Enhanced Component Performance Study

Emergency Diesel Generators

1998–2011

1. INTRODUCTION

This report presents an enhanced performance evaluation of emergency diesel generators (EDGs) at U.S. commercial nuclear power plants. This report does not estimate values for use in probabilistic risk assessments (PRAs), but does evaluate component performance over time. The 2010 Component Reliability Update [Reference 1], which is an update to Reference 2 (NUREG/CR-6928) reports EDG unreliability estimates using Equipment Performance and Information Exchange (EPIX) data from 1998–2010 and maintenance unavailability (UA) performance data using Mitigating Systems Performance Index (MSPI) Basis Document data from 2002–2010 for use in PRAs.

The trend evaluations in this study are based on the operating experience failure reports from fiscal year (FY) 1998 through FY 2011 as reported in EPIX. The EDG failure modes considered are failure-to-start (FTS), failure-to-load-and-run (FTLR), and failure-to-run > 1 hour (FTR>1H). EDG train maintenance unavailability data for trending are from the same time period, as reported in the Reactor Oversight Program (ROP) and the MSPI. In addition to the presentation of the component failure mode data and the UA data, an 8-hour component total unreliability is calculated and trended.

Previously, component studies relied on operating experience obtained from licensee event reports (LERs), Nuclear Plant Reliability Data System (NPRDS), and EPIX. The EPIX database (which includes as a subset the MSPI designated devices) has matured to the point where component availability and reliability can be estimated with a higher degree of assurance of accuracy. In addition, the EPIX population of data is much larger than the population used in the previous studies.

The objective of the effort for the updated component performance studies is to obtain annual performance trends of failure rates and probabilities. An overview of the trending methods, glossary of terms, and abbreviations can be found in the Overview and Reference document on the Reactor Operational Experience Results and Databases web page.

The objective of the enhanced component performance study is to present an analysis of factors that could influence the system and component trends in addition to annual performance trends of failure rates and probabilities. The factors analyzed for the EDG component are the differences in failures between all demands and actual unplanned (ESF) demands (Section 6.2), differences among manufacturers (Section 6.3), and differences among EDG ratings (Section 6.4). Statistical analyses of these differences are performed and results showing whether pooling is acceptable across these factors. In addition, engineering analyses were performed with respect to time period and failure mode (Section 6.5). The factors analyzed are: sub-component, failure cause, detection method, recovery, manufacturer, and EDG rating.

2. SUMMARY OF FINDINGS

The results of this study are summarized in this section. Of particular interest is the existence of any statistically significant[1] increasing trends. In this update, the following extremely statistically significant increasing trends were identified in the EDG results:

- Failure rate estimate trend for EPS EDGs, industry-wide EDG FTR>1H trend. (see Figure 3)
- Frequency (events per reactor year) of FTR>1H events, EPS and HPCS EDGs (see Figure 16)

Highly statistically significant increasing trends were identified in the EDG results:

- EPS, industry-wide EDG unreliability trend (8-hour mission). (see Figure 9)

The increasing trend in the EPS EDG unreliability (Figure 9) is primarily due to the increasing trend in the greater than 1 hour failure to run events (reflected in Figure 3 and Figure 16).

Statistically significant decreasing trends were identified in the EDG results for the following:

- Frequency (events per reactor year) of load and run $\leq$ 1 hour demands, EPS and HPCS EDGs (see Figure 12)

An ongoing concern in the industry is whether industry data adequately represent standby component performance during unplanned (ESF) demands. Section 6.2 shows the results of the consistency check between industry data and ESF detected failure data for EDGs. The consistency checks using unplanned demand data indicate that the FTLR and FTR failure observations and the Total EDG unreliability are consistent with their industry-average distribution from Table 2. The EPS EDG FTS lies in the upper 95% of the predictive distribution (superior performance).

Section 6.3 shows the results of the consistency check between EDG manufacturers. One manufacturer's EPS EDG performance lies in the lower 5% (degraded performance), however, this manufacturer involves very few EPS EDGs, and so the data are limited. The rest of the manufacturers lie within the 5% to 95% interval and are consistent with the industry-average performance.

Section 6.4 shows the results of the consistency check between EDG ratings. The ratings all lie within the 5% to 95% interval and are consistent with the industry-average performance.

---

[1] Statistically significant is defined in terms of the 'p-value.' A p-value is a probability indicating whether to accept or reject the null hypothesis that there is no trend in the data. P-values of less than or equal to 0.05 indicate that we are 95% confident that there is a trend in the data (reject the null hypothesis of no trend.) By convention, we use the "Michelin Guide" scale: p-value < 0.05 (statistically significant), p-value < 0.01 (highly statistically significant); p-value < 0.001 (extremely statistically significant).

3. FAILURE PROBABILITIES AND FAILURE RATES

3.1 Overview

The industry-wide failure probabilities and failure rates of EDGs have been calculated from the operating experience for FTS, FTLR, and FTR>1H. The EDG data set obtained from EPIX includes EDGs in the systems listed in Table 1. Table 2 shows industry-wide failure probability and failure rate results for the EPS EDG from Reference 2. Table 3 shows the industry-wide failure probability and failure rate results for the HPCS EDG. The HPCS EDG failure probability was not fully analyzed in Reference 1 and is presented here based on the current EPIX data that has been reviewed at the INL.

Table 1. EDG systems.

System	Description	EDG Count
EPS	Emergency power supply	223
HPCS	High pressure core spray	8
	Total	231

The EDGs are assumed to operate both when the reactor is critical and during shutdown periods. The number of EDGs in operation is assumed to be constant throughout the study period. All demand types are considered—testing, non-testing, and, as applicable, emergency safeguard feature (ESF) demands.

Table 2. Industry-wide distributions of p (failure probability) and λ (hourly rate) for EPS EDGs.

Failure Mode	5%	Median	Mean	95%	Distribution		
					Type	α	β
FTS	1.45E-03	2.77E-03	2.89E-03	4.73E-03	Beta	8.11	2.798E+03
FTLR	9.61E-04	3.34E-03	3.78E-03	8.10E-03	Beta	2.77	7.311E+02
FTR>1H	4.04E-04	1.02E-03	1.10E-03	2.06E-03	Gamma	4.49	4.093E+03

Table 3. Industry-wide distributions of p (failure probability) and λ (hourly rate) for HPCS EDGs.

Failure Mode	5%	Median	Mean	95%	Distribution		
					Type	α	β
FTS	2.86E-03	3.18E-02	4.32E-02	1.23E-01	Beta	1.09	2.423E+01
FTR	1.52E-04	1.02E-03	1.30E-03	3.38E-03	Gamma	1.50	1.155E+03

3.2 EDG Failure Probability and Failure Rate Trends

Trends in the EPS and HPCS failure probabilities and failure rates are shown in Figure 1 to Figure 6. The data for the trend plots are contained in Table 14 to Table 19.
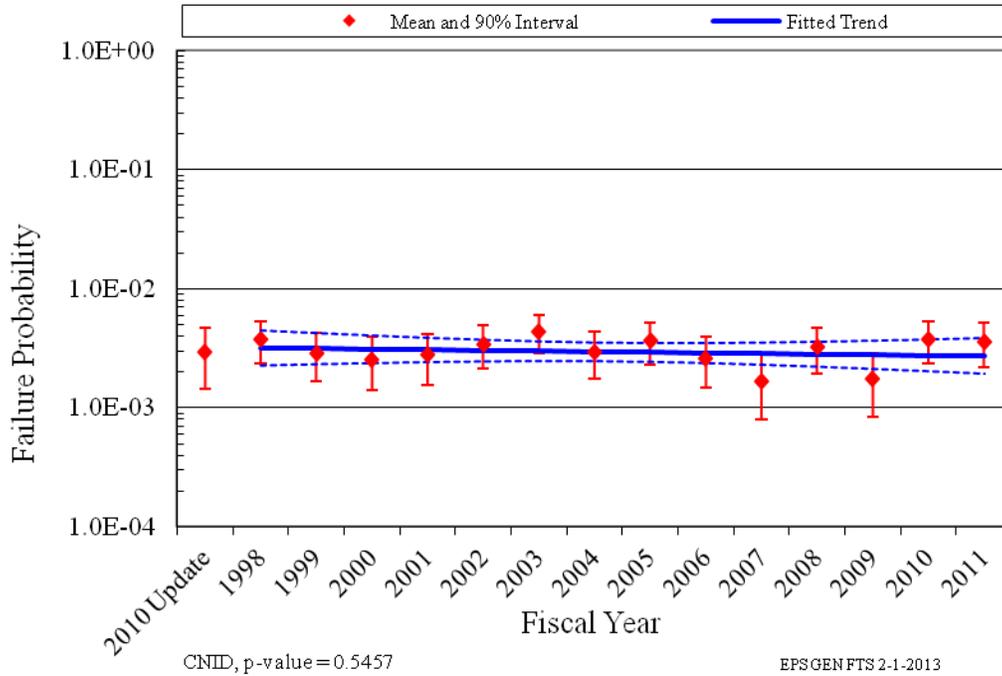
Figure 1. Failure probability estimate trend for EPS EDGs, industry-wide EDG FTS trend.

Figure 2. Failure probability estimate trend for EPS EDGs, industry-wide EDG FTLR trend.

Figure 3. Failure rate estimate trend for EPS EDGs, industry-wide EDG FTR>1H trend.

Figure 4. Failure probability estimate trend for HPCS EDGs, industry-wide EDG FTS trend.
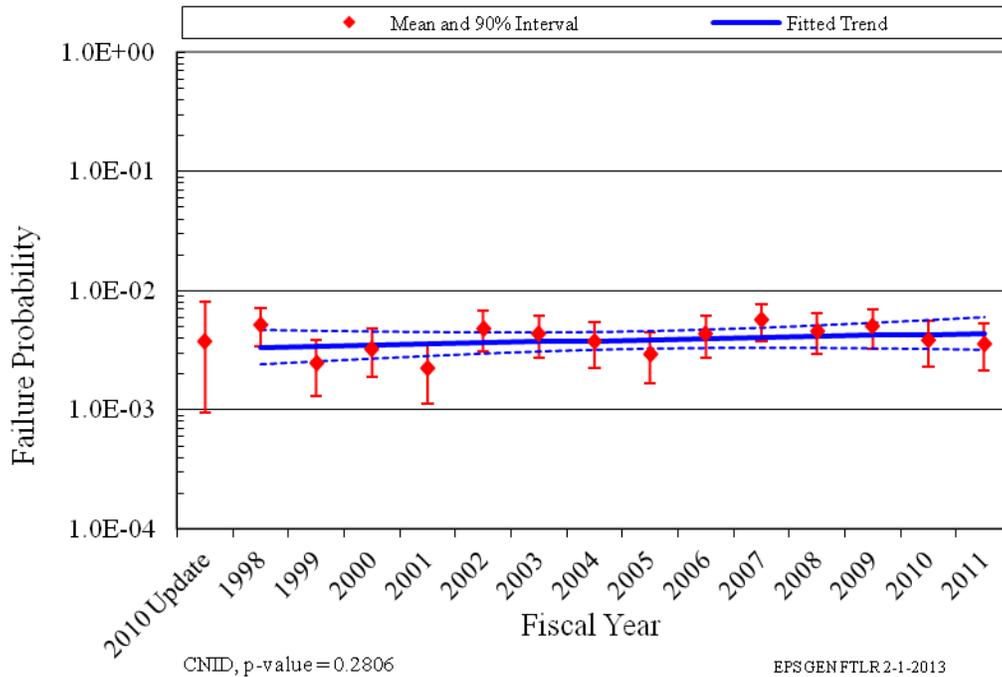
Figure 5. Failure probability estimate trend for HPCS EDGs, industry-wide EDG FTLR trend.

