# AUXILIARY FEEDWATER EXECUTIVE SUMMARY

This report presents a performance analysis of auxiliary feedwater (AFW) systems at 72 United States commercial pressurized water reactors (PWRs). The evaluation is based on the operating experience from 1987 through 1995, 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 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 AFW system.

This study used as its source data the operating experience from 1987 through 1995 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 a U.S. commercial nuclear power plant experienced engineer from a risk and reliability perspective.

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

The AFW system configurations for the 72 plants used in this study differ considerably. AFW systems comprise different levels of pump train redundancy and diversity. To facilitate the assessment of the AFW systems, 11 AFW design classes were identified, and the plants were categorized accordingly.

## Major Findings

Based on the 1987–1995 experience data, there were no failures of the entire AFW system identified in 1,117 unplanned system demands. A simple Bayes estimate of the AFW system unreliability using this data is 4.5E-04 (probability of failure per demand) with an associated 90% uncertainty interval of [1.8E-06, 1.7E-03]. Using a system level fault tree model that combines individual failure modes, the operational unreliability of the AFW system calculated by arithmetically averaging the results of 72 plant-specific models is 3.4E-05. Individual plant results vary over two orders of magnitude, from 1.5E-06 to 6.2E-04. The variability largely reflects the diversity found in AFW system designs. However, there is some variation in results among plants with similar AFW designs. This is attributed to the plant-to-plant differences in the 1987–1995 experience data, and to a lesser degree, differences in the levels of redundancy in the feed control/injection headers. The estimates of AFW operational unreliability using fault tree analyses are plotted in Figure ES-1. Contributions to unreliability varied depending on the design and plant-specific data. Details for each class are provided in Section 3.2 of the report.

AFW designs composed of only turbine-driven pumps were the least reliable, while AFW designs comprising three redundant trains of diverse design (e.g., two motor and one turbine driven pumps) were more reliable. AFW designs consisting of four trains (three motor and one turbine) are not significantly different in reliability terms from the two motor and one-turbine pump designs. The benefits of additional trains of redundancy to AFW system reliability are offset by the effects of common cause failures. Although the AFW designs consisting solely of turbine-driven pumps tend to be less reliable in routine operations, for potential station blackout situations, they would be more reliable than their counterparts would with multiple motor-driven pump trains.

Generally, the turbine-driven pump trains are about a factor of 10 less reliable than motor-driven pumps trains and a factor of four less reliable than the diesel driven pump trains. There is no appreciable plant-to-plant variation within the driver-specific pump train unreliabilities, this further supports the observation that AFW system unreliability (based on the 1987–1995 experience) is mostly influenced by the levels of redundancy and diversity in the specific system design. The plant-specific pump train unreliabilities are plotted in Figure ES-2.

