Reactor Core Isolation Cooling Executive Summary

This report presents a performance evaluation of the reactor core isolation cooling (RCIC) system at 29 U.S. commercial boiling water reactors (BWRs). The evaluation was based on the operating experience from 1987 through 1993, as reported in Licensee Event Reports (LERs). The objectives of the study were: (1) to estimate the system unreliability based on operating experience and to compare these estimates with the assumptions, models, and data used in Probabilistic Risk Assessments and Individual Plant Evaluations (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 RCIC system.

The RCIC system unreliabilities 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 individual failure modes were calculated by reviewing the failure information, categorizing each event by failure mode, and then estimating the corresponding number of demands (both successes and failures). Twenty-one plant risk source reports (i.e., PRAs, IPEs and NUREGs) were used for comparison with the RCIC reliability results obtained in this study. The information extracted from the source documents contain RCIC statistics for all but one of the 29 plants. The major findings are:

- The RCIC system unreliability (including recovery) calculated based on the operating experience data in which RCIC is required to inject to the reactor vessel for short-term missions (less than 15 minutes) is 0.04. The short-term missions typically follow a reactor scram where feedwater is available and the main steam isolation valves are open. If recovery is excluded, the short-term mission unreliability is 0.06. This unreliability is primarily attributed to failures to start, typically as a result of problems in controlling turbine speed where the problem is caused by either personnel error or hardware problems that result in turbine overspeed trips.

- The estimate of RCIC system unreliability calculated based on the operating experience data in which RCIC is required to inject to the reactor vessel for missions that are longer than 15 minutes and up to several hours is 0.08. The long-term missions typically follow a reactor scram where feedwater is not available and/or the reactor vessel is isolated. If recovery is excluded, the long-term mission unreliability is 0.16. The difference in the unreliability estimate calculated for the long-term missions as compared to the short-term missions is attributed mainly to restarting the turbine and maintaining reactor vessel water level. This unreliability is primarily due to hardware failures associated with restarting the turbine or the cycling of motor-operated valves.

- The estimate of RCIC system unreliability for the 24-hour missions typically modeled in PRAs is 0.18. If recovery is excluded, the mission unreliability is 0.43. The unreliability is dominated by failure to run (24-hour mission time), failure to restart, and failure during the recirculation mode of operation.

- Figures ES-1 and ES-2 display plant-specific estimates of RCIC system unreliability for three specific sets of mission requirements. Figure ES-1 estimates are based on the operating experience data extrapolated to the 24-hour mission typically modeled in PRA/IPEs. Figure ES-2 displays plant-specific estimates with separate estimates for short term (shorter than 15 minutes in duration) and long-term (longer than 15 minutes) missions.

- For the short-term mission unreliability, failures attributed to the start sequence (other than injection valve) are the leading contributor (48%). The leading contributor to the long-term mission unreliability is the failure to restart the RCIC system for subsequent injection of coolant (41%). Failure to run (FTR) is the largest contributor (36%), based on a 24-hour mission time, for the RCIC system PRA-based unreliability. For the failure to run failure mode, the failures found during unplanned demands were the result of personnel errors in operation of the flow controller and a spurious isolation of the turbine steam supply. The spurious isolation of the turbine steam supply was a failure mechanism not identified as a major contributor to the system failure probability in the PRA/IPEs.

- Comparing the estimates of RCIC system unreliability calculated from the information contained in PRA/IPEs to the estimates (with recovery) calculated from the operating experience data revealed that most (approximately 75%) of the PRA/IPE point estimates lie within the uncertainty interval associated with the operating experience estimate. However, about 21% of the PRA/IPE estimates predict better performance than identified by the estimates calculated from the operating experience data. These plants fall below the 5th percentile of the distribution computed from the operating experience data.

- It was found that most of the PRA/IPEs do not model the RCIC system in the way it is observed to be operated in the operating experience data. Specifically, the maintenance of reactor vessel water level by either restart and/or recirculation following initial injection is generally not modeled. For the PRA/IPEs that model the system with the restart and/or recirculation modes of RCIC, the failure probabilities assigned to these modes of operation appear to be too optimistic. For example, the initial failure to start (other than the injection valve) probabilities and the restart failure probabilities differ by about a factor of 2.6 according to the operating experience data. However, the PRA/IPEs use the same probabilities for restart as for initial start. According to the operating experience data, the failure to restart contribution to overall unreliability is about a factor of two greater than the failure to start (other than the injection valve) contribution (27% versus 12%, respectively).