Figure 6. Failure rate estimate trend for HPCS EDGs, industry-wide EDG FTR>1H trend.
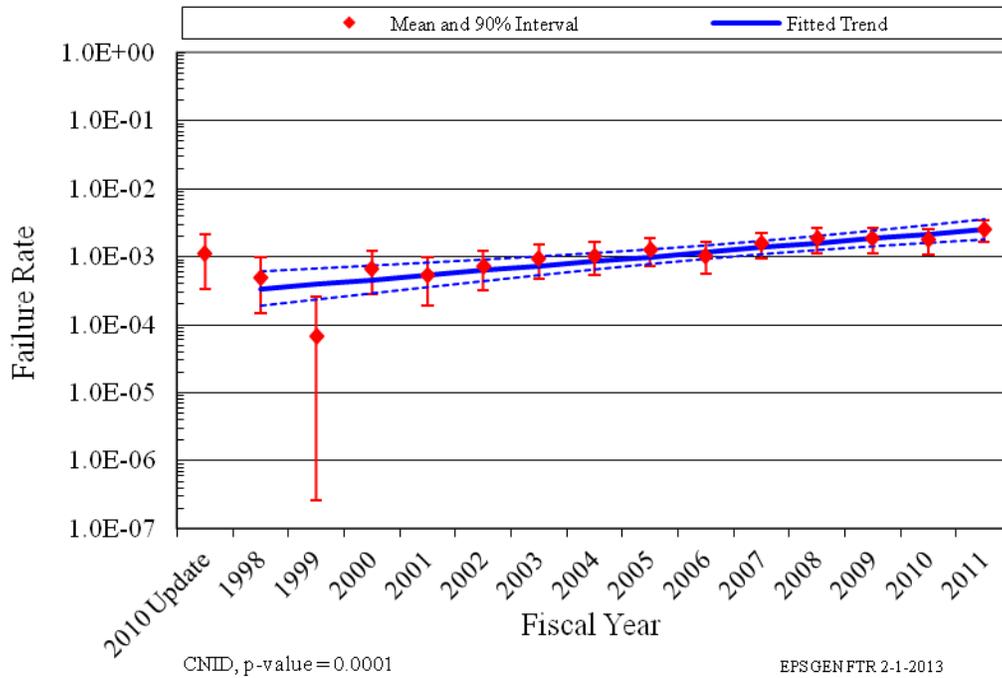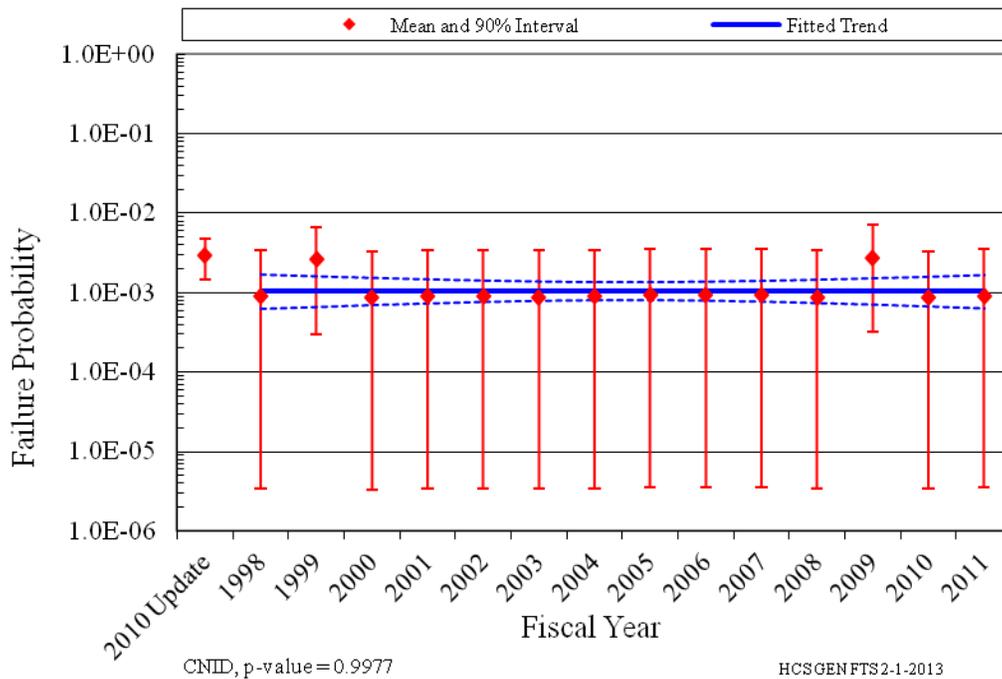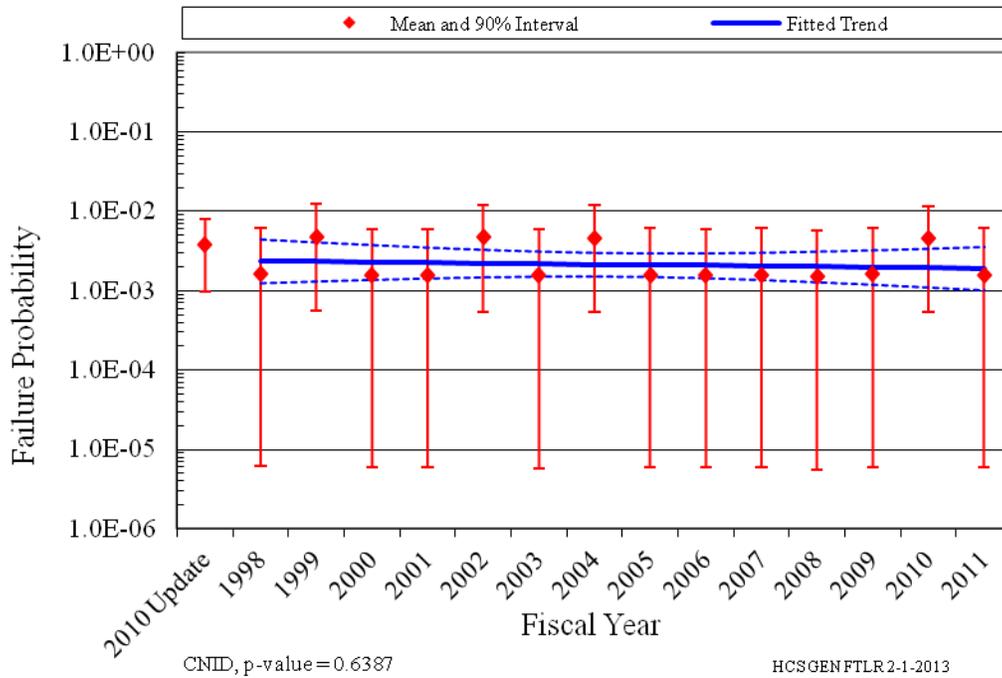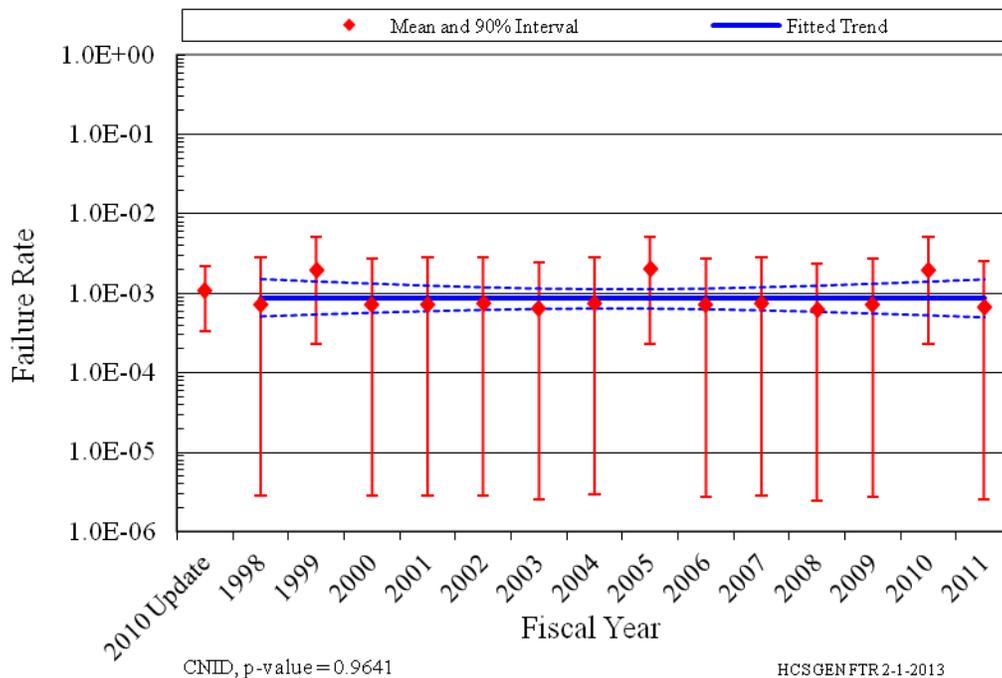
In the plots, the means of the posterior distributions from the Bayesian update process were trended across the years. The posterior distributions were also used for the vertical bounds for each year. The 5th

and 95th percentiles of these distributions give an indication of the relative variation from year to year in the data. When there are no failures, the interval tends to be larger than the interval for years when there are one or more failures. The larger interval reflects the uncertainty that comes from having little information in that year's data. Such uncertainty intervals are determined by the prior distribution. In each plot, a relatively "flat" constrained noninformative prior distribution (CNID) is used, which has large bounds.

The horizontal curves plotted around the regression lines in the graphs show 90 percent simultaneous confidence bands for the fitted lines. The simultaneous confidence band bounds are larger than ordinary confidence intervals for the trended values because they form a band that has a 90% probability of containing the entire line. In the lower left hand corner of the trend figures, the regression p-values are reported. They come from a statistical test on whether the slope of the regression line might be zero. Low p-values indicate that the slopes are not likely to be zero, and that trends exist.

Further information on the trending methods is provided in Section 2 of the Overview and Reference document. A final feature of the trend graphs is that the baseline industry values from Table 2 are shown for comparison.

4. UNAVAILABILITY

4.1 Overview

The industry-wide test or maintenance unavailability (UA) of EDG trains has been calculated from the operating experience. UA data are for EDG trains, which can include more than just the EDG. However, in most cases the EDG contributes the majority of the UA reported. Table 4 shows overall results for the EDG from Reference 1 based on UA data from MSPI Basis Documents, covering 2002 to 2010. In the calculations, planned and unplanned unavailable hours for a train are combined.

Table 4. Industry distributions of unavailability for EDGs.

Description	Mean	Distribution	α	β
Emergency Diesel Generator Test or Maintenance (EPS)	1.44E-02	Beta	3.71	254.7
Emergency Diesel Generator Test or Maintenance (HPCS)	1.06E-02	Beta	42.88	4021.4

4.2 EDG Unavailability Trends

For the 1998-2011 period, the following are overall maintenance unavailability data. Note that these data do not supersede the data in Table 4 for use in risk assessments.

Trends in EDG train unavailability are shown in Figure 7 and Figure 8. Data tables for these figures are Table 20 and Table 21, respectively. The EDGs in systems EPS and HPCS are trended. The trend charts show the results of using data for each year based on selected system-specific component unavailability data over time. The yearly (1998–2011) unavailability and reactor critical hour data were obtained from the ROP (1998 to 2001) and MSPI (2002 to 2011) data for the EDG component. The total downtimes during operation for each plant and year were summed, and divided by the corresponding number of EDG-reactor critical hours. Unavailability data for shutdown periods are not reported.

A change in reporting requirements for UA occurred in 2002. The ROP data (1998–2001) did not include EDG overhaul outages while plants were in critical operation, while the MSPI (2002–2011) requires plants to report such outages. The annual means of these two groups are statistically significant, indicating that there is strong evidence that they differ. This change in reporting is believed to result in most of the approximately 50% increase in UA observed between the 1998–2001 data and the 2002–2011 data. The 1998–2001 data do not exhibit a statistically significant trend as shown in Figure 7. However, the 2002–2011 data do exhibit a statistically significant trend as shown in Figure 7.

Linear model 2002 to 2010, p-value = 0.0134
Linear model 1998 to 2001, p-value = 0.2527

EPSGENUA 9-10-2012

Figure 7. EPS EDG UA trend.