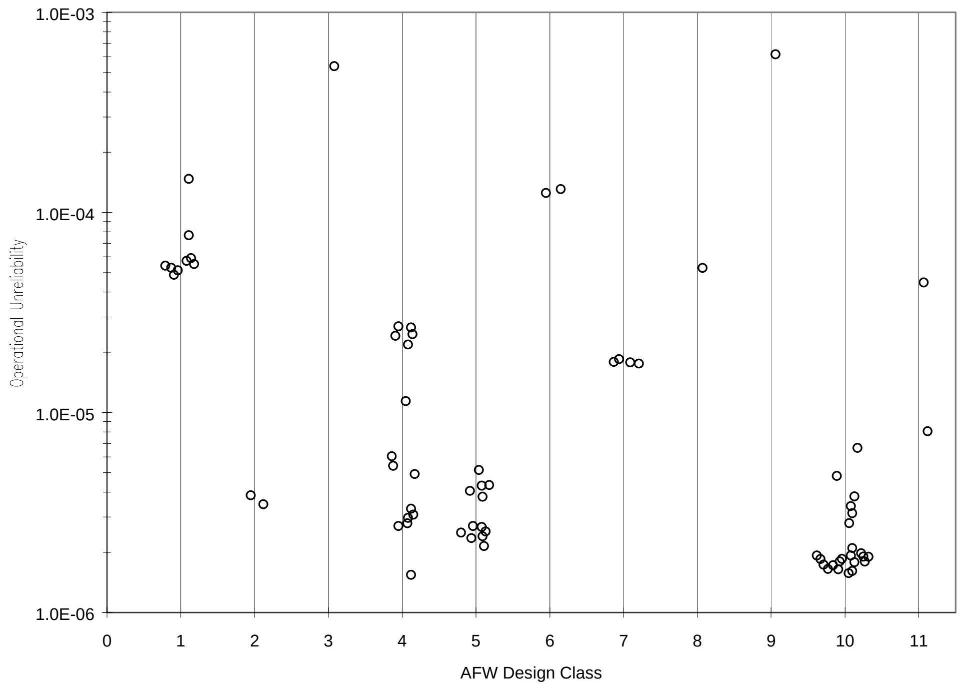


**Figure ES-1.** Plant-specific estimates of AFW system unreliability grouped by design class for an operational mission. Uncertainties are not plotted in order to provide better resolution of the plant-specific means.

The industry-wide arithmetic average of AFW system unreliability for a PRA mission (i.e. 24 hour run-time requirement) calculated using data extracted from PRA/IPEs is 3.4E-04. The corresponding estimate based on the 1987–1995 experience is 2.1E-03 or about a factor of six greater than the average of the PRA/IPE values. Neither of these estimates account for non-safety trains and equipment available at some plants (for example, the use of non-safety grade startup feedwater pumps). A plot of these estimates is shown in Figure ES-3. The major differences between the two estimates are attributable to the probabilities associated with failure of the primary AFW system water source (e.g., CST suction path, generally not considered as being probabilistically important in most PRA/IPEs), and the AFW turbine-driven pump failure to run (a significantly higher failure rates results when using the relatively limited 1987–1995 experience data).

However, the loss of suction source was a dominant contributor to many of the design classes. This event, though rare, is important because it disables the designed redundancy of the AFW systems and is usually discounted or not modeled in PRAs. There was one failure of a suction source during the 1,117 unplanned system demands observed in the operational experience. This failure occurred during an automatic start of two motor-driven pumps in which, suction pressure was insufficient for pump operation, which caused an automatic shift to the assured source (service water). The low suction pressure condition was a result of operating with the AFW condensate storage tank isolated, while not maintaining adequate level in the upper surge tank, which provides an alternate source of feedwater to AFW. Even though AFW pump suction shifted to the assured source (service water), the service water system was fouled with clams and sludge which caused the AFW flow control valves to the steam generators to clog with clams and sludge significantly reducing flow to two of four steam generators.

