# Emergency Diesel Generator Executive Summary

This report presents an evaluation of the performance of emergency diesel generator (EDG) trains at U.S. commercial nuclear power plants. The study is based on the operating experience from 1987 through 1993, as reported in Licensee Event Reports (LERs) and Special Reports. The data extracted from LERs and Special Reports for plants reporting under Regulatory Guide 1.108 requirements were analyzed in three ways (referred to in this report for simplicity as RG-1.108 data). First, the EDG train unreliability was estimated, and the factors affecting unreliability were determined. The estimates were analyzed to uncover trends and patterns within EDG train reliability. The trend and pattern analysis yielded insights into the performance of the EDG train on plant-specific and industry-wide bases. Second, comparisons were made between the estimates calculated in this report and EDG train unreliabilities reported in the selected PRAs, IPEs, and NUREGs (PRA/IPEs). The objective of the comparisons was to indicate where RG-1.108 data support or fail to support the assumptions, models, and data used in the PRA/IPEs. Third, plant-specific estimates of EDG train reliability derived from the RG-1.108 data were calculated. These estimates were compared to the station blackout (SBO) target reliability goals. For the non-RG-1.108 population of EDGs, the results of a cursory analysis and comparisons derived solely from LER data associated with unplanned demands were presented.

Twenty-nine plant risk source documents, PRA/IPEs, were used for comparison with the EDG reliability results obtained in this study. The information extracted from the source documents contains relevant EDG train statistics for 44 plants comprising 97 EDGs. The data represent approximately 40% of the plants and EDGs at operating nuclear power plants. Of the 44 plants, 29 report in accordance with the requirements identified in Regulatory Guide 1.108.

EDG train unreliabilities were estimated using a fault tree model to combine broadly defined train failure modes such as failure to start or failure to run into an overall EDG train unreliability. The failure probabilities for the individual failure modes were calculated by reviewing the failure information, categorizing each failure event by failure-mode, and then estimating the corresponding number of demands (both successes and failures). Approximate PRA/IPE-based unreliabilities were calculated from the failure data documented in the respective PRA/IPE for the start, load, run, and maintenance phases of the EDG train operation.

The estimated EDG train unreliability derived from unplanned and cyclic test demand data for the RG-1.108 plants was 0.044. The EDG train unreliability was estimated from 50 failures observed during 181 unplanned demands and 682 cyclic (18 month) surveillance tests. The observed failures were classified as failure to start, failure to run, or maintenance out of service. Maintenance out of service was further classified as to whether or not the plant was in a shutdown condition at the time of the demand. In addition, recoveries of EDG trains from failures during unplanned demands were identified. The unreliability estimate includes consideration of recovery of EDG train failures, maintenance out of service while the plant is not in a shutdown condition, and assumes an 8-hour mission time. Maintenance out of service is the major contributor to EDG train unreliability. Approximately 70% of the unreliability is attributed to maintenance being performed on an EDG train at the time of an unplanned demand. If recovery is excluded, the estimate of EDG train unreliability is 0.069. The causes of unreliability were primarily electrical in nature and typically the result of hardware malfunctions.

The EDG train failures observed during an unplanned demand, which contributed to EDG unreliability appeared to be difficult for operators to diagnose and recover. These EDG train failures were caused by problems associated with instrumentation and controls, and electrical subsystems. The failures associated with the instrumentation and controls subsystem were difficult for plant personnel to diagnose, and were the result of intermittent actuation of the temperature and pressure switches in the automatic shutdown circuits. In approximately 50% of these failures, troubleshooting activities failed to find a cause for the EDG failure and the EDG was restarted without performing any corrective maintenance. In one case, the troubleshooting lasted 2.5 hours with the safety-related bus de-energized throughout the troubleshooting. The failures associated with the electrical subsystem were the result of a personnel error in operation of a running EDG, and a hardware-related problem in the timer for the sequencer.

The EDG train failures that occurred during cyclic surveillance tests, which contributed to unreliability, were either the result of electrical-related failures, or leaking/loose components. The electrical-related failures primarily contributed to the failure to start probability. These failures were primarily the result of blown fuses and the malfunction of relays, potentiometers, contacts, solenoids, and resistors associated with the voltage regulator, governor, and sequencer. The failures that resulted from either leaking or loose components dominated the failure to run probability. The leaking or loose category of failures was associated with a broad variety of components. However, the leaking or loose components were typically the result of errors associated with maintenance (improper assembly of the components) and either vibration or wear-induced fatigue failure. A significant number of the leaking or loose components appeared over an hour after the EDG was running, and therefore may not be detected in the monthly test due to the short run time of the monthly test, compared to the cyclic test's endurance run.

