and valves, 40% and 27%, respectively.

Leading causes of failure. Seven out of ten failures of the HPCI system observed in the 1987–1998 experience were attributed to hardware-related problems. Personnel errors caused 17% of all HPCI system failures. However, 70% of these failures were immediately identified, meaning that the failures were of the nature where plant personnel were able to respond to the failures immediately after they occurred.