- The operating data contained five instances where multiple systems (RCIC, high pressure coolant injection, and sometimes reactor water cleanup) either had failed or had the potential to fail concurrently; these instances may be common cause failures. The events involved motor-operated valves, the steam leak detection circuitry, and the turbine governors. In two of the five instances the RCIC and high pressure coolant injection systems were affected during an unplanned demand. The other events were discovered during surveillance testing (2) and other routine plant operations (1).

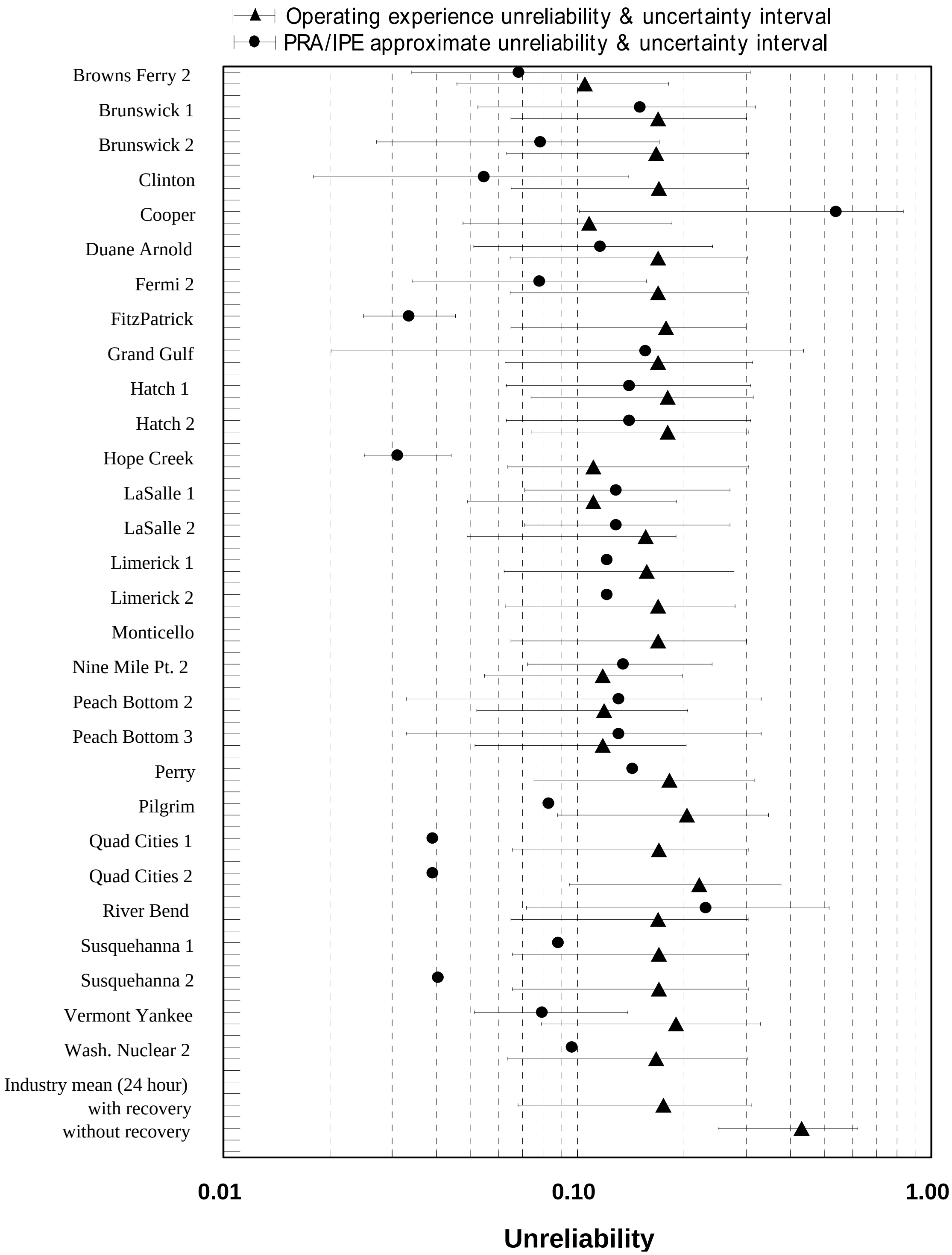

Figure ES-1. Plant-specific estimates of RCIC system unreliability for 24-hour missions derived from PRA/IPE assumptions and information and from operating experience data.