The average of the plant-specific RG-1.108-based estimates of EDG train unreliability is in agreement (approximately 13% higher) with the average of the PRA/IPE estimates, assuming an 8-hour run time of the EDG. Generally, the RG-1.108-based estimate for failure to start and maintenance out of service probabilities agree with their respective PRA/IPE counterparts. However, for a 24-hour mission time for the EDG train, the average PRA/IPE estimate of failure to run is approximately a factor of 30 higher than the corresponding RG-1.108-based estimate. Figure ES-1 provides a plot of PRA/IPE and RG-1.108 estimates of EDG train unreliabilities and uncertainties for RG-1.108 reporting plants.

Based on the mean reliability, all of the RG-1.108 plants (44) with an EDG target reliability goal of 0.95 attain the SBO target goal provided that the unavailability of the EDG due to maintenance is ignored. The reliability estimate for the overall population of EDGs at RG-1.108 plants with a 0.95 SBO target goal is 0.987, with a corresponding uncertainty interval of 0.96, 0.99. For the RG-1.108 plants with a EDG target reliability goal of 0.975, eighteen of the nineteen RG-1.108 plants, based on the mean reliability, attain the reliability goal provided that the unavailability of the EDG due to maintenance is ignored. The EDGs associated with the plant not achieving the 0.975 reliability goal had a mean reliability of 0.971. However, when uncertainty is accounted for, these EDGs have approximately a 0.54 probability of meeting or exceeding the 0.975 reliability goal. The reliability estimate for the overall population of EDGs at RG-1.108 plants with a 0.975 target goal is 0.985, with a corresponding uncertainty interval of 0.95, 0.99.

The effect of maintenance unavailability on EDG reliability is significant based on the RG-1.108 data. The technical basis for the Station Blackout Rule assumes that such unavailability is negligible (0.007). The estimate derived from the RG-1.108 data for maintenance out of service is 0.03. Forty of the 44 RG-1.108 plants with 0.95 target reliability attain the goal when comparing mean estimates. The reliability estimate for the overall population of EDGs at RG-1.108 plants with a 0.95 target goal is 0.956, with a corresponding uncertainty interval of 0.92, 0.99. For the RG-1.108 plants with an EDG target reliability goal of 0.975, none of the EDGs meet the target reliability goal. The reliability estimate for the overall population of EDGs at RG-1.108 plants with a 0.975 target goal is 0.954, with a corresponding uncertainty interval of 0.91, 0.98.

