HIGH-PRESSURE SAFETY INJECTION EXECUTIVE SUMMARY

This report presents a performance analysis of High-Pressure Safety Injection (HPI) systems at 72 United States commercial pressurized water reactors (PWRs). The evaluation is based on the operating experience from 1987 through 1997, as reported in Licensee Event Reports (LERs). The objectives of the study are: (1) to estimate the system unreliability based on operating experience and to compare these estimates with the estimates using data from probabilistic risk assessments and individual plant examinations (PRA/IPEs); and (2) to review the operating data from an engineering perspective to determine trends and patterns seen in the data and provide insights into the failures and failure mechanisms associated with the operation of the HPI system.

This study used as its source data the operating experience from 1987 through 1997 as reported in LERs. The Sequence Coding and Search System (SCSS) database was used to identify LERs for review and classification for this study. The reportability requirements of 10 CFR 50.73 (LER rule) were not used to define or classify any events used in this study. The full text of each LER was reviewed by an U.S. commercial nuclear power plant experienced engineer from a risk and reliability perspective.

The HPI system unreliabilities (injection phase only) were 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. Forty-seven plant risk reports (i.e., PRAs, IPEs, and NUREGs) were used for comparison to the HPI reliability results obtained in this study. These reports document HPI system information for 72 PWR plants.

The HPI system configurations (and operation) for the 72 plants used in this study differ considerably. HPI systems consist of different levels of pump train redundancy and diversity. To facilitate the assessment of the HPI systems, six HPI design classes were identified, and the plants were categorized accordingly.

Major Findings

Overall unreliability. Based on the 1987–1997 experience data, there were no failures of the entire HPI system identified in 224 unplanned system demands. System level fault tree models that use more detailed segment-level data and individual failure modes produce an unreliability of the HPI system of 4.5E-04 (calculated by arithmetically averaging the results of 72 plant-specific models).

Plant-specific results. Individual plant results vary by about a factor of fifty, from 6.0E-05 to 3.5E-03. The variability among the six HPI design classes largely reflects the diversity found in HPI system designs. The variability within design classes is attributed to the difference in design and operating characteristics rather than differences in plant-specific performance. The estimates of HPI unreliability using operating experience from LERs and fault tree analyses are plotted in Figure ES-1. Contributions to unreliability varied depending on the design and operation of the HPI system. Details for each class are provided in Section 3.2 of the report.

Dominant contributors to unreliability. Common cause failure (CCF) is the leading contributor to the HPI system unreliability. The importance of CCF is typical of redundant train systems that are highly reliable. Although there were no actual CCFs events identified in the unplanned SI actuations, there were CCF events identified in the 1987–1997 experience that occurred other than during an unplanned demand.

The dominant contributors to CCF were:

- Failures in HPI mini-flow lines,
- Hardware failures attributed to procedural or design flaws affecting redundant trains,
- Gas binding,
- Failed MOVs affecting the functionality of injection headers or suction path, and
- Level indication in suction tanks.

Comparisons to PRA/IPEs. The industry-wide arithmetic average of HPI system unreliability calculated using data (component failure probabilities, maintenance unavailability, etc.) extracted from PRA/IPEs is 5.8E-04. The corresponding estimate based on the 1987–1997 experience is 4.5E-04. A plot of these estimates is shown in Figure ES-2. PRA/IPE and operating experience estimates were generally comparable except for HPI Design Class 6.

For 50% of the Design Class 6 plants, the unreliabilities based on the IPE data are one or more orders of magnitudes lower than the unreliabilities calculated using operating experience. This difference is attributed to the low probabilities assigned to passive component failures such as the RWST in these IPEs.

Unplanned demand trend. Trends were identified in the frequency of the HPI unplanned demands, which includes both actual SI and inadvertent SI actuation. When plotted against calendar year, the unplanned demand frequency exhibited a statistically significant decreasing trend (Figure ES-3). Based on the fitted rate shown in Figure ES-3, the unplanned demand frequency for HPI for a population of 72 PWRs decreased from approximately 48 per year in 1987 to approximately 6 per year in 1997. This constitutes an improving trend in the frequency of events challenging the HPI system.