Logit model, p-value = 0.3549

HCSEDGUA9-10-2012
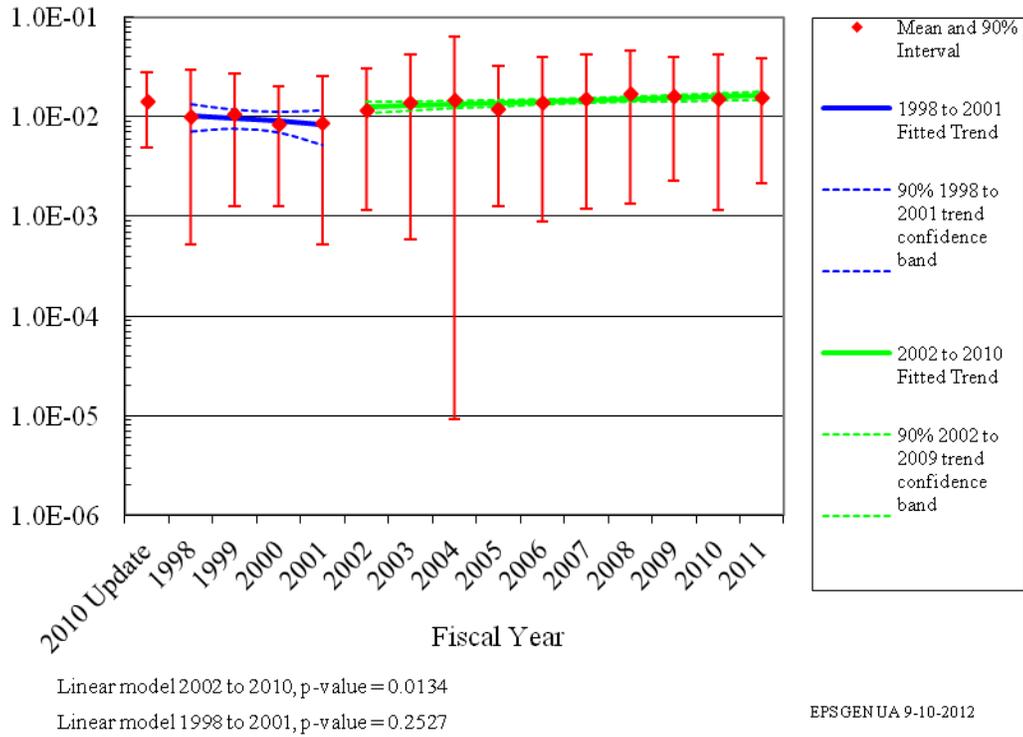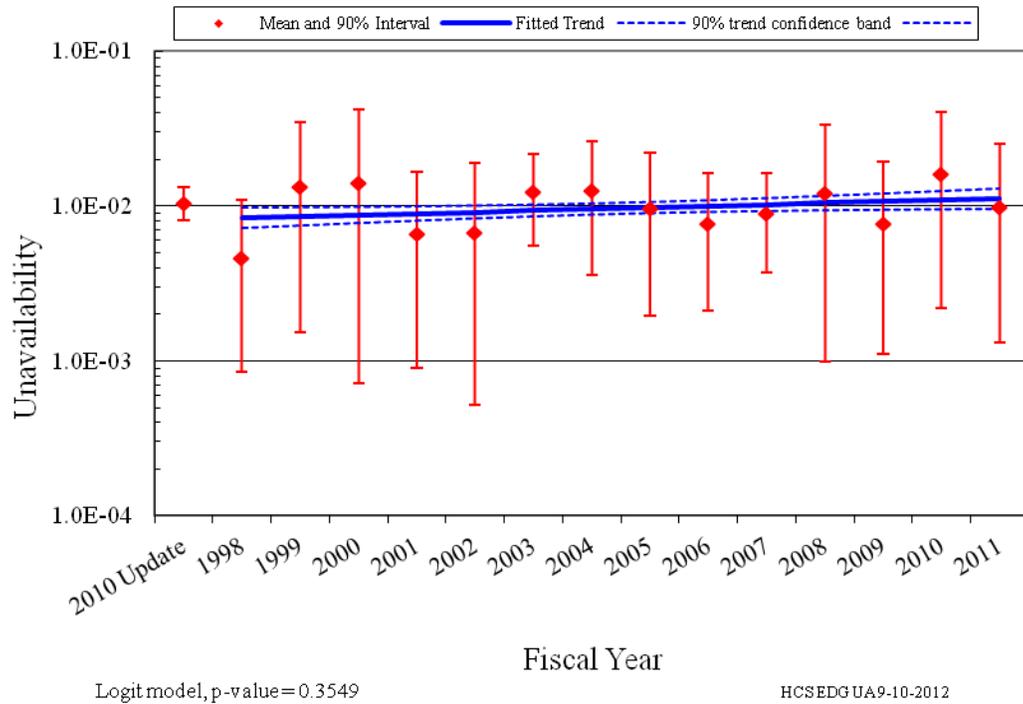
Figure 8. HPCS EDG UA trend.

The mean and variance for each year is the sample mean and variance calculated from the plant-level unavailabilities for that year. The vertical bar spans the calculated 5th to 95th percentiles of the beta distribution with matching means.

Further information on the trending methods is provided in Section 3 of the Overview and Reference document. In the lower left hand corner of the trend figures, the p-value is reported.

5. EDG UNRELIABILITY TRENDS

Trends in total component unreliability are shown in Figure 9 and Figure 10. Plot data for these Figures are in Table 22 and Table 23, respectively. Total unreliability is defined as the result of an OR gate with the FTS, FTLR, FTR, and UA as basic event inputs. The probability of FTR is calculated for 7 hours to provide the results for an 8-hour mission. The trends are shown at the system-specific level across the industry. The trending method is described in more detail in Section 4 of the Overview and Reference document. In the lower left hand corner of the trend figures, the regression method is reported.

Figure 9. EPS, industry-wide EDG unreliability trend (8-hour mission).
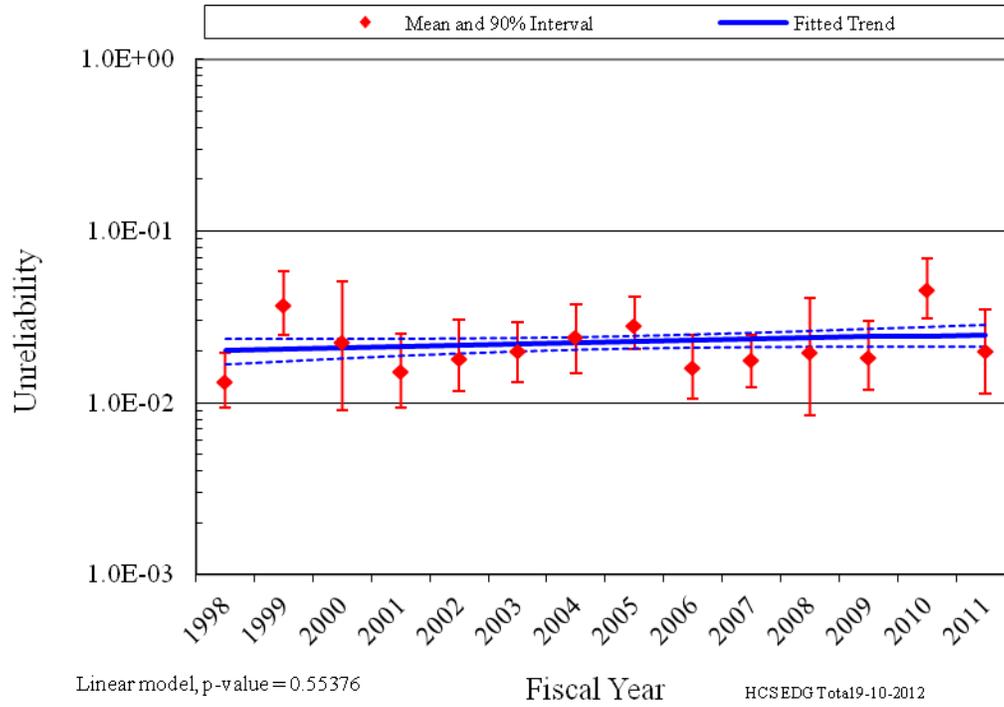
Figure 10. HPCS, industry-wide EDG unreliability trend (8-hour mission).

6. ENGINEERING ANALYSIS

The engineering analysis section presents an analysis of factors that could influence the system and component trends. Engineering trends of component failures and demands are presented in Section 6.1. Differences between testing and actual unplanned demands 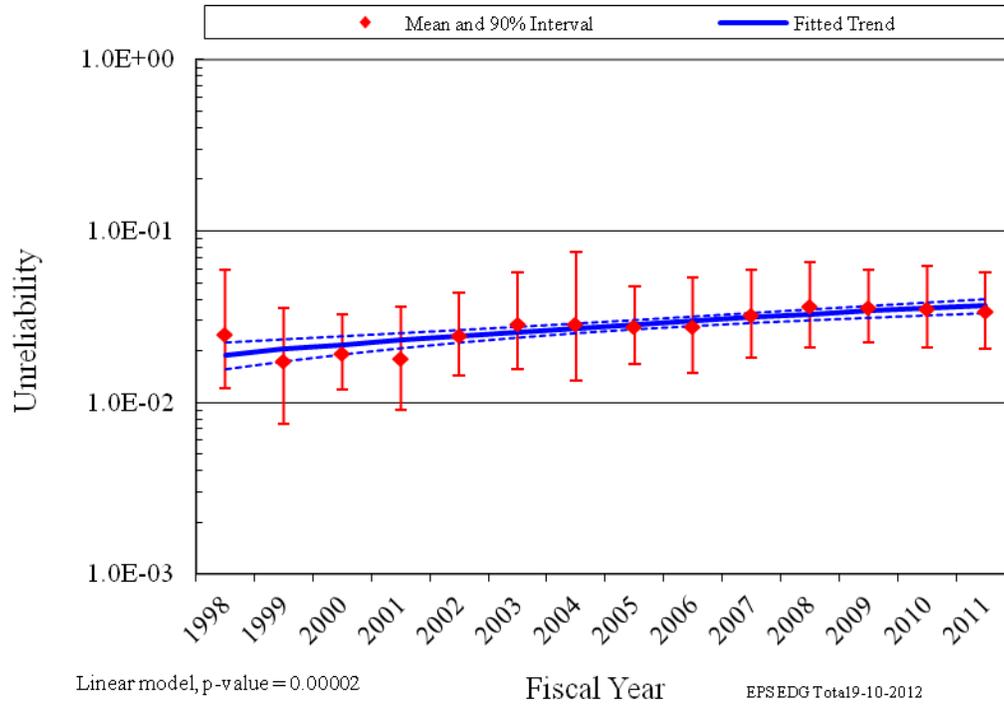are presented in Section 6.2, differences among manufacturers are presented in Section 6.3, and differences among EDG ratings are presented in Section 6.4. Statistical analyses of these differences are performed and results showing whether pooling is acceptable across these factors. In addition, engineering analyses were performed with respect to time period and failure mode are presented in Section 6.5. The factors analyzed were: sub-component, failure cause, detection method, manufacturer, and EDG rating.

6.1 Engineering Trends

This section presents frequency trends for EPS and HPCS EDG failures and demands. The data are normalized by reactor year for plants that have the equipment being trended. Figure 11 shows the trend for EPS and HPCS EDG demands. Figure 12 shows the trend for EPS and HPCS EDG load and run demands. Figure 13 shows the trend for the EPS and HPCS EDG run hours. Table 24, Table 25, and Table 26 provide the plot data, respectively.

Figure 14 shows the trend for EPS and HPCS EDG FTS events. Figure 15 shows the trend EPS and HPCS EDG FTLR events and Figure 16 shows the trend for the EPS and HPCS EDG FTR events. Table 27, Table 28, and Table 29 provide the plot data, respectively.

Table 5 summarizes the failures by system and year for the FTS failure mode. Table 6 summarizes the failures by system and year for the FTLR failure mode. Table 7 summarizes the failures by system and year for the FTR>1H failure mode.

The systems from Table 1 are trended together for each figure. The rate methods described in Section 2 of the Overview and Reference document are used.