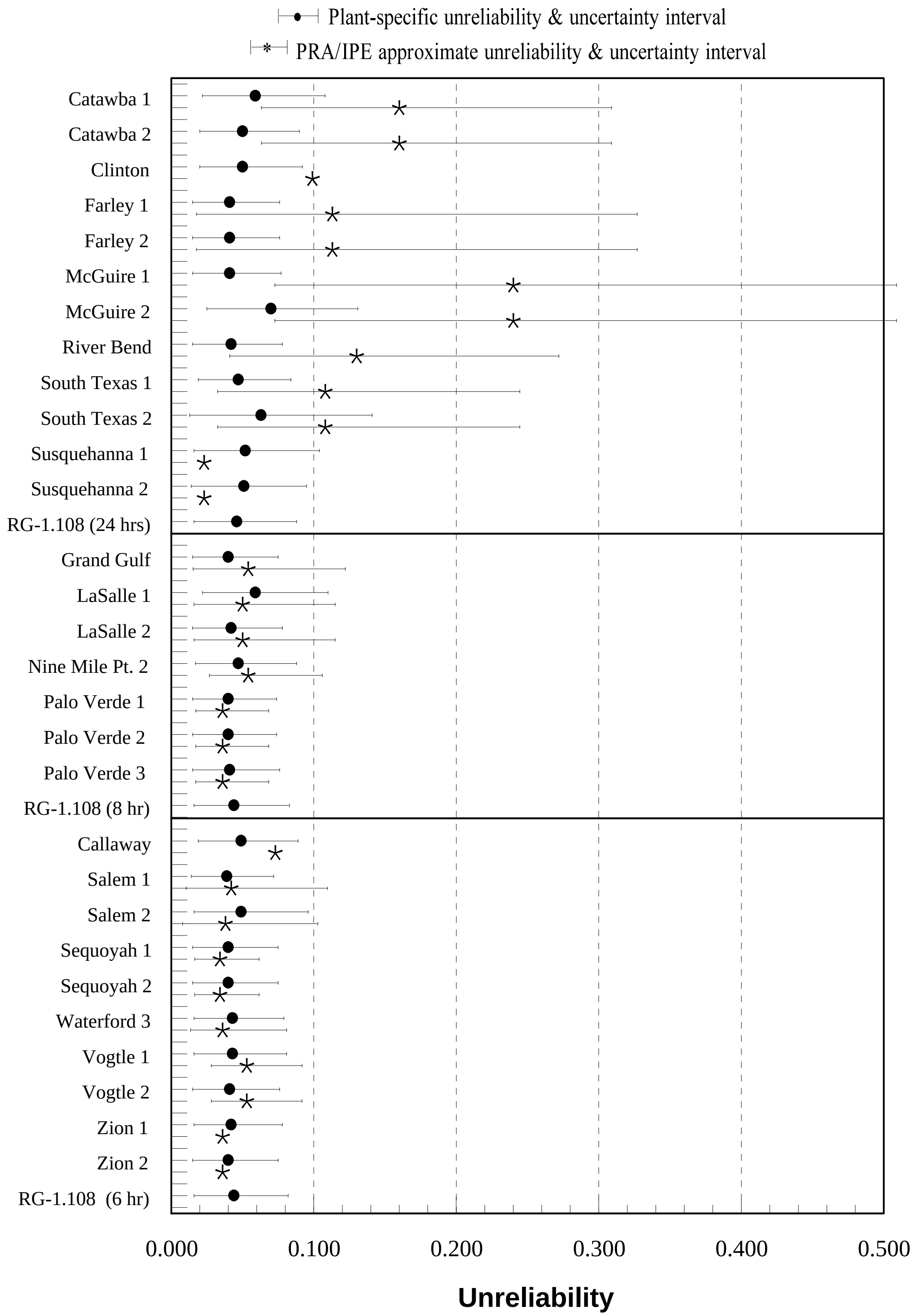


**Figure ES-1.** Plot of PRA/IPE and RG-1.108 estimates of EDG train unreliabilities and uncertainties with recovery for Regulatory Guide 1.108 reporting plants. The FTR contribution is based on the mission time stated in the PRA/IPE (with the exception of Susquehanna and Palo Verde).

Based on the limited failure data (i.e., unplanned demand data only) for the non-RG-1.108 plants, reliability parameters estimated for this population of EDGs tend to agree with those generated for the RG-1.108 plants. The reliability estimate (without maintenance unavailability) for the overall population of EDGs at the non-RG-1.108 plants is 0.984, with a corresponding uncertainty interval of 0.97, 0.99. This unreliability is attributed to hardware-related failures of the output breaker that were not observed in the RG-1.108 reporting plants. Owing to the sparseness of the non-RG-1.108 data, the reliability estimates apply to either SBO target reliability goal. The reliability estimate for the overall population of EDGs at the non-RG-1.108 plants with maintenance unavailability included is 0.958, with a corresponding uncertainty interval of 0.92, 0.98.

Trending analysis of the failure rate, unplanned demand rate and unreliability data by year indicates no statistically significant trend over the 7 years of the study period. However, the smallest number of events for any given year did occur in 1993. The analysis of plant-specific unreliability by low-power license date indicates no statistically significant trend. However, analysis of plant-specific EDG failure rate by low-power license date identifies a statistically significant trend. The trend indicates that the plants with low-power license dates from 1980–1990 typically had an EDG failure rate greater than those plants with a low-power license date prior to 1980. The trend observed by low-power license date for the EDG failure rate requires further investigation as to the cause of the trend. Information in the LERs was not sufficient to determine the reason for the trend. Each of the trending analyses is provided in Figures ES-2 through 6.