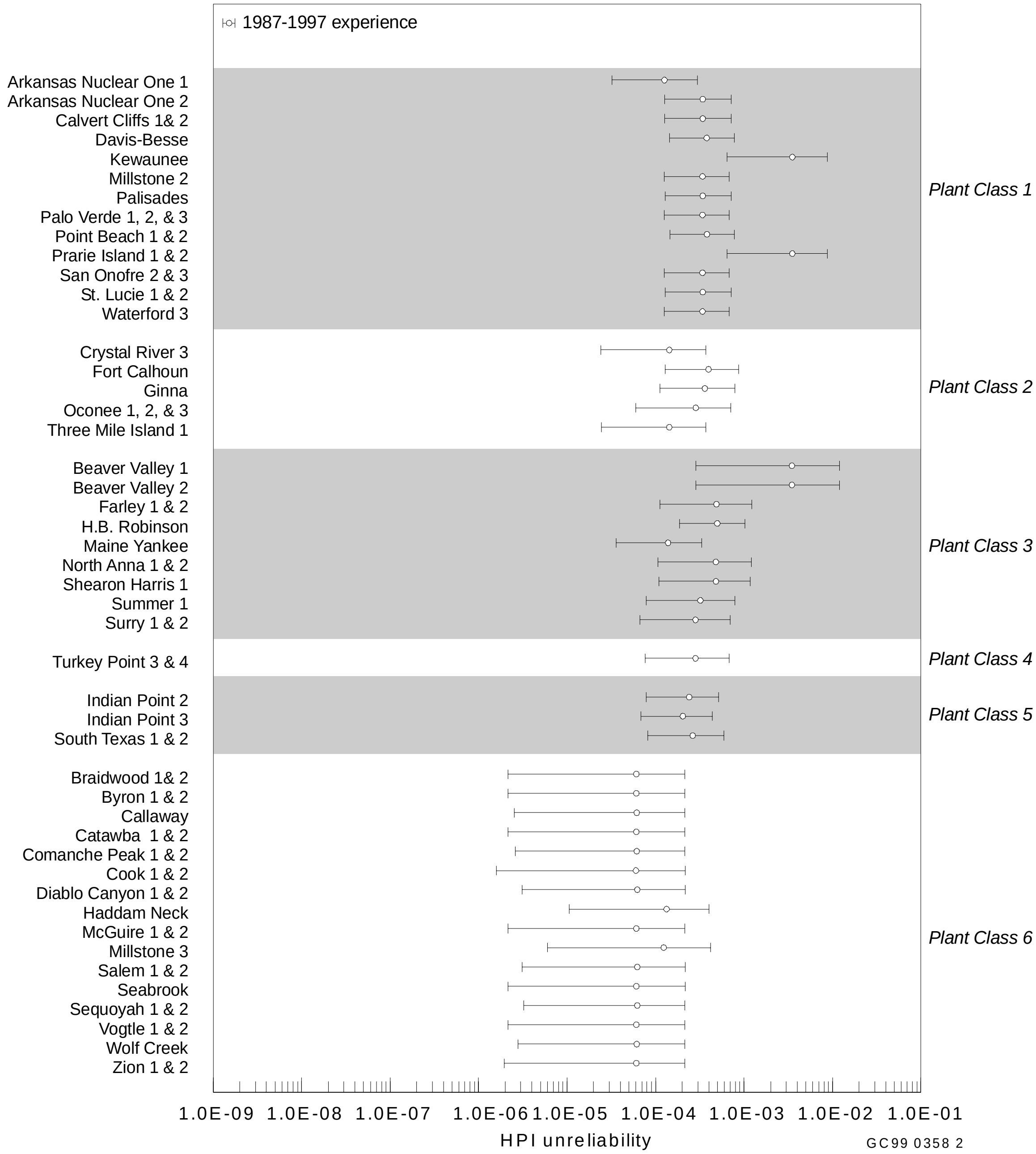

Figure ES-1. Plant-specific estimates of HPI system unreliability (injection phase only) grouped by design class.