Figure 11. Frequency (events per reactor year) of start demands, EPS and HPCS EDGs.
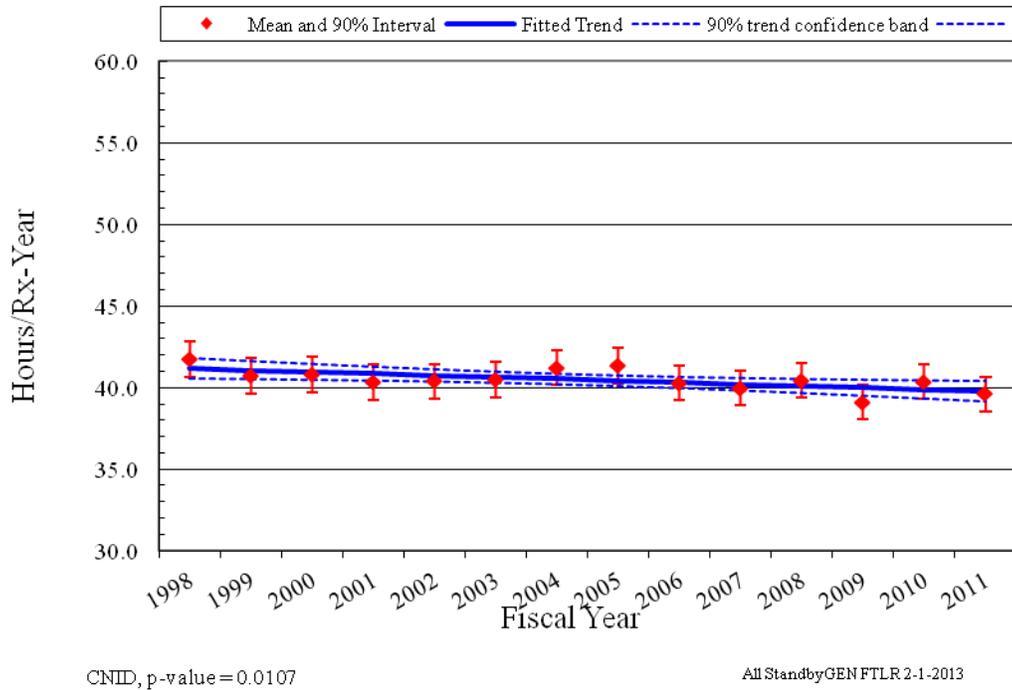
Figure 12. Frequency (events per reactor year) of load and run ≤ 1 hour demands, EPS and HPCS EDGs.
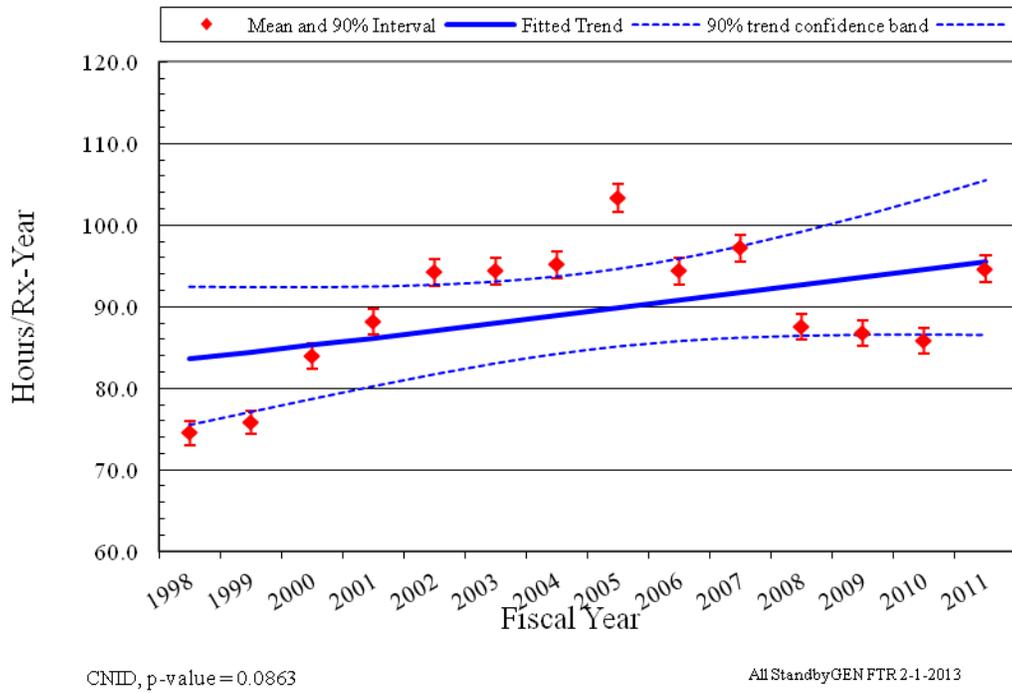
Figure 13. EPS and HPCS EDG run hours per reactor year.
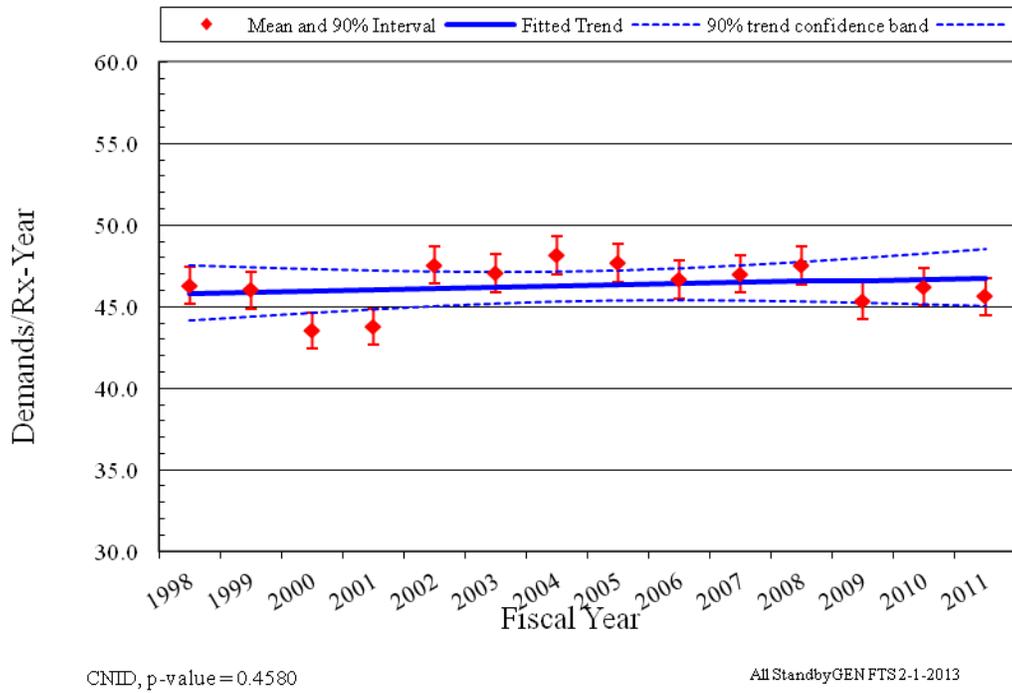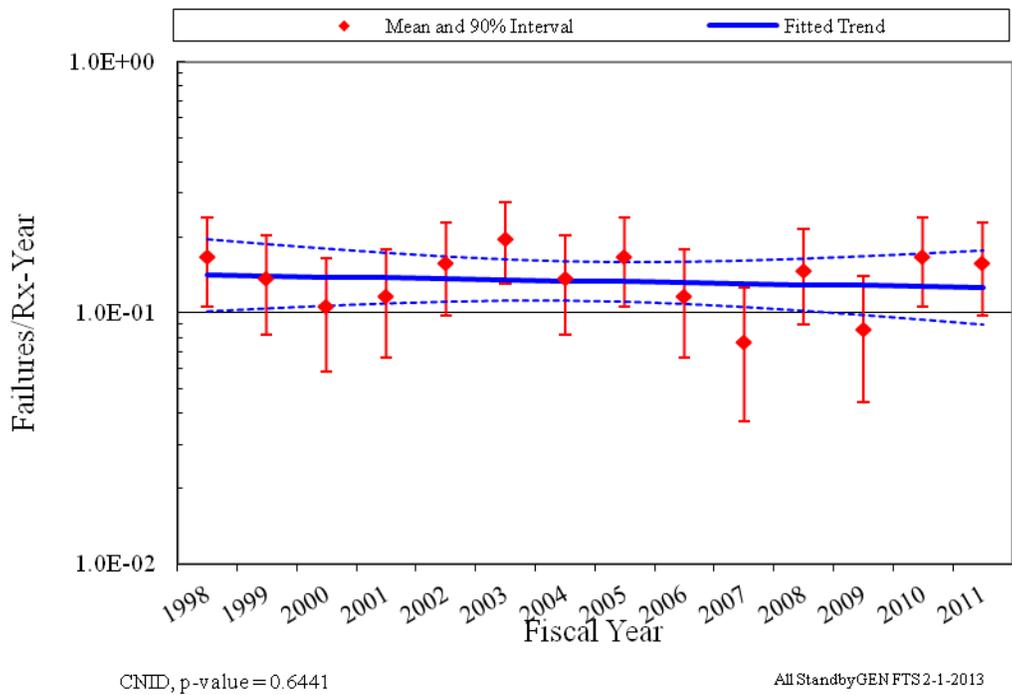

Figure 14. Frequency (events per reactor year) of FTS events, EPS and HPCS EDGs.
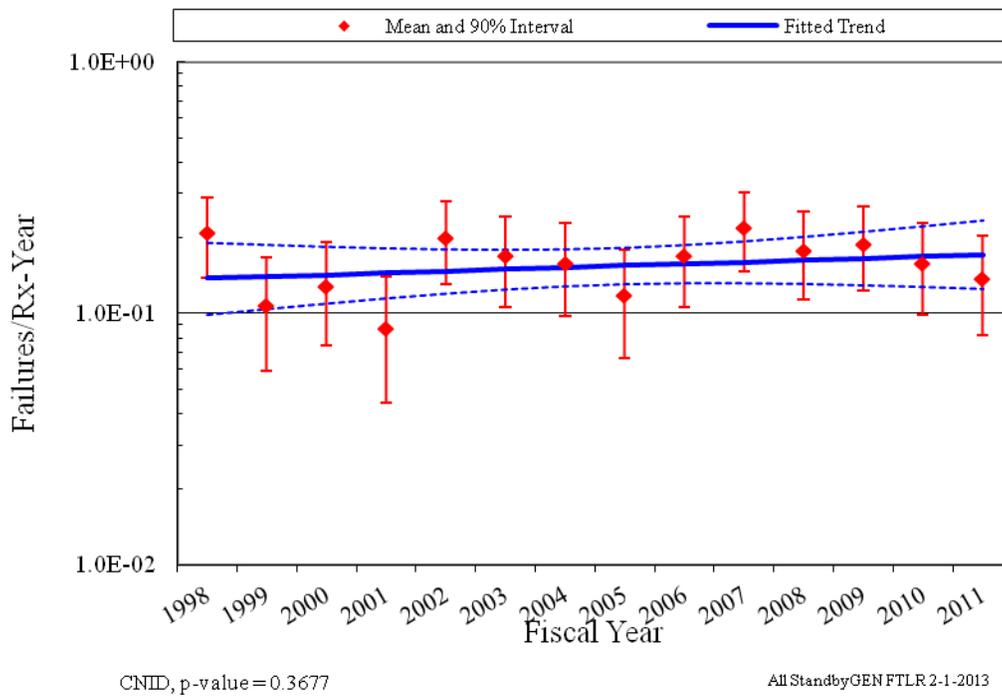
Figure 15. Frequency (events per reactor year) of FTLR events, EPS and HPCS EDGs.
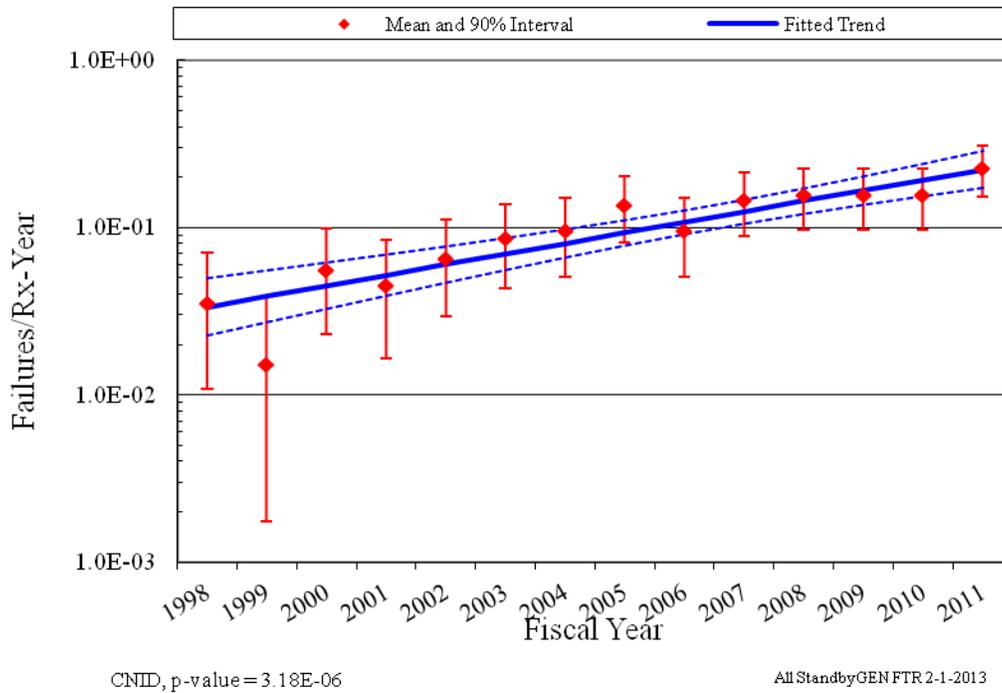
Figure 16. Frequency (events per reactor year) of FTR>1H events, EPS and HPCS EDGs.