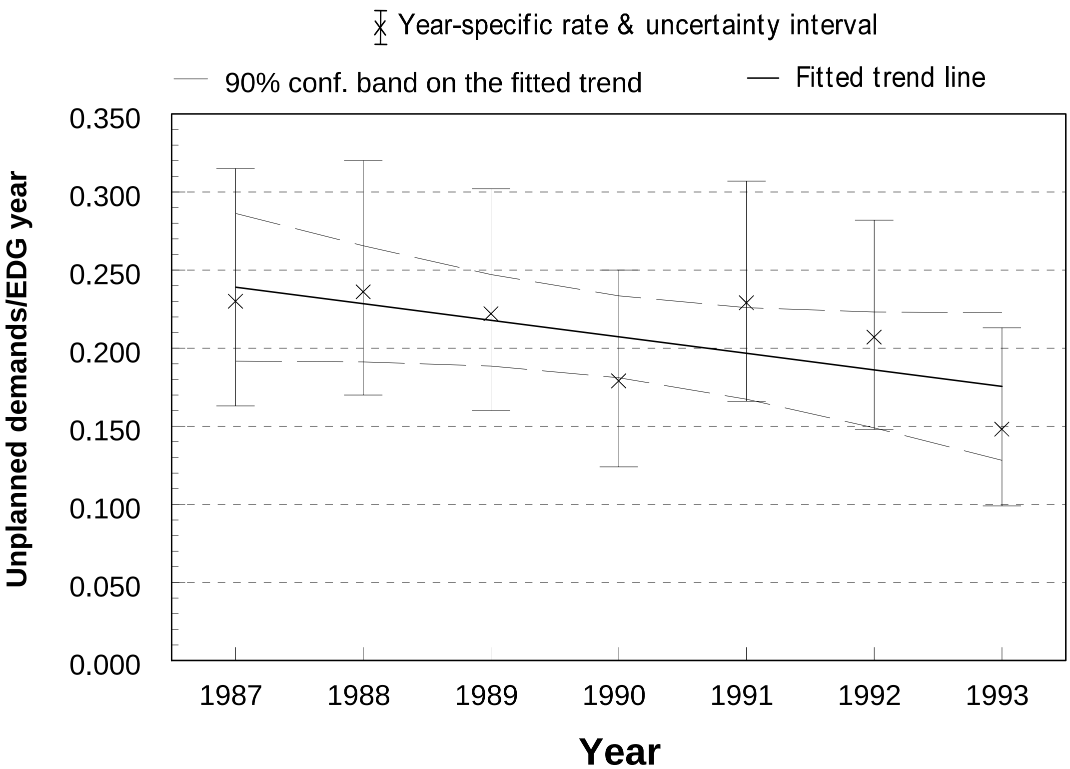


**Figure ES-2.** EDG unplanned demands per EDG-year with 90% confidence intervals and fitted trend. The trend is not statistically significant (P-value=0.08).