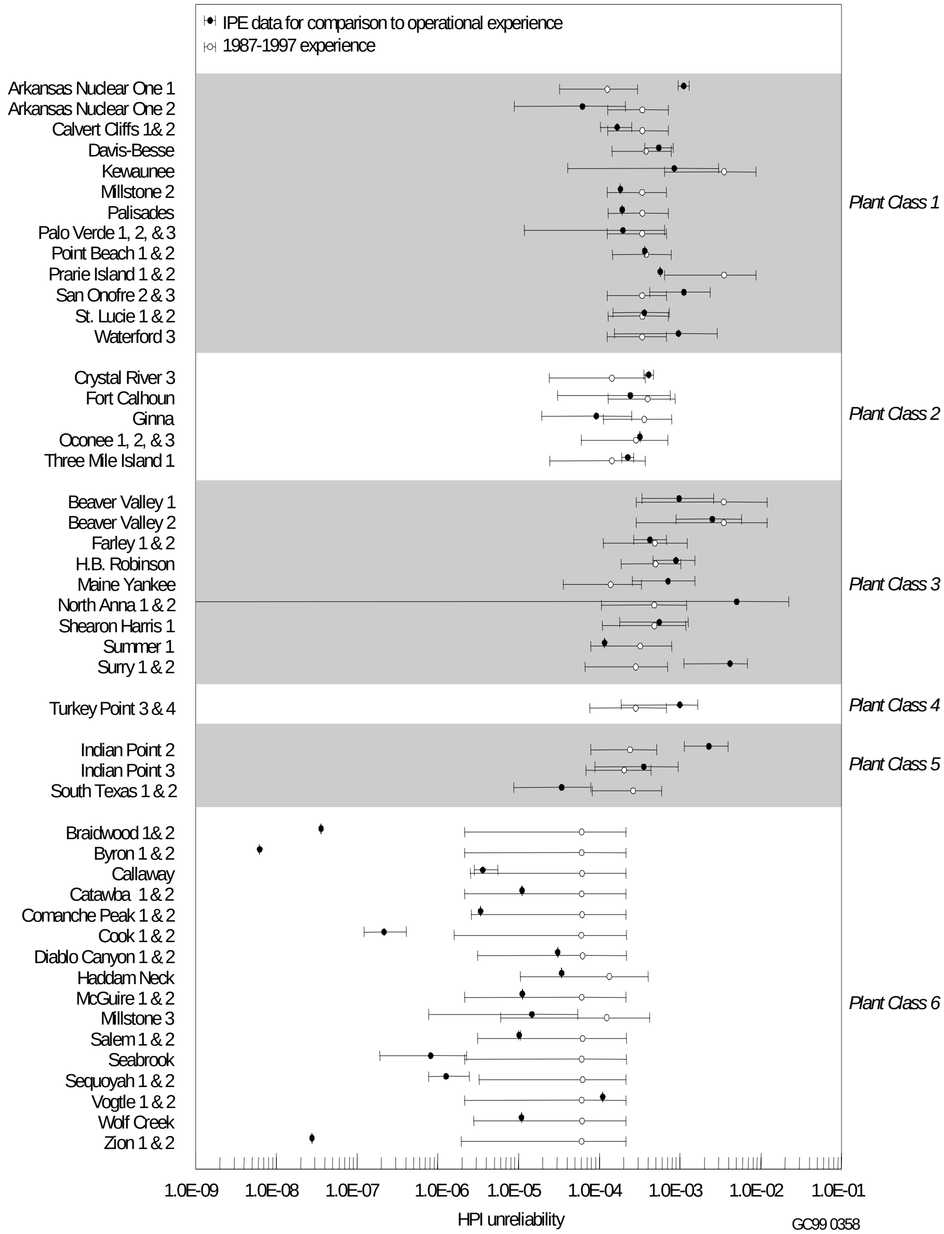

Figure ES-2. Plant-specific estimates of HPI system unreliability (injection phase only) grouped by design class.