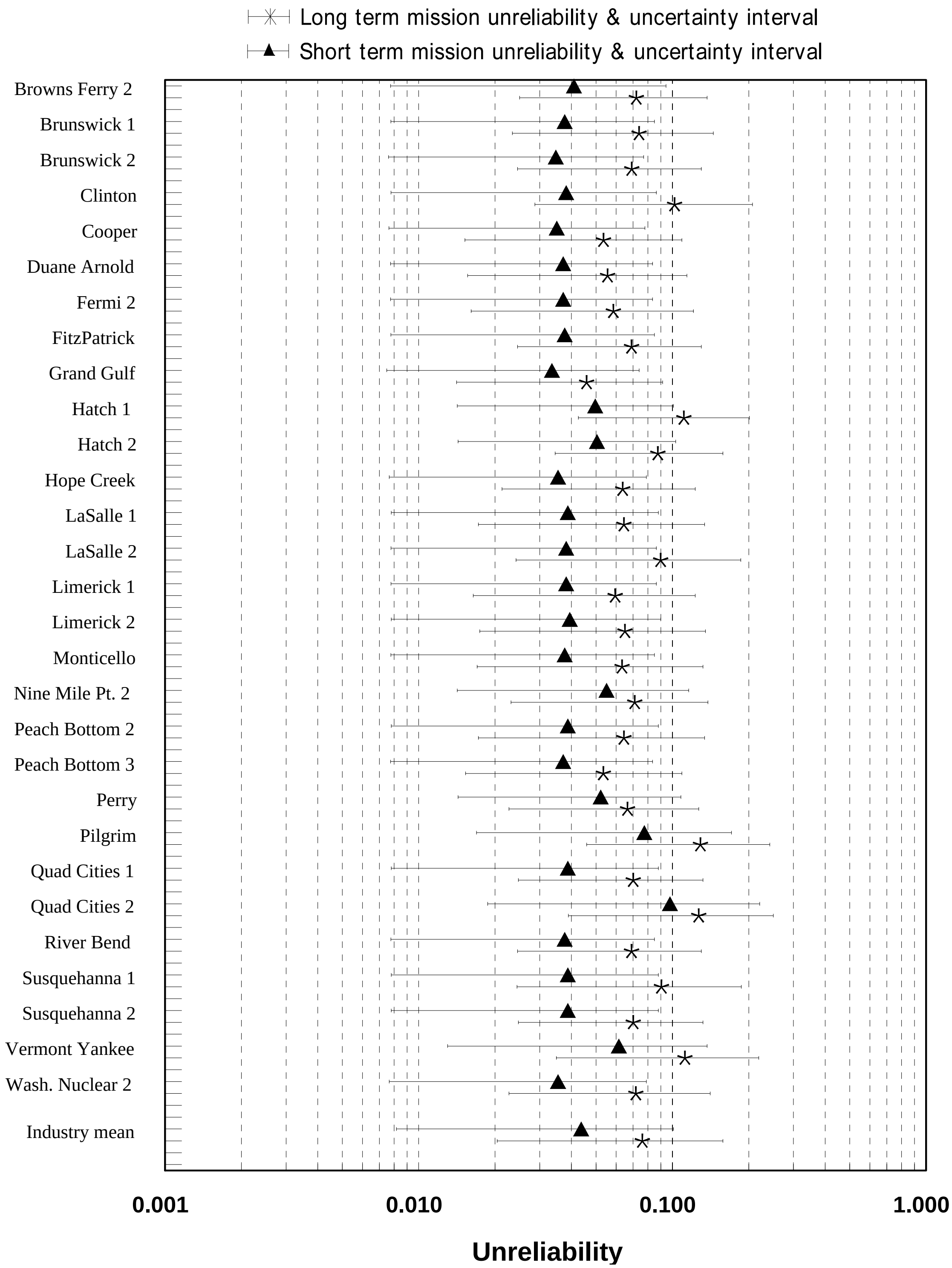

Figure ES-2. Plant-specific estimates of RCIC system unreliability for the short term and long term missions observed in the operating experience.

- For the short-term missions, a decreasing trend in RCIC system unreliability with respect to calendar year was identified by statistical analysis of the operating data. In addition, some indication of a trend was identified in the short-term unreliability with regard to low-power license date, but it is not a strong indication. More data (i.e., more operating experience) are needed before this trend can be statistically verified or disproved. No statistical trends were identified with regard to long term RCIC unreliability. Figures ES-3 and ES-4 provide plots of the short term RCIC unreliability.

- When plotted against plant operating year (see Figure ES-5), the unplanned demand frequency exhibits a statistically significant decreasing trend. This is likely a result of a corresponding decrease in unplanned plant trips, which typically include a RCIC system actuation. Failure frequency exhibits no trend when plotted against plant operating year (Figure ES-6). There was no correlation observed between the plant's low-power license date and the frequency of failures per operating year (Figure ES-7). The average number of failures per operating year was 0.62. This average frequency was observed for plants licensed from 1970 through 1990. Two plants licensed in the 1970s and two plants licensed in the 1980s had relatively high failure frequencies.