Table 5. Summary of EDG failure counts for the FTS failure mode over time by system.

System Code	EDG Count	EDG Percent	FY 98	FY 99	FY 00	FY 01	FY 02	FY 03	FY 04	FY 05	FY 06	FY 07	FY 08	FY 09	FY 10	FY 11	Total	Percent of Failures
EPS	223	96.5%	16	12	10	11	15	19	13	16	11	7	14	7	16	15	182	98.9%
HCS	8	3.5%		1										1			2	1.1%
Total	231	100.0%	16	13	10	11	15	19	13	16	11	7	14	8	16	15	184	100.0%

Table 6. Summary of EDG failure counts for the FTLR failure mode over time by system.

System Code	EDG Count	EDG Percent	FY 98	FY 99	FY 00	FY 01	FY 02	FY 03	FY 04	FY 05	FY 06	FY 07	FY 08	FY 09	FY 10	FY 11	Total	Percent of Failures
EPS	EPS	223	96.5%	20	9	12	8	18	16	14	11	16	21	17	18	14	13	207
HCS	HCS	8	3.5%		1			1		1						1		4
Total	Total	231	100.0%	20	10	12	8	19	16	15	11	16	21	17	18	15	13	211

Table 7. Summary of EDG failure counts for the FTR>1H failure mode over time by system.

System Code	EDG Count	EDG Percent	FY 98	FY 99	FY 00	FY 01	FY 02	FY 03	FY 04	FY 05	FY 06	FY 07	FY 08	FY 09	FY 10	FY 11	Total	Percent of Failures
EPS	223	96.5%	3		5	4	6	8	9	12	9	14	15	15	14	22	136	97.8%
HCS	8	3.5%		1						1					1		3	2.2%
Total	231	100.0%	3	1	5	4	6	8	9	13	9	14	15	15	15	22	139	100.0%

6.2 Comparison of EPIX EPS EDG Unplanned Demand Results with Industry Results

Because the EPIX EPS EDG data are dominated by test demands (over 95% of the demands are typically from tests), an ongoing concern is whether these mostly test data adequately represent EPS EDG performance during unplanned demands. This comparison evaluates the same dataset for standby components that is used for the overall trends shown in this document, but limits the failure data to those that are discovered during an ESF demand and the ESF demands reported in EPIX. The data are further limited to FY 2003 to present since the ESF demand reporting in EPIX is inconsistent prior to FY 2003.

To answer this question, EPIX failure records were reviewed to identify actual unplanned EPS EDG demands involving bus under voltage conditions. Such events require the associated EPS EDG to start, load onto the bus and power the bus until normal power is recovered to the bus. There are additional EPS EDG unplanned demands in which a bus under voltage condition did not exist. In those cases, the EPS EDG did not have to load and power the bus. Such unplanned demands do not fully exercise the mission of the EPS EDGs and therefore were not counted.

The EPS EDG unplanned demand data covering FY 2003 – 2011 are summarized in Table 8. Consistency between the unplanned demand data and industry-average performance (from Table 2) was evaluated using the predictive distribution approach outlined in the *Handbook of Parameter Estimation for Probabilistic Risk Assessment*, NUREG/CR-6823, Sections 6.2.3.5 and 6.3.3.4 [Reference 3]. Simulation is required.

The unplanned demand data were aggregated at the plant level (failures and demands). Assuming each plant can have a different failure probability, the industry-average distribution (from Table 2) was sampled for each plant. The predicted number of events for each plant was evaluated using the binomial distribution with the plant-specific failure probability and its associated number of demands. Then the total number of predicted failures was obtained by summing the individual plant results. This process was repeated 1000 times (Latin hypercube sampling), each time obtaining a total number of predicted failures. The 1000 sample results were ordered from high to low. Then the actual number of unplanned demand failures observed (listed in Table 8) was compared with this ordered sample to determine the probability of observing this number of failures or greater. If the probability was greater than 0.05 and less than 0.95, then the unplanned demand performance was considered to be consistent with the industry-average distribution obtained from the EPIX data analysis.

Table 8. EPS EDG unplanned demand performance comparison with industry-average performance from EPIX data.

Failure Modes	Plants	Demands or Hours	Failures	Expected Failures	Probability of ≥ Failures	Consistent with Industry-Average Performance?
FTS	96	311	0	0.9	1.00	No
FTLR	96	195	1	0.7	0.35	Yes
FTR	96	2364.7	4	18.0	0.08	Yes
Total EDG Unreliability (8 hours)	96	311 and 2,364.7 h	5	19.6	0.21	Yes

The consistency checks using unplanned demand data indicate that the FTLR and FTR failure observations and the Total EDG unreliability are consistent with their industry-average distribution from Table 2. The EPS EDG FTS lies in the upper 95% of the predictive distribution (superior performance).

6.3 EPS EDG Performance by Manufacturer

Table 9 presents the results of the evaluation of EPS EDG performance by manufacturer. EPIX contains information on EPS EDG manufacturers, but it appears that over the years some manufacturers have changed names or have been acquired by other manufacturers. Therefore, in order to identify the original manufacturer, the EPIX information was supplemented by other EPS EDG reports. The results are a consistency check against the industry-average distributions in Table 2. The comparison was made for the combination of all three failure modes. One manufacturer's EPS EDG performance lies in the lower 5% (degraded performance), however, this manufacturer involves very few EPS EDGs, and so the data are limited. The rest of the manufacturers lie within the 5% to 95% interval and are consistent with the industry-average performance.

Table 9. EPS EDG performance by manufacturer.

EPS EDG Manufacturer Performance Consistency with Industry-Average Performance - FTS, FTLR, and FTR Combined						
Manufacturer	Code	EPS EDGs	Observed Failures	Expected Failures	Probability ≥ Observed Failures	Consistent with Industry-Average Performance? (note a)
Worthington Corp	WC	4	34	10.3	0.00	**No**
SAC/Compair Luchard/Jeumont Schndr	SC/JS	3	11	5.5	0.07	**Yes**
Fairbanks Morse/Colt	FM/C	65	159	136.8	0.12	**Yes**
TransAmerica DeLaval	TD	20	54	43.4	0.19	**Yes**
Nordberg	NB	8	22	19.4	0.37	**Yes**
Electro Motive/General Motors	EM/GM	68	127	129.3	0.65	**Yes**
ALCO Power	AP	24	40	46.6	0.79	**Yes**
Cooper Bessemer	CB	31	59	85.7	0.92	**Yes**
Totals		223	506	477.2		
a. If the probability of observing the actual failures or greater is ≥ 0.05 and ≤ 0.95, then the manufacturer performance is considered to be consistent with the industry-average performance.						

6.4 EPS EDG Performance by Rating

Table 10 presents the results of the evaluation of EPS EDG performance by rating. The results are a consistency check against the industry-average distributions in Table 2. The comparison was made for the combination of all three failure modes. The ratings all lie within the 5% to 95% interval and are consistent with the industry-average performance.

Table 10. EPS EDG performance by rating.

Rating	EPS EDGs	Observed Failures	Expected Failures	Probability ≥ Observed Failures	Consistent with Industry-Average Performance? (note a)
EPS EDG Rating Performance Consistency with Industry-Average Performance – FTS, FTLR, and FTR Combined					
50-249 KW	2	4	12.0	0.64	Yes
1,000-4,999 KW	169	364	345.0	0.32	Yes
5,000-99,999 KW	52	128	126.0	0.34	Yes
Totals	223	496	483.0		
a. If the probability of observing the actual failures or greater is ≥ 0.05 and ≤ 0.95, then the rating performance is considered to be consistent with the industry-average performance.					

6.5 EPS EDG Engineering Analysis by Failure Modes

The engineering analysis of EPS EDG failure sub-components, causes, detection methods, and recovery are presented in this section. Each analysis divides the events into two periods: before July 2003 and after July 2003 (the start of the data begins in FY 1998 and the last date is FY 2011). This breakdown was chosen for two reasons: first, July 2003 represents a point in which the MSPI data collection attains a "higher level" of scrutiny; second, this date represents a point about half way through the full data period.

The second division of the events is by the failure mode determined after EPIX data review by the staff. See Section 0 for more description of failure modes.

EPS EDG sub-component contributions to the three failure modes are presented in Figure 17. The sub-component contributions are similar to those used in the CCF database. For FTS, instrumentation and control and the generator piece parts have the highest percentage contributions to failures. FTLR high contributors include the breaker and instrumentation and control. Finally, FTR high contributors include the cooling, engine, fuel oil, and instrumentation and control.

EPS EDG cause group contributions to the three failure modes are presented in Figure 18. The cause groups are similar to those used in the CCF database. Table 11 shows the breakdown of the cause groups with the specific causes that were coded during the data collection. The most likely cause is grouped as Internal. Internal means that the cause was related to something within the EPS EDG component such as a worn out part or the normal internal environment. Of particular interest is the Design cause group under the fail to run failure mode. Notice that this group increased in importance in the current period over the previous period.

EPS EDG detection methods to the three failure modes are presented in Figure 19. The most likely detection method is testing, which is the prevalent detection method for most standby components.

EPS EDG recovery to the three failure modes are presented in Figure 20. The overall non-recovery to recovery ratio is approximately 10:1.

Table 11. Component failure cause groups.