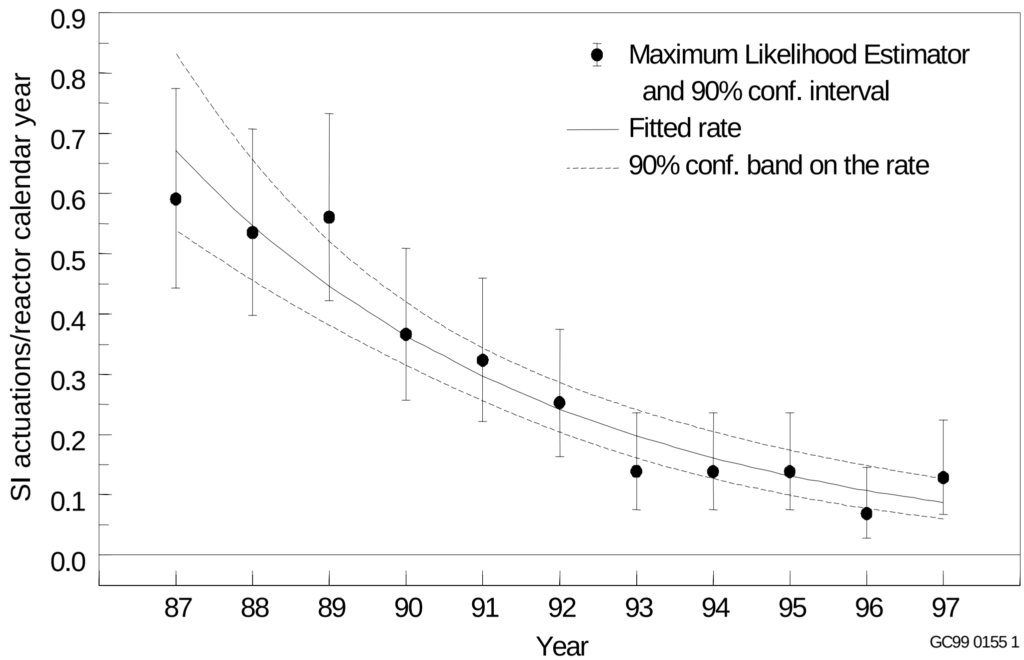

Figure ES-3. Frequency (events per reactor-calendar year) of all SI actuations, as a function of calendar year, calculated assuming that the frequency does not depend on plant age (low-power license date), with confidence limits on the individual frequencies. The decreasing trend is highly statistically significant (p-value is 0.0001).

When the frequency of HPI unplanned demands (both actual and inadvertent SI actuation) was modeled as a function of low-power license date, a statistically significant increasing trend was detected. Figure ES-4 is a plot of the unplanned demand frequency of SI actuation as a function of low-power license date. According to Figure ES-4, the frequency of unplanned demands for HPI of plants that were licensed recently, on the average, is expected to be higher than that of older plants. However, the absolute difference in the frequency was small. Based on the fitted rate shown in Figure ES-4, a plant that received a low-power license in 1967 can be expected to experience an unplanned HPI demand about once every 4 years. In comparison, a plant that received a low-power license in 1993 can be expected to experience an unplanned HPI demand once every 2½ years. Furthermore, the significance of this difference is limited since the frequency of total unplanned demands from all plants has been trending down yearly.

Failure trend. The frequency of failure events observed during unplanned demands and other detection methods such as testing were analyzed to determine trends. Figure ES-5 plots the HPI system failure frequency as a function of calendar year. A statistically significant decreasing trend was identified in the frequency of reportable failure events of the HPI system when modeled as a function of calendar year. Based on the fitted rate shown in Figure ES-5, the frequency of reportable failure events of the HPI system for a population of 72 PWRs decreased from approximately 18 per year in 1987 to approximately 7 per year in 1997.