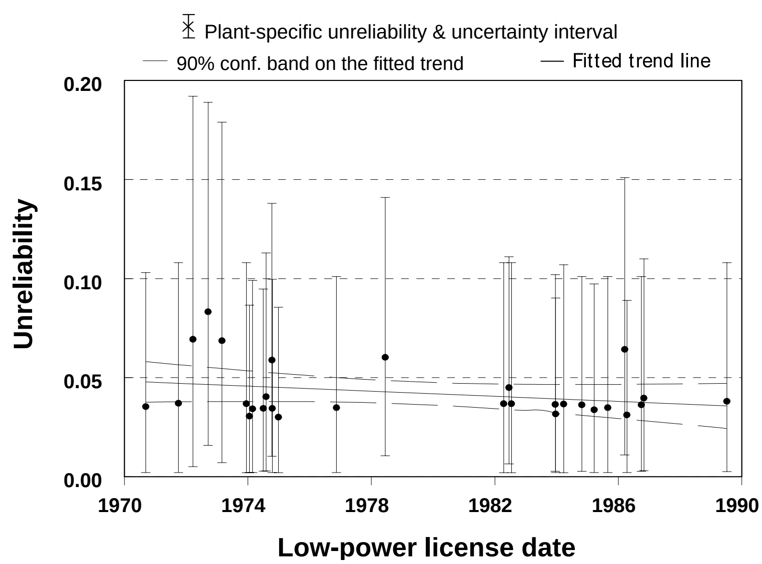

Figure ES-3. Plant-specific RCIC system unreliabilities (including recovery) for short term missions plotted against low-power license dates. The plotted trend indicates some increase in reliability (i.e., reduced unreliability), but the trend is not statistically significant (P-value = 0.15).

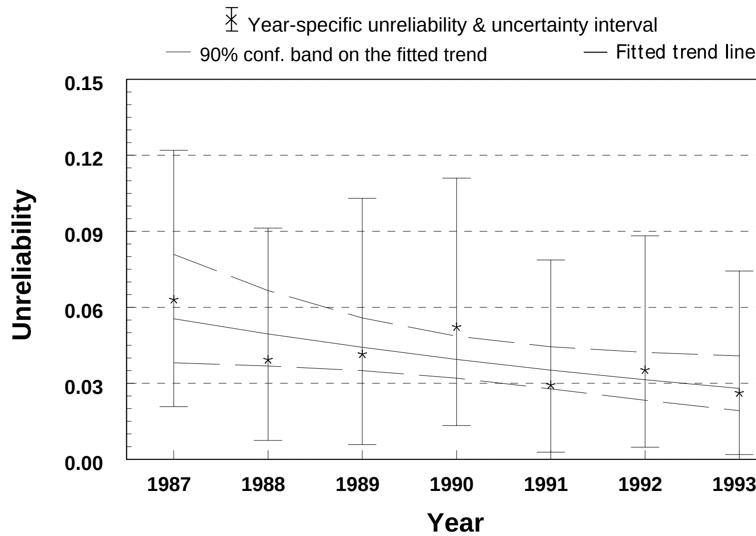

Figure ES-4. RCIC system unreliabilities (including recovery) for short term missions by calendar year. The plotted trend is statistically significant (P-value = 0.03).