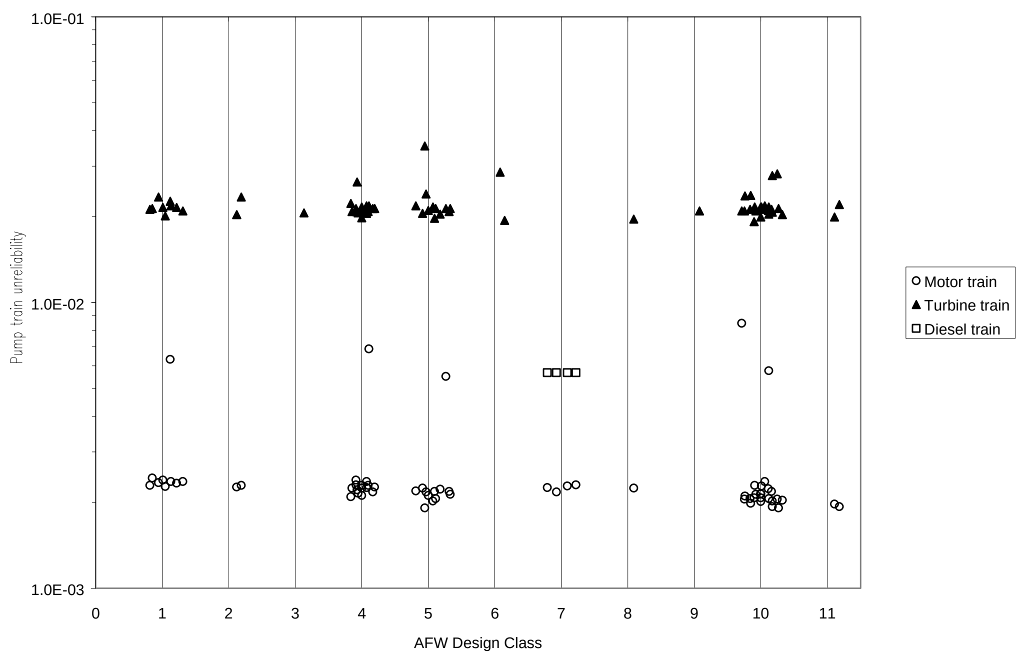


**Figure ES-2.** Plant-specific estimates of AFW system pump train operational unreliability grouped by design class.

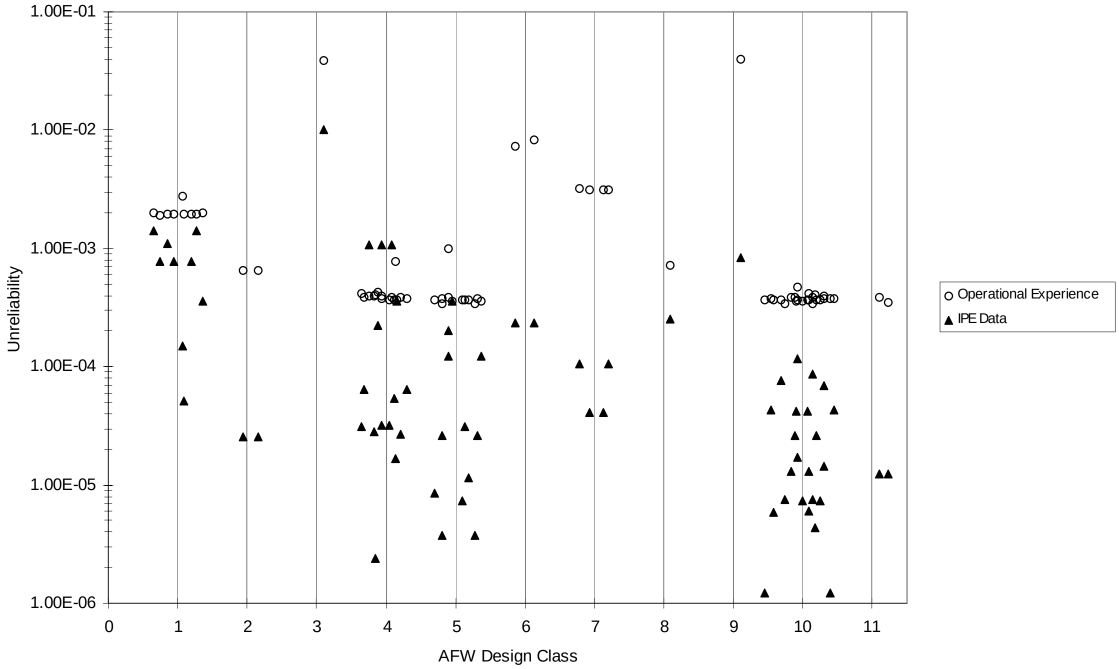


**Figure ES-3.** Plot of the PRA/IPE and operating experience estimates of AFW unreliability for a PRA mission. Uncertainties are not plotted in order to provide better resolution of the plant-specific means.

No trends were identified in the AFW operational mission unreliability when plotted against calendar year (Figure ES-4) or low-power license date (Figure ES-5). Although a decreasing trend is visible when unreliability is plotted against calendar year or low-power license date, the trends are not statistically significant. Trends were identified in the frequency of the AFW unplanned demands. When plotted against calendar year, the unplanned demand frequency exhibited a statistically significant decreasing trend (Figure ES-6). When unplanned demand frequency is plotted against low-power license dates, a statistically significant increasing trend was identified (Figure ES-7).