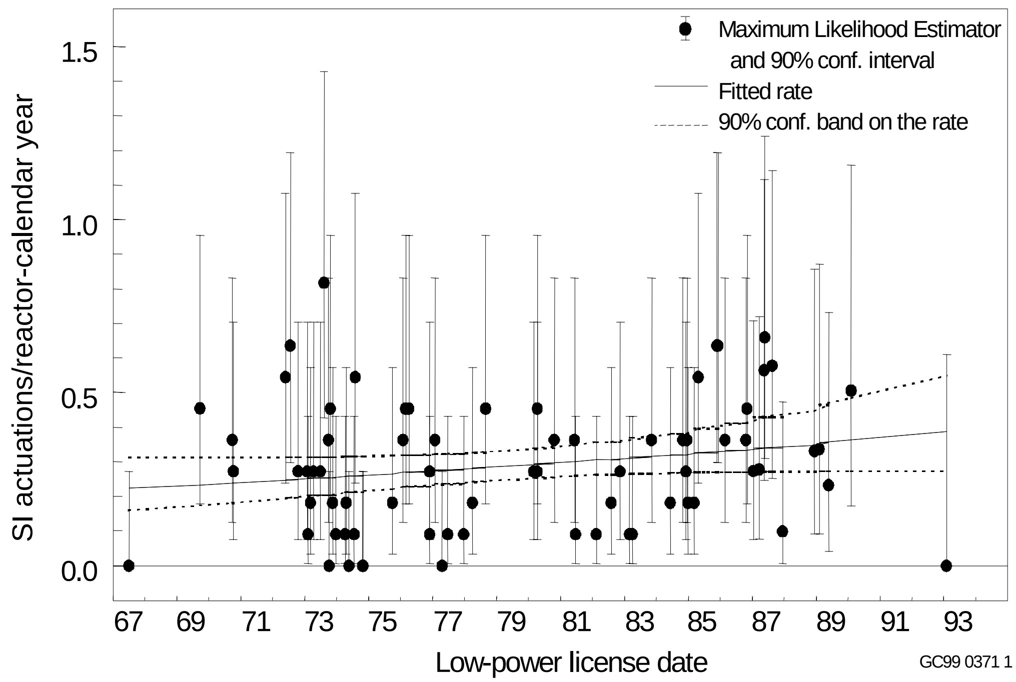

Figure ES-4. Frequency (events per reactor-calendar year) of all SI actuations, as a function of low-power license date. Each point corresponds to a single plant. The calculations for this figure ignore the effect of calendar year. The increasing trend in low-power license date is statistically significant (p-value is 0.01).

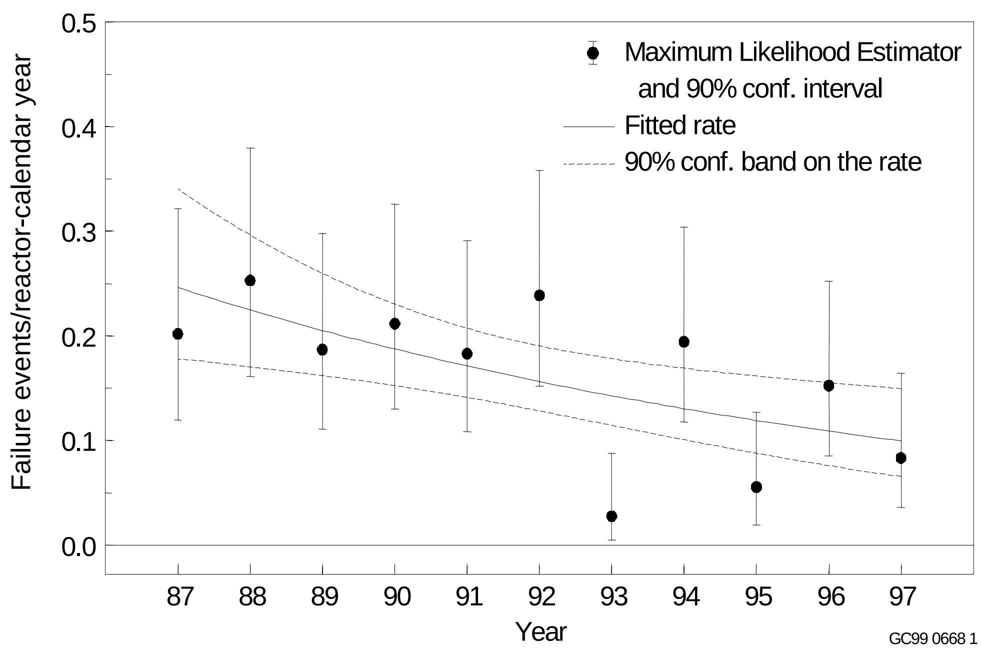

Figure ES-5. Frequency (events per reactor-calendar year) of all HPI failure events, as a function of calendar year. The calculations for this figure ignore the effect of low-power license date and plant-specific variation. The decreasing trend in year is statistically significant (p-value is 0.02).

A statistically significant decreasing trend was identified when the frequency of HPI failure events was modeled as a function of low-power license date. Figure ES-6 is a plot of the frequency of

HPI failure events as a function of low-power license date. According to Figure ES-6, the frequency of reportable failure events of the HPI systems of plants that were licensed recently, on the average, is expected to be lower than that of older plants.