Group	Specific Cause	Description
Design	Construction/installation error or inadequacy	Used when a construction or installation error is made during the original or modification installation. This includes specification of incorrect component or material.
Design	Design error or inadequacy	Used when a design error is made.
Design	Manufacturing error or inadequacy	Used when a manufacturing error is made during component manufacture.
External	State of other component	Used when the cause of a failure is the result of a component state that is not associated with the component that failed. An example would be the diesel failed due to no fuel in the fuel storage tanks.
External	Ambient environmental stress	Used when the cause of a failure is the result of an environmental condition from the location of the component.
Human	Accidental action (unintentional or undesired human errors)	Used when a human error (during the performance of an activity) results in an unintentional or undesired action.
Human	Human action procedure	Used when the procedure is not followed or the procedure is incorrect. For example: when a missed step or incorrect step in a surveillance procedure results in a component failure.
Human	Inadequate maintenance	Used when a human error (during the performance of maintenance) results in an unintentional or undesired action.
Internal	Internal to component, piece-part	Used when the cause of a failure is a non-specific result of a failure internal to the component that failed other than aging or wear.
Internal	Internal environment	The internal environment led to the failure. Debris/Foreign material as well as an operating medium chemistry issue.
Internal	Setpoint drift	Used when the cause of a failure is the result of setpoint drift or adjustment.
Internal	Age/Wear	Used when the cause of the failure is a non-specific aging or wear issue.
Other	Unknown	Used when the cause of the failure is not known.
Other	Other (stated cause does not fit other categories)	Used when the cause of a failure is provided but it does not meet any one of the descriptions.
Procedure	Inadequate procedure	Used when the cause of a failure is the result of an inadequate procedure operating or maintenance.
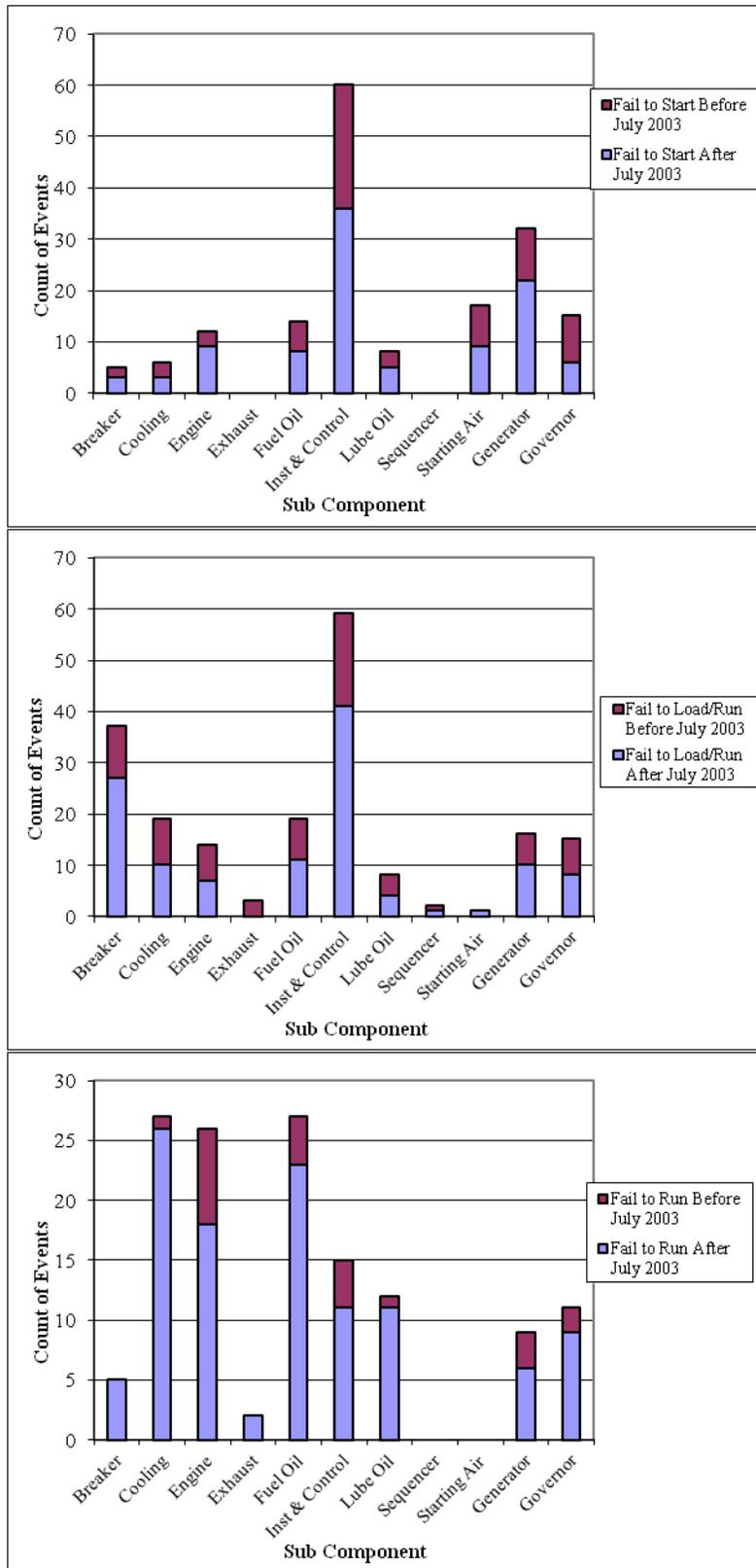
Figure 17. EPS EDG failure breakdown by period, sub component, and failure mode.
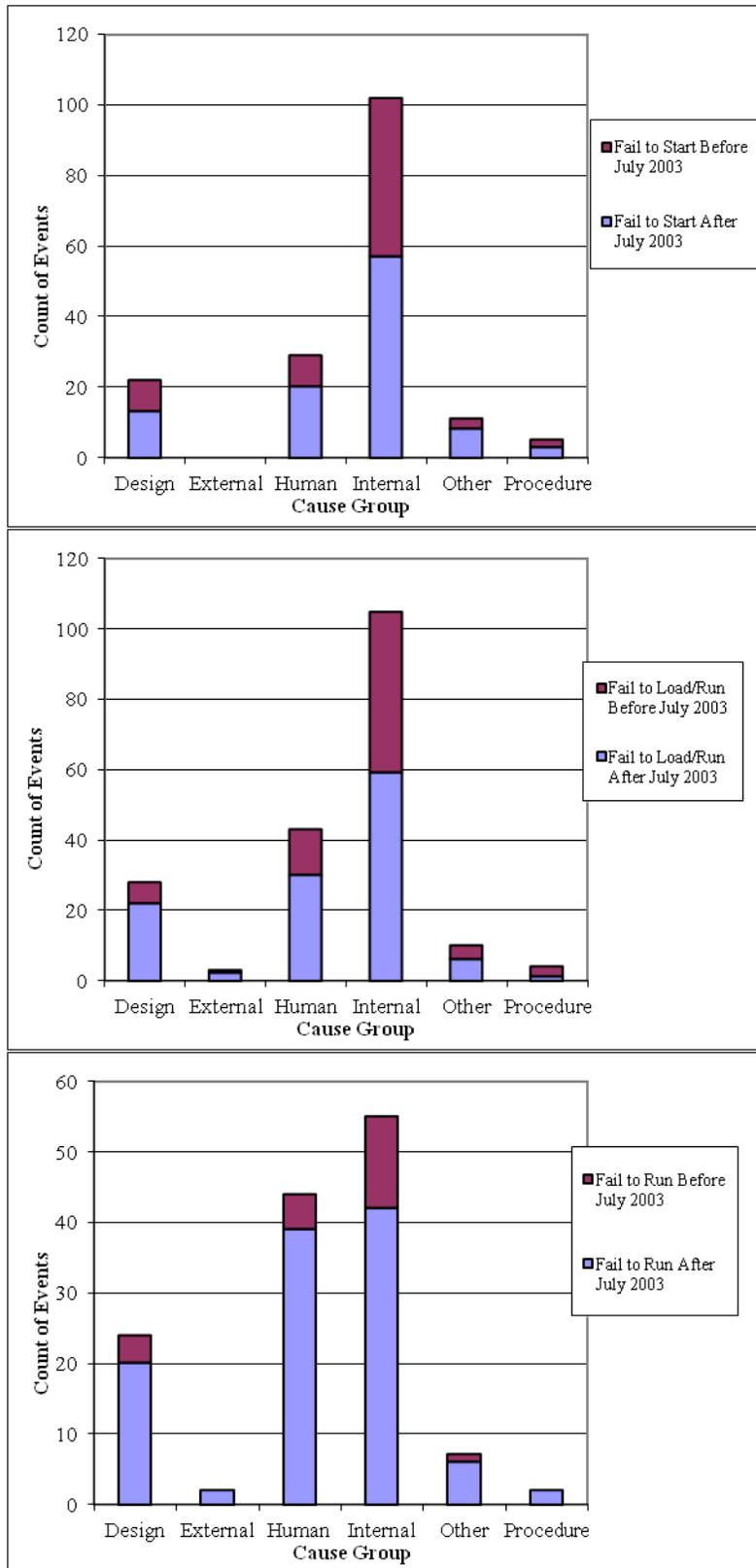
Figure 18. EPS EDG breakdown by time period, cause group, and failure mode.
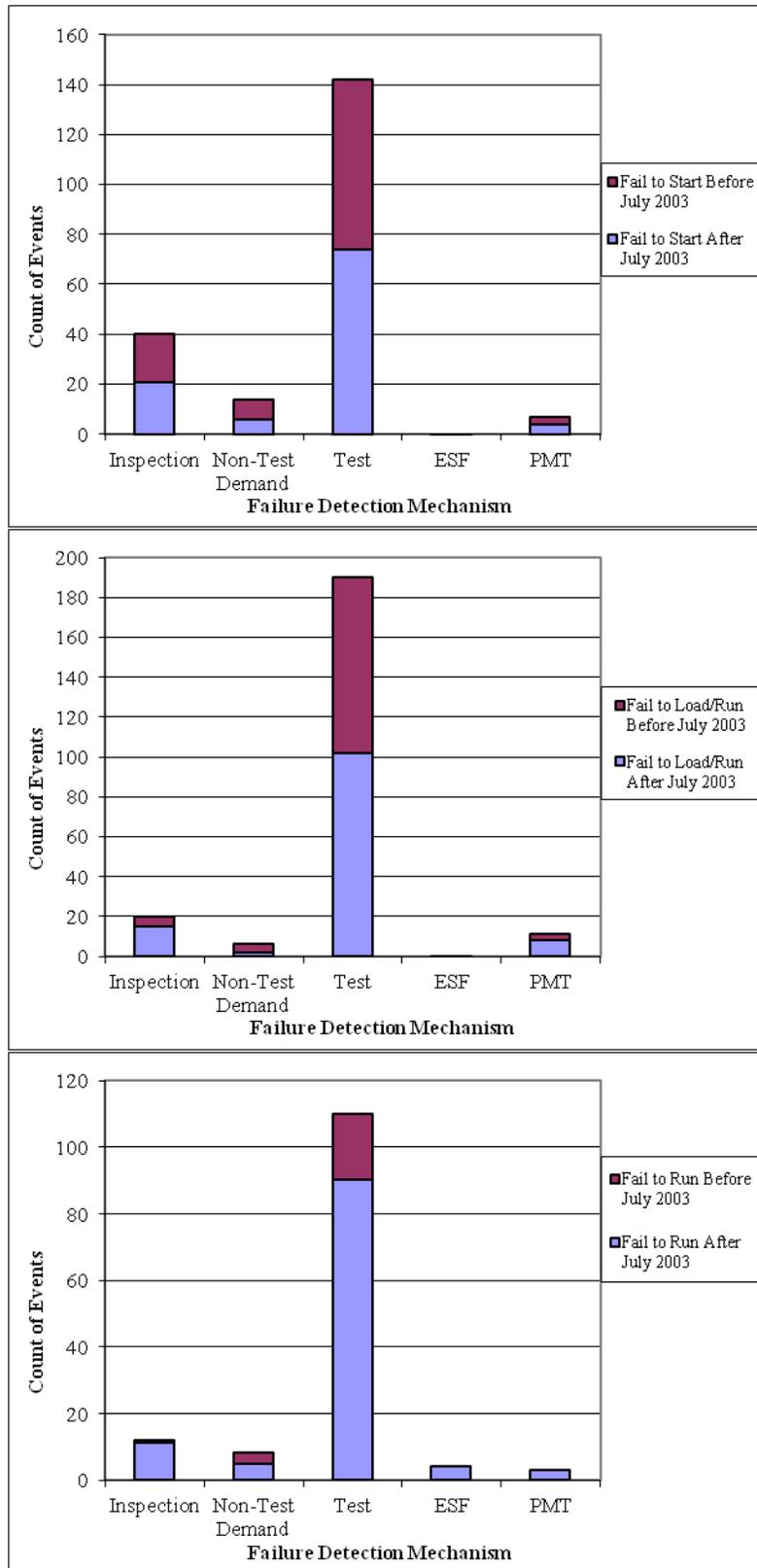
Figure 19. EPS EDG component failure distribution by period, failure mode, and method of detection.
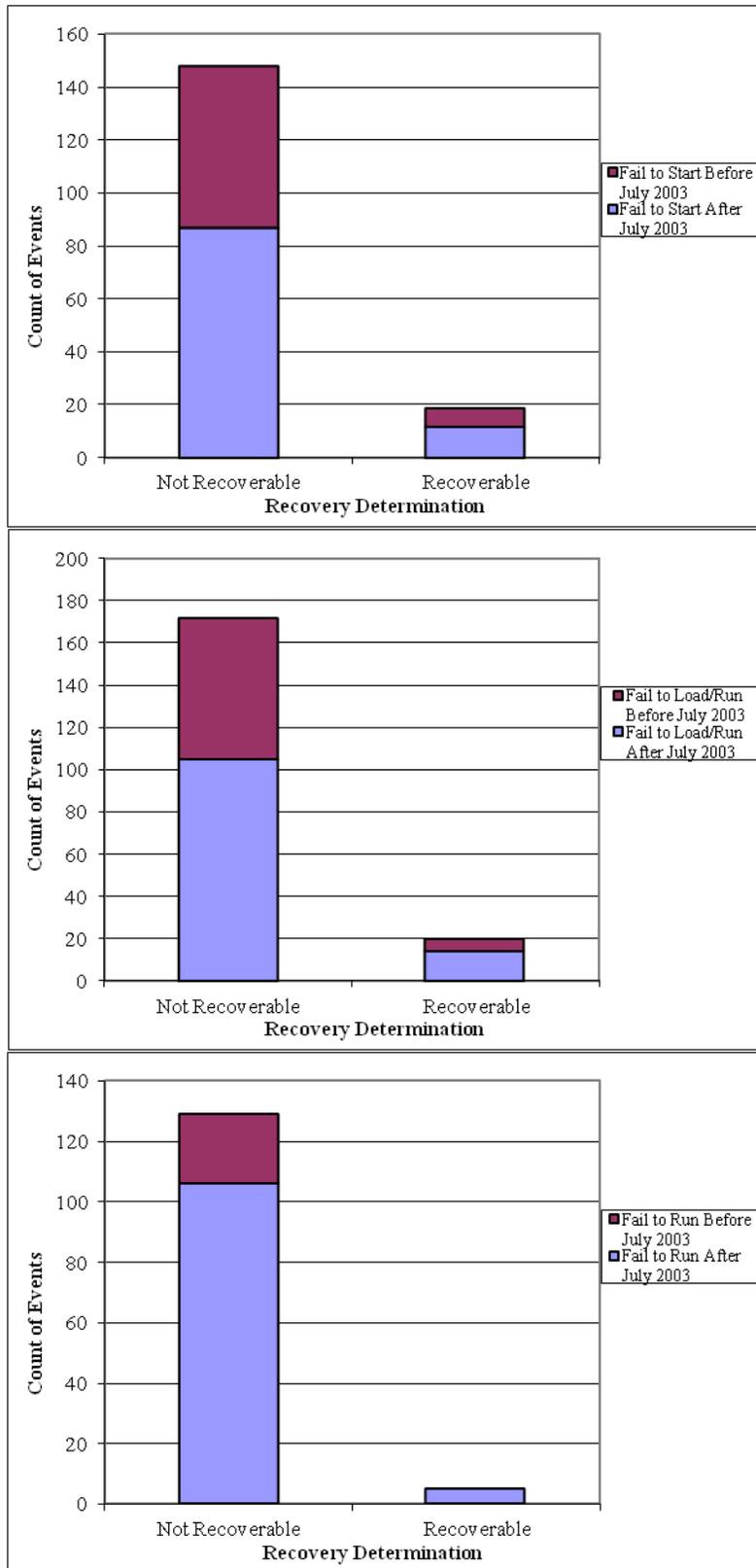
Figure 20. EPS EDG component failure distribution by period, failure mode, and recovery.