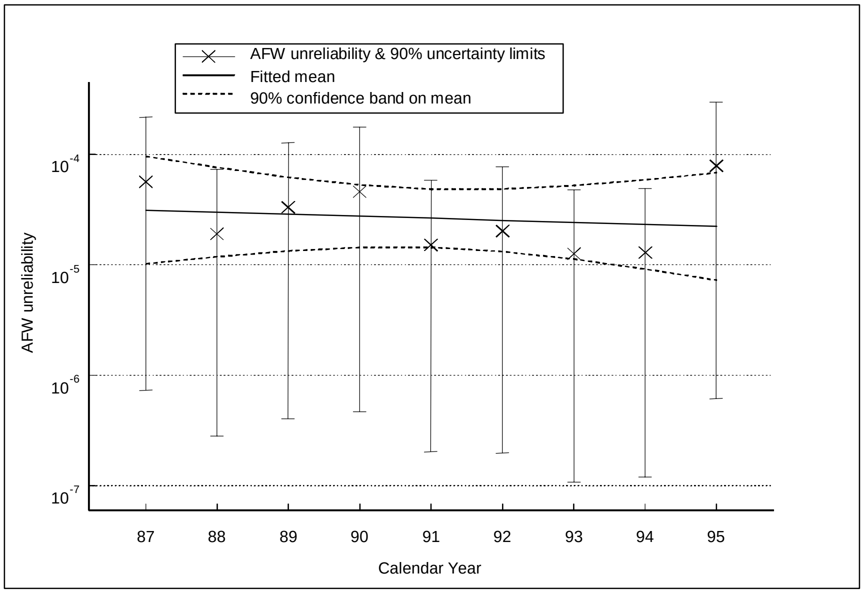


**Figure ES-4.** AFW system unreliability plotted by calendar year. The plotted trend is not statistically significant (P-value = 0.66).

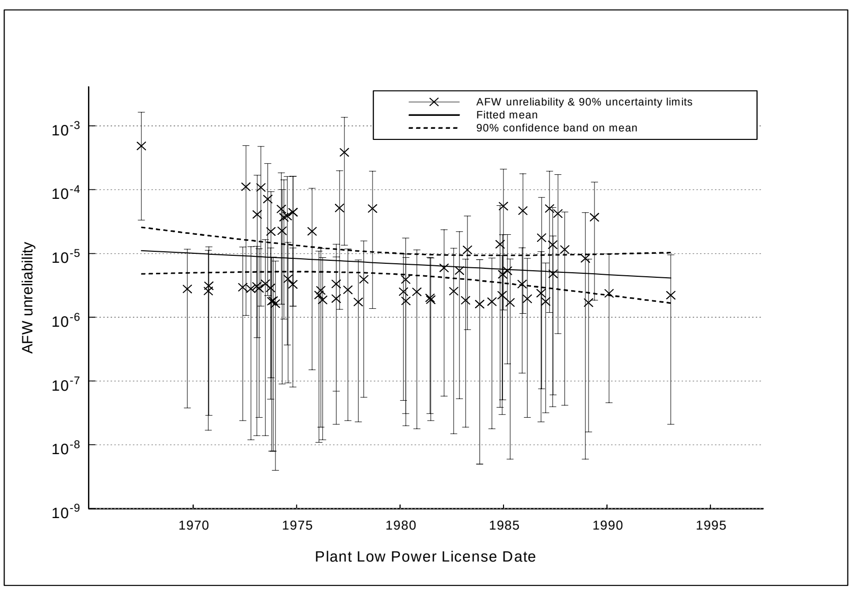


**Figure ES-5.** Plant-specific AFW system unreliability plotted by low-power license dates. The plotted trend is not statistically significant (P-value = 0.18).