Based on the fitted rate shown in Figure ES-6, a plant that received a low-power license in 1967 can be expected to report a failure affecting HPI about once every 4 years. In comparison, a plant that received a low-power license in 1993 can be expected to report a failure affecting HPI once every 10 years. The significance of this difference is limited since the frequency of reportable failures from all plants has been trending down yearly. Furthermore, an examination of the nature of the failures associated with older versus newer plants showed that the observed trend is not indicative of aging.

Information Notices. The dominant contributor to HPI unreliability from the analysis of operating experience was CCF. A review of Information Notices issued between 1987 and 1997 relating to HPI failures showed that most of them (11 out of 14) were related to CCF events or conditions. The other Information Notices addressed cracks in HPI pipe welds and a single HPI train failure.

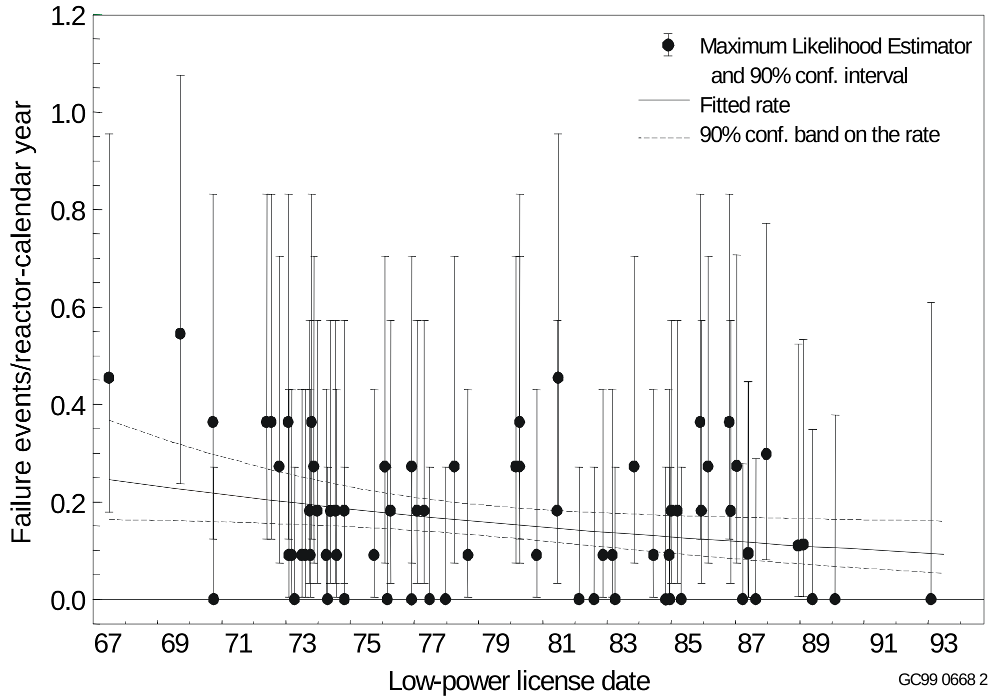

Figure ES-6. Frequency (events per reactor-calendar year) of all HPI failure events, as a function of low-power license date. Each point corresponds to a single plant. The calculations for this figure ignore the effect of calendar year. The decreasing trend in low-power license date is statistically significant (p-value = 0.026).

Accident Sequence Precursor Events. The dominant contributor to HPI unreliability from the analysis of operating experience was CCF. The more significant ASP events (conditional core damage probability greater than 1.0E-04) were also related to CCF of the HPI system. The ASP events of lesser significance (conditional core damage probability between 1.0E-04 and 1.0E-06) generally involved single train failures rather than CCF. This result is consistent with the results of the HPI unreliability analysis that indicated individual segment failures are not dominant contributors.

Data reporting. The HPI unreliability analysis and insights derived from the analysis were based on three HPI train failures that occurred during unplanned demands and 21 common cause failure events reported between 1987–1997. Failures affecting a single train of the HPI system are not reportable nor are demands such as surveillance tests. Therefore, the additional failure data and demands from events other than unplanned demands do not constitute an unbiased sample. Reporting of these failures and demands (such as that proposed for inclusion in EPIX) could enhance our ability to estimate HPI unreliability and derive insights from the operating experience for feedback to the regulatory programs.