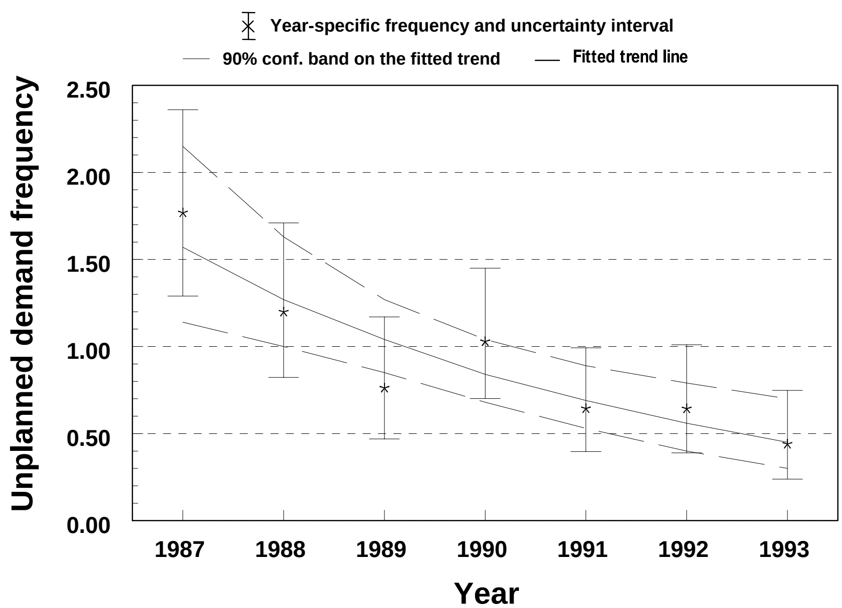

Figure ES-5. RCIC unplanned demands per plant operating year, with 90% uncertainty intervals and confidence band on the fitted trend. The trend is statistically significant (P-value = 0.003).

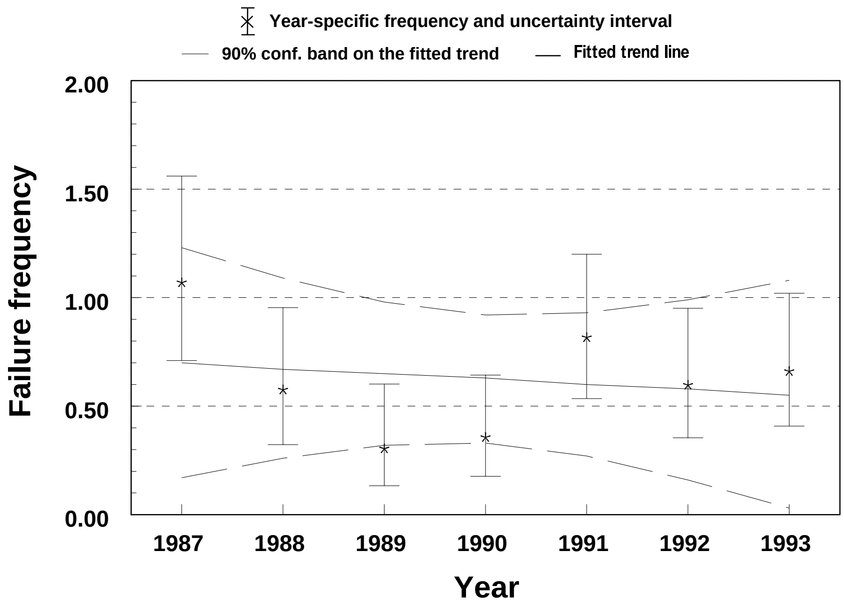

Figure ES-6. RCIC failures per plant operating year, with 90% uncertainty intervals and confidence band on the fitted trend. The trend is not statistically significant (P-value = 0.67).

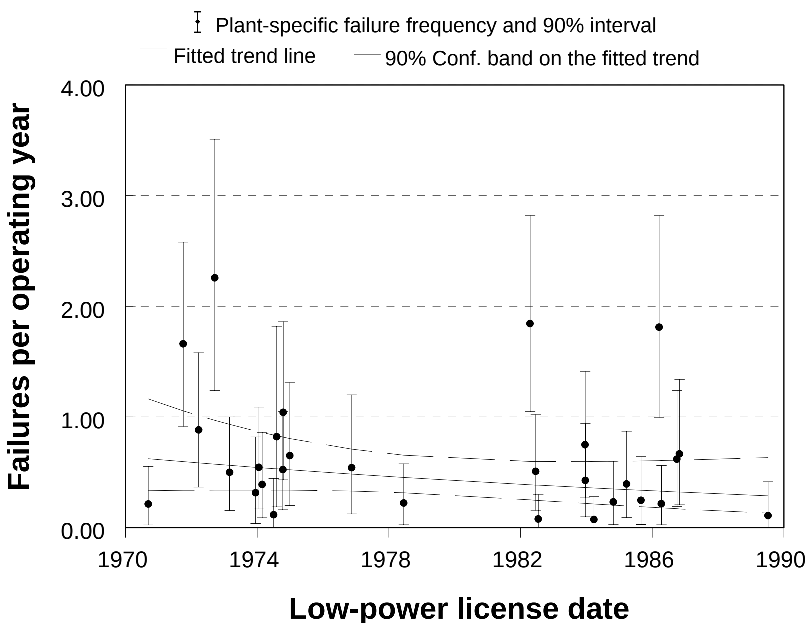

Figure ES-7. Plant-specific RCIC system failures per operating year, plotted against low-power license date. The trend is not statistically significant (P-value = 0.17).