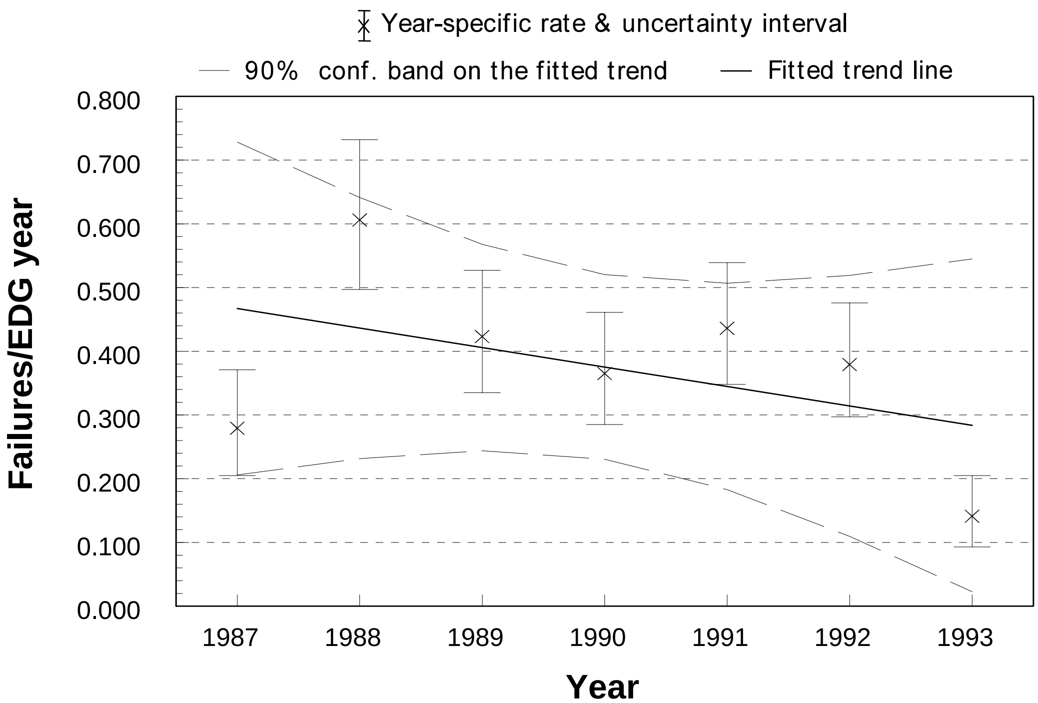


**Figure ES-3.** EDG failures per EDG-year with 90% confidence intervals and fitted trend. The trend is not statistically significant (P-value=0.30).

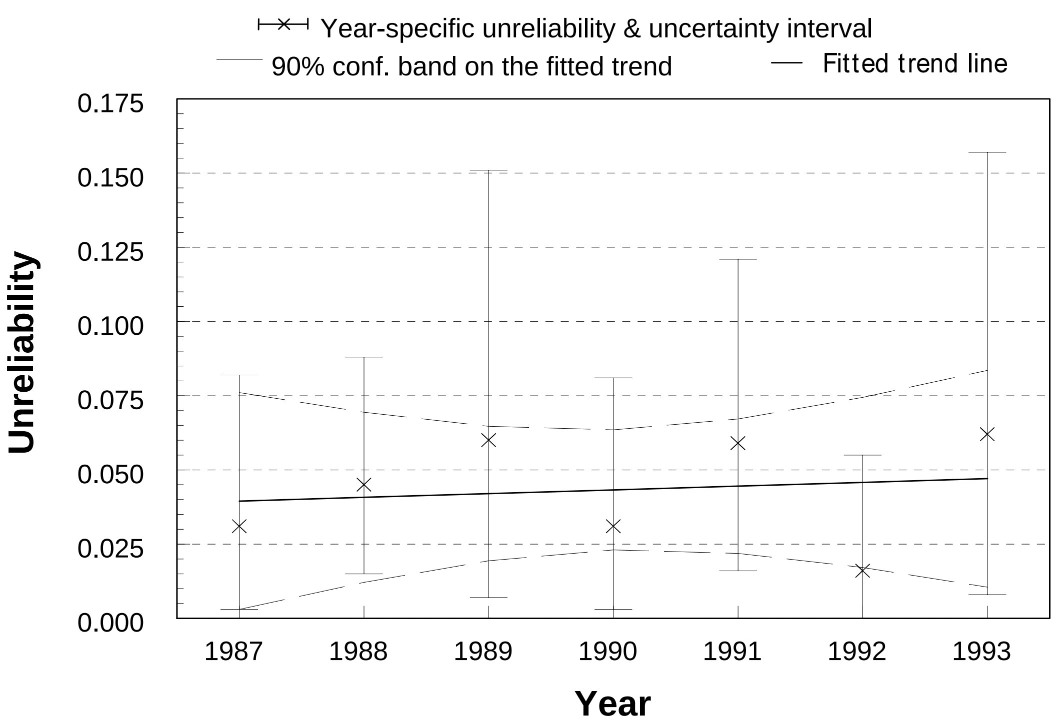


**Figure ES-4.** EDG train unreliability by calendar year, based on a constrained noninformative prior and annual data. Ninety percent Bayesian intervals and a fitted trend are included. The trend is not statistically significant (P-value=0.75).