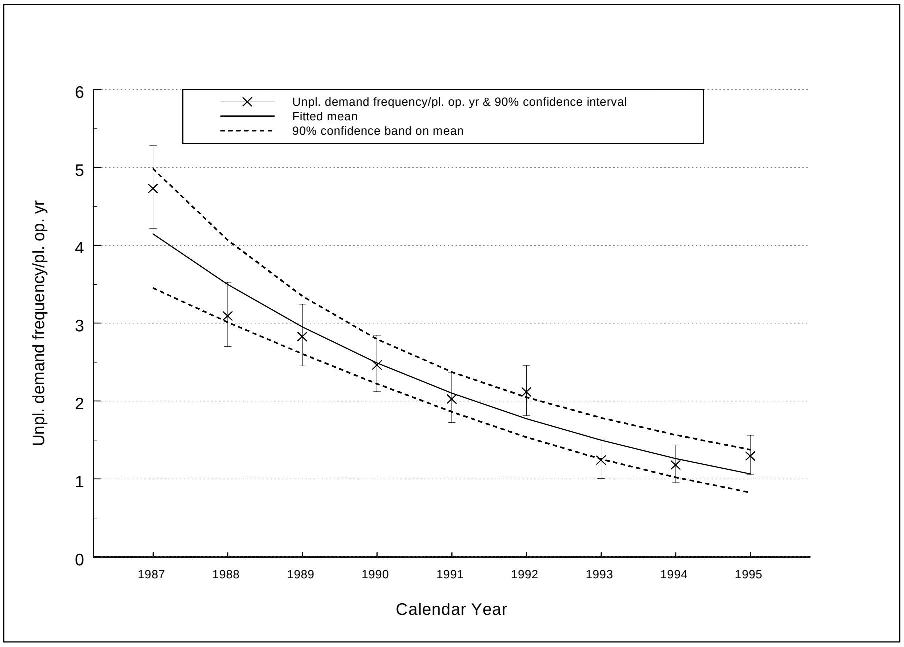


**Figure ES-6.** Unplanned demands trended by calendar year, with confidence limits on the individual frequencies. The decreasing trend is highly statistically significant (P-value <5E-5).

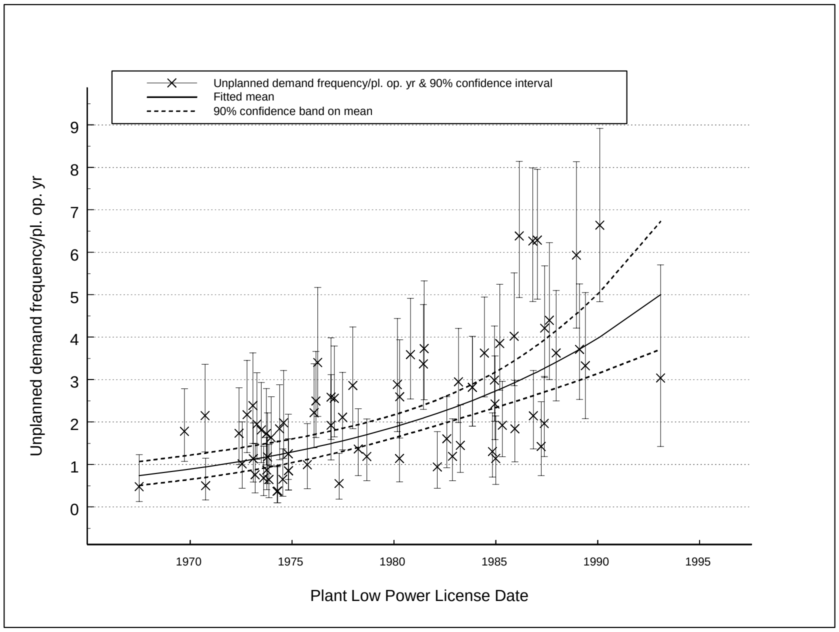


**Figure ES-7.** Unplanned demand frequency versus low-power license date, with confidence limits on the frequencies. The increasing trend is highly statistically significant (P-value <5E-5).

Estimates of AFW unreliability have been used in past regulatory analyses and rulemaking addressing the design and operation of the AFW system, in particular, the Standard Review Plan

(NUREG-0800), Station Blackout (NUREG-1032), and ATWS (SECY-83-293). The estimates provided in these documents were compared with the estimates presented in this report, based on the 1987–1995 operating experience. These comparisons demonstrated that the operating-experience-based estimates are similar to or slightly better than those used in the regulatory applications.