Figure 21 shows the percentage of failure events for the three failure modes segregated by EPS EDG manufacturer as indicated in the EPIX database. Table 12 shows the distribution of the various manufacturers of EPS EDGs in the EPIX database used in this study. Based on the information given in Figure 21, the EPS EDG manufacturer is not correlated to any particular failure mode distribution. The EPS EDG manufacturer group SAC/Compair Luchard/Jeumont Schndr does not show any fail to start events, but also only has three EDGs in that group.

Table 12. EPS EDG population manufacturers.

Manufacturer	Code	EPS EDGs
Worthington Corp	WC	4
Nordberg	NB	8
SAC/Compair Luchard/Jeumont Schndr	SC/JS	3
TransAmerica DeLaval	TD	20
ALCO Power	AP	24
Fairbanks Morse/Colt	FM/C	65
Cooper Bessemer	CB	31
Electro Motive/General Motors	EM/GM	68
Totals		223
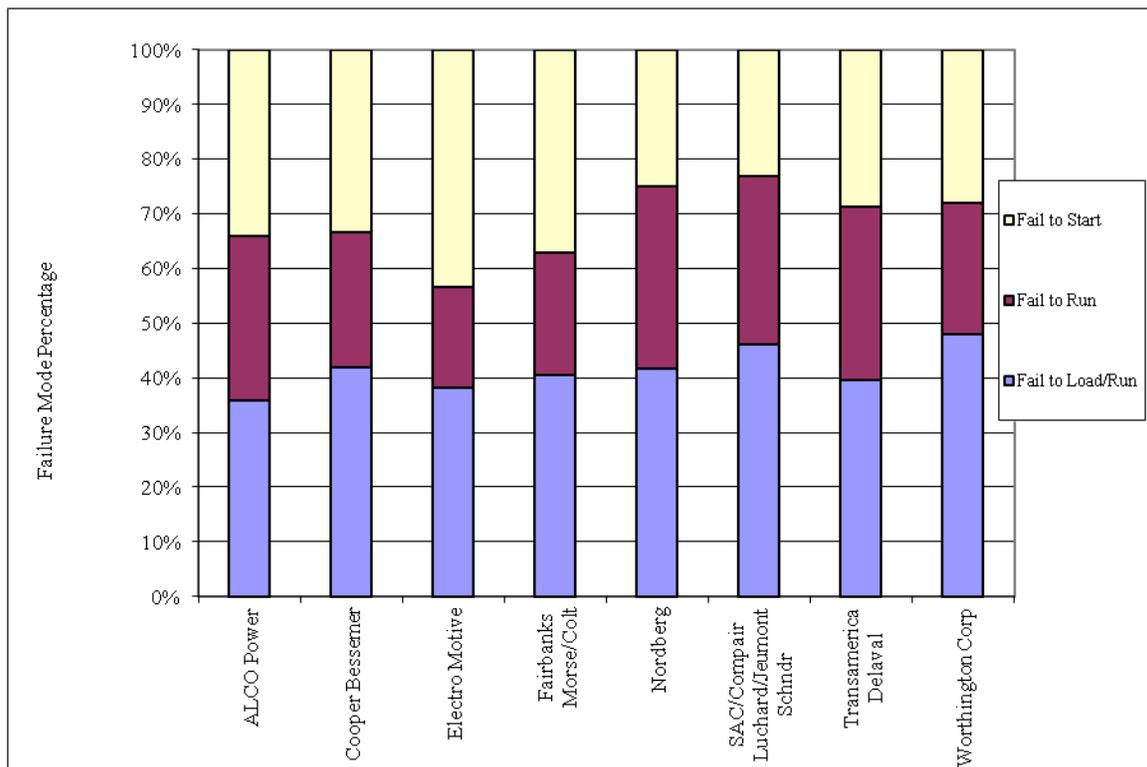
Figure 21. EPS EDG failure distribution by manufacturer.

Figure 22 shows the percentage of failure events for the three failure modes segregated by EPS EDG rating as indicated in the EPIX database. Table 13 shows the distribution of the various rated EPS

EDGs in the EPIX database used in this study. Based the information given in Figure 22, the EPS EDG rating is not correlated to any particular failure mode distribution.

Table 13. EPS EDG population by rating.

EPS EDG Rating	Count
50-249 KW	2
1,000-4,999 KW	169
5,000-99,999 KW	52
Total	223
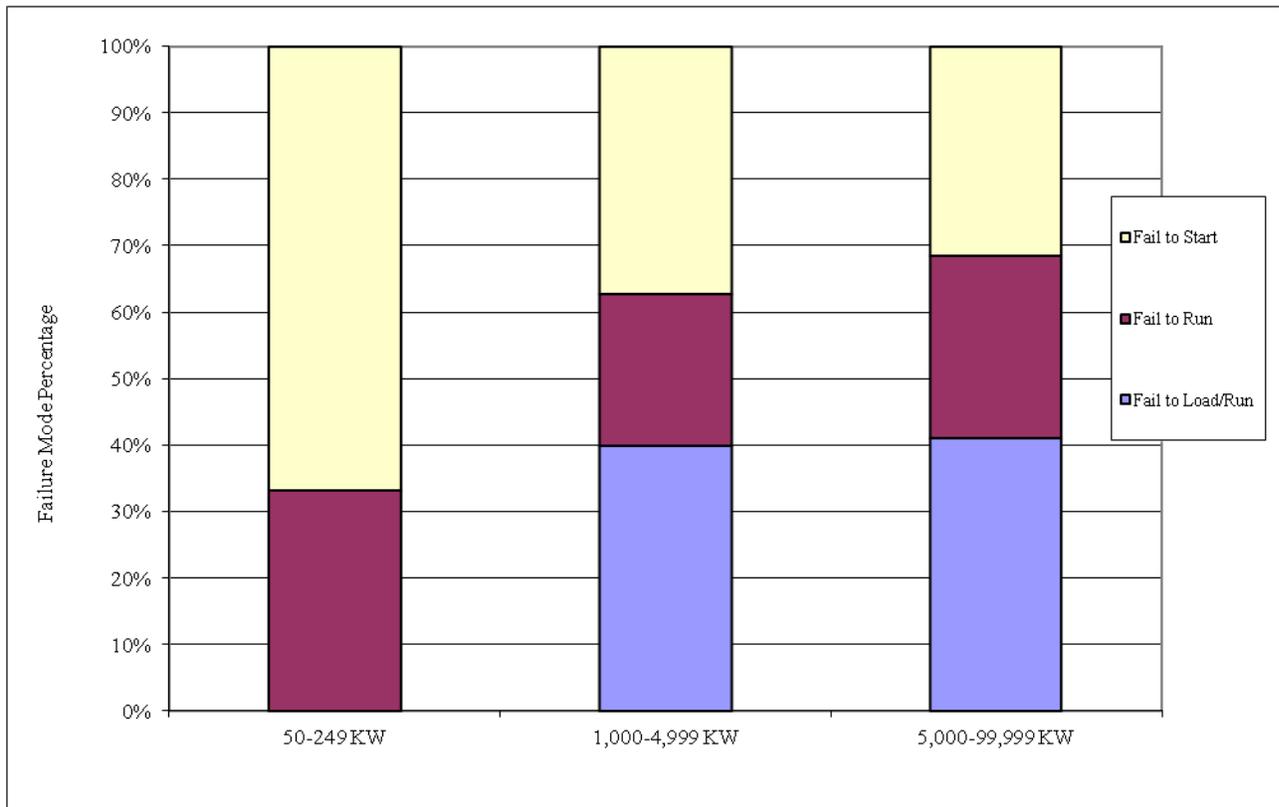
Figure 22. EPS EDG component failure modes by EPS EDG rating.

7. EPS EDG ASSEMBLY DESCRIPTION

The emergency diesel generators (EDGs) are those within the Class 1E ac electrical power system at U.S. commercial nuclear power plants and those in the high-pressure core spray (HPCS) systems. Station blackout (SBO) EDGs are not included.

The EDG includes the diesel engine with all components in the exhaust path, electrical generator, generator exciter, output breaker, combustion air, lube oil systems, fuel oil system, and starting compressed air system, and local instrumentation and control circuitry. The sequencer is excluded from the EDG component. For the service water system providing cooling to the EDGs, only the devices providing control of cooling flow to the EDG heat exchangers are included. Room heating and ventilating is not included.

The EDG failure modes include fail to start (FTS), fail to load and run for one hour (FTLR), and fail to run beyond one hour (FTR>1H). These failure modes were used in NUREG/CR-6928 and are similar to those used in the MSPI Program. There is some uncertainty concerning when the run hours should start to be counted; should they start as soon as the EDG starts or should they start only after the output circuit breaker has closed? For this study, the run hours start as soon as the EDG is started, which is the way data have been reported in EPIX.

Guidelines for determining whether a component event reported in EPIX is to be included in FTS, FTLR, or FTR>1H are similar to those used in the MSPI Program. In general, any circumstance in which the component is not able to meet the performance requirements defined in the probabilistic risk assessment (PRA) is counted. This includes conditions revealed through testing, operational demands, unplanned demands, or discovery. Also, run failures that occur beyond the typical 24-hour mission time in PRAs are included. However, certain events are excluded: slow engine starting times that do not exceed the PRA success criteria, conditions that are annunciated immediately in the control room without a demand, and run events that are shown to not have caused an actual run failure within 24 hours. Also, events occurring during maintenance or post-maintenance testing that are related to the actual maintenance activities are excluded. Finally, in contrast to the MSPI Program, a general guideline on slow starting times is to include only those slow starts requiring more than 20 seconds as FTS events, similar to what was done for the CCF database and the EDG system study. (In the MSPI Program, most licensees chose to use technical specification requirements for fast starts as their success criteria – typically less than 10 seconds to start.) All of the EDG events within EPIX were reviewed to ensure that they were binned to the correct failure mode – FTS, FTLR, FTR>1H, or no failure. However, even given detailed descriptions of failure events, this binning still required some judgment and involves some uncertainty.

Guidelines for counting demands and run hours are similar to those in the MSPI Program. Start and load/run demands include those resulting from tests, operational demands, and unplanned demands. Demands during maintenance and post-maintenance testing are excluded. Similarly, run hours include those from tests, operational demands, and unplanned demands. Note that the test demands and run hours dominate the totals, compared with operational and unplanned demands and run hours.