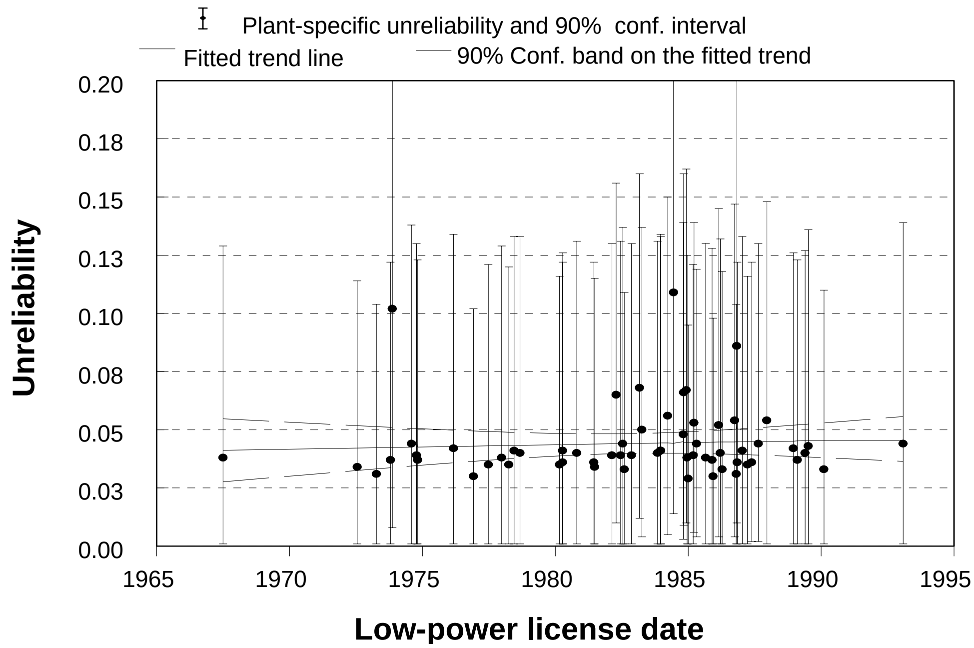


**Figure ES-5.** Plant-specific unreliability based on constrained noninformative prior distributions and an 8-hour mission, plotted against low-power license date. Ninety percent Bayesian intervals and a fitted trend are included. The trend is not statistically significant (P-value=0.62).

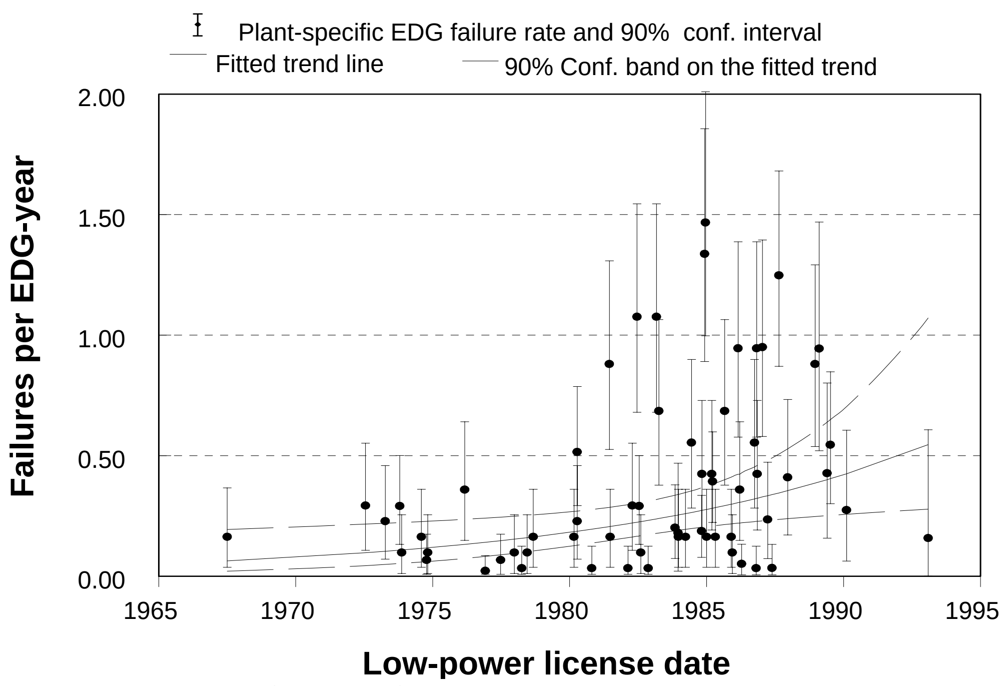


**Figure ES-6.** Plant-specific EDG failures per EDG-year, plotted against low-power license date. Ninety percent Bayesian intervals and a fitted trend are included. The trend, based on a fit of the logarithms of the rates as a function of low-power license date, is statistically significant (P-value=0.007).