8. DATA TABLES

Table 14. Plot data for EPS EDG FTS industry trend. Figure 1

FY/ Source	Failures	Demands	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
2010 Update						1.45E-03	4.74E-03	2.89E-03
1998	16	4244.2	3.19E-03	2.27E-03	4.48E-03	2.36E-03	5.35E-03	3.74E-03
1999	12	4200.0	3.15E-03	2.33E-03	4.26E-03	1.67E-03	4.30E-03	2.86E-03
2000	10	3986.4	3.12E-03	2.38E-03	4.07E-03	1.39E-03	3.92E-03	2.53E-03
2001	11	4013.9	3.08E-03	2.43E-03	3.90E-03	1.56E-03	4.20E-03	2.75E-03
2002	15	4372.6	3.04E-03	2.47E-03	3.75E-03	2.12E-03	4.94E-03	3.42E-03
2003	19	4314.4	3.01E-03	2.48E-03	3.64E-03	2.86E-03	6.06E-03	4.36E-03
2004	13	4443.4	2.97E-03	2.48E-03	3.56E-03	1.75E-03	4.34E-03	2.93E-03
2005	16	4393.4	2.94E-03	2.44E-03	3.53E-03	2.28E-03	5.18E-03	3.62E-03
2006	11	4299.3	2.90E-03	2.39E-03	3.53E-03	1.46E-03	3.93E-03	2.58E-03
2007	7	4336.4	2.87E-03	2.31E-03	3.56E-03	8.05E-04	2.77E-03	1.67E-03
2008	14	4372.0	2.83E-03	2.22E-03	3.62E-03	1.95E-03	4.67E-03	3.20E-03
2009	7	4171.9	2.80E-03	2.12E-03	3.69E-03	8.36E-04	2.88E-03	1.73E-03
2010	16	4231.3	2.77E-03	2.02E-03	3.78E-03	2.37E-03	5.37E-03	3.75E-03
2011	15	4198.2	2.73E-03	1.93E-03	3.88E-03	2.20E-03	5.14E-03	3.55E-03

Table 15. Plot data for EPS EDG FTLR industry trend. Figure 2

FY/ Source	Failures	Demands	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
2010 Update						9.59E-04	8.11E-03	3.78E-03
1998	20	3849.8	3.36E-03	2.40E-03	4.71E-03	3.42E-03	7.12E-03	5.16E-03
1999	9	3749.4	3.43E-03	2.54E-03	4.64E-03	1.30E-03	3.88E-03	2.45E-03
2000	12	3761.5	3.50E-03	2.68E-03	4.58E-03	1.87E-03	4.82E-03	3.22E-03
2001	8	3708.4	3.58E-03	2.82E-03	4.53E-03	1.13E-03	3.59E-03	2.22E-03
2002	18	3709.0	3.65E-03	2.96E-03	4.50E-03	3.13E-03	6.77E-03	4.82E-03
2003	16	3715.3	3.72E-03	3.08E-03	4.50E-03	2.71E-03	6.14E-03	4.30E-03
2004	14	3796.5	3.80E-03	3.19E-03	4.53E-03	2.25E-03	5.40E-03	3.70E-03
2005	11	3808.1	3.88E-03	3.26E-03	4.61E-03	1.66E-03	4.45E-03	2.92E-03
2006	16	3701.8	3.96E-03	3.31E-03	4.74E-03	2.72E-03	6.16E-03	4.31E-03
2007	21	3676.4	4.04E-03	3.32E-03	4.92E-03	3.79E-03	7.75E-03	5.66E-03
2008	17	3710.3	4.13E-03	3.31E-03	5.15E-03	2.92E-03	6.46E-03	4.56E-03
2009	18	3600.3	4.21E-03	3.28E-03	5.41E-03	3.22E-03	6.96E-03	4.97E-03
2010	14	3697.7	4.30E-03	3.24E-03	5.70E-03	2.31E-03	5.54E-03	3.79E-03
2011	13	3640.5	4.39E-03	3.19E-03	6.03E-03	2.14E-03	5.30E-03	3.58E-03

Table 16. Plot data for EPS EDG FTR>1H industry trend. Figure 3

FY/ Source	Failures	Run Time (h)	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
2010 Update						3.40E-04	2.18E-03	1.09E-03
1998	3	6876.9	3.38E-04	1.90E-04	6.01E-04	1.48E-04	9.63E-04	4.79E-04
1999	0	6922.7	3.95E-04	2.35E-04	6.64E-04	2.68E-07	2.61E-04	6.80E-05
2000	5	7776.1	4.61E-04	2.90E-04	7.34E-04	2.79E-04	1.20E-03	6.71E-04
2001	4	8168.7	5.38E-04	3.57E-04	8.13E-04	1.93E-04	9.84E-04	5.24E-04
2002	6	8752.5	6.28E-04	4.38E-04	9.03E-04	3.21E-04	1.22E-03	7.08E-04
2003	8	8677.3	7.34E-04	5.35E-04	1.01E-03	4.76E-04	1.52E-03	9.34E-04
2004	9	8870.4	8.57E-04	6.50E-04	1.13E-03	5.44E-04	1.62E-03	1.02E-03
2005	12	9549.7	1.00E-03	7.82E-04	1.28E-03	7.32E-04	1.89E-03	1.25E-03
2006	9	8746.1	1.17E-03	9.30E-04	1.47E-03	5.52E-04	1.64E-03	1.04E-03
2007	14	9034.4	1.36E-03	1.09E-03	1.71E-03	9.36E-04	2.25E-03	1.53E-03
2008	15	8020.0	1.59E-03	1.25E-03	2.02E-03	1.14E-03	2.66E-03	1.84E-03
2009	15	8024.9	1.86E-03	1.42E-03	2.43E-03	1.14E-03	2.66E-03	1.83E-03
2010	14	7874.6	2.17E-03	1.60E-03	2.94E-03	1.07E-03	2.56E-03	1.75E-03
2011	22	8710.8	2.53E-03	1.78E-03	3.59E-03	1.68E-03	3.37E-03	2.46E-03

Table 17. Plot data for HPCS EDG FTS industry trend. Figure 4

FY/ Source	Failures	Demands	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
2010 Update						1.45E-03	4.74E-03	2.89E-03
1998	0	152.5	1.04E-03	6.33E-04	1.72E-03	3.42E-06	3.40E-03	8.85E-04
1999	1	171.2	1.04E-03	6.68E-04	1.63E-03	3.01E-04	6.69E-03	2.58E-03
2000	0	162.1	1.04E-03	7.03E-04	1.55E-03	3.36E-06	3.34E-03	8.70E-04
2001	0	142.4	1.04E-03	7.36E-04	1.48E-03	3.48E-06	3.46E-03	9.01E-04
2002	0	144.2	1.04E-03	7.66E-04	1.42E-03	3.47E-06	3.45E-03	8.98E-04
2003	0	156.9	1.04E-03	7.90E-04	1.38E-03	3.39E-06	3.37E-03	8.78E-04
2004	0	142.4	1.04E-03	8.03E-04	1.36E-03	3.48E-06	3.46E-03	9.01E-04
2005	0	134.4	1.04E-03	8.05E-04	1.35E-03	3.53E-06	3.51E-03	9.15E-04
2006	0	134.4	1.04E-03	7.94E-04	1.37E-03	3.53E-06	3.51E-03	9.14E-04
2007	0	128.3	1.04E-03	7.73E-04	1.41E-03	3.57E-06	3.55E-03	9.25E-04
2008	0	156.9	1.04E-03	7.44E-04	1.46E-03	3.39E-06	3.37E-03	8.78E-04
2009	1	136.7	1.04E-03	7.12E-04	1.53E-03	3.20E-04	7.11E-03	2.74E-03
2010	0	159.9	1.04E-03	6.77E-04	1.61E-03	3.37E-06	3.36E-03	8.74E-04
2011	0	135.8	1.04E-03	6.42E-04	1.70E-03	3.52E-06	3.50E-03	9.12E-04

Table 18. Plot data for HPCS EDG FTLR industry trend. Figure 5

FY/ Source	Failures	Demands	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
2010 Update						9.59E-04	8.11E-03	3.78E-03
1998	0	112.7	2.39E-03	1.26E-03	4.50E-03	6.14E-06	6.25E-03	1.63E-03
1999	1	119.9	2.35E-03	1.33E-03	4.13E-03	5.59E-04	1.24E-02	4.79E-03
2000	0	126.6	2.31E-03	1.40E-03	3.81E-03	5.87E-06	5.98E-03	1.55E-03
2001	0	121.6	2.27E-03	1.46E-03	3.53E-03	5.96E-06	6.07E-03	1.58E-03
2002	1	125.6	2.23E-03	1.50E-03	3.31E-03	5.49E-04	1.22E-02	4.70E-03
2003	0	130.2	2.19E-03	1.54E-03	3.13E-03	5.81E-06	5.91E-03	1.54E-03
2004	1	130.7	2.16E-03	1.54E-03	3.02E-03	5.40E-04	1.20E-02	4.63E-03
2005	0	120.7	2.12E-03	1.52E-03	2.97E-03	5.98E-06	6.09E-03	1.58E-03
2006	0	122.7	2.09E-03	1.46E-03	2.97E-03	5.94E-06	6.05E-03	1.57E-03
2007	0	120.4	2.05E-03	1.39E-03	3.03E-03	5.99E-06	6.09E-03	1.59E-03
2008	0	141.4	2.02E-03	1.30E-03	3.12E-03	5.61E-06	5.71E-03	1.49E-03
2009	0	116.2	1.98E-03	1.21E-03	3.25E-03	6.07E-06	6.18E-03	1.61E-03
2010	1	135.7	1.95E-03	1.12E-03	3.41E-03	5.32E-04	1.18E-02	4.56E-03
2011	0	121.0	1.92E-03	1.02E-03	3.59E-03	5.98E-06	6.08E-03	1.58E-03

Table 19. Plot data for HPCS EDG FTR>1H industry trend. Figure 6

FY/ Source	Failures	Run Time (h)	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
2010 Update						3.40E-04	2.18E-03	1.09E-03
1998	0	203.0	8.75E-04	5.12E-04	1.49E-03	2.87E-06	2.81E-03	7.30E-04
1999	1	280.1	8.73E-04	5.42E-04	1.41E-03	2.31E-04	5.13E-03	1.97E-03
2000	0	220.6	8.72E-04	5.72E-04	1.33E-03	2.80E-06	2.73E-03	7.12E-04
2001	0	201.1	8.71E-04	6.00E-04	1.26E-03	2.88E-06	2.81E-03	7.32E-04
2002	0	198.3	8.70E-04	6.25E-04	1.21E-03	2.89E-06	2.82E-03	7.35E-04
2003	0	286.1	8.69E-04	6.43E-04	1.17E-03	2.56E-06	2.50E-03	6.51E-04
2004	0	193.0	8.67E-04	6.52E-04	1.15E-03	2.91E-06	2.85E-03	7.41E-04
2005	1	272.6	8.66E-04	6.50E-04	1.15E-03	2.33E-04	5.18E-03	1.99E-03
2006	0	221.8	8.65E-04	6.37E-04	1.17E-03	2.79E-06	2.73E-03	7.11E-04
2007	0	196.5	8.64E-04	6.16E-04	1.21E-03	2.90E-06	2.83E-03	7.37E-04
2008	0	320.1	8.63E-04	5.89E-04	1.26E-03	2.45E-06	2.40E-03	6.24E-04
2009	0	222.5	8.61E-04	5.59E-04	1.33E-03	2.79E-06	2.73E-03	7.10E-04
2010	1	280.5	8.60E-04	5.28E-04	1.40E-03	2.31E-04	5.13E-03	1.97E-03
2011	0	275.6	8.59E-04	4.97E-04	1.48E-03	2.60E-06	2.54E-03	6.60E-04

Table 20. Plot data for EPS EDG UA trend. Figure 7

FY/ Source	UA Hours	Critical Hours	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
2010 Update						4.90E-03	2.78E-02	1.44E-02
1998	16175.1	1641222	1.03E-02	7.15E-03	1.35E-02	5.25E-04	2.98E-02	1.00E-02
1999	23400.1	2213152	9.70E-03	7.61E-03	1.18E-02	1.27E-03	2.73E-02	1.06E-02
2000	18405.2	2228580	9.06E-03	6.98E-03	1.12E-02	1.27E-03	2.02E-02	8.24E-03
2001	19096.4	2209557	8.42E-03	5.23E-03	1.16E-02	5.28E-04	2.53E-02	8.68E-03
2002	23650.6	2087421.6	1.25E-02	1.08E-02	1.43E-02	1.15E-03	3.04E-02	1.14E-02
2003	27824.2	2051652.3	1.30E-02	1.15E-02	1.44E-02	5.94E-04	4.18E-02	1.37E-02
2004	30925.8	2102001.0	1.34E-02	1.21E-02	1.46E-02	9.15E-06	6.28E-02	1.48E-02
2005	24607.3	2059514.7	1.38E-02	1.27E-02	1.49E-02	1.25E-03	3.20E-02	1.20E-02
2006	28741.5	2096727.1	1.42E-02	1.32E-02	1.52E-02	8.80E-04	3.97E-02	1.38E-02
2007	31474.6	2091219.4	1.46E-02	1.37E-02	1.56E-02	1.19E-03	4.24E-02	1.52E-02
2008	34611.9	2088040.2	1.50E-02	1.40E-02	1.61E-02	1.34E-03	4.63E-02	1.67E-02
2009	33145.7	2086914.0	1.55E-02	1.42E-02	1.67E-02	2.30E-03	3.97E-02	1.60E-02
2010	30682.7	2061553.2	1.59E-02	1.44E-02	1.74E-02	1.14E-03	4.25E-02	1.51E-02
2011	31158.5	2026956.9	1.63E-02	1.45E-02	1.81E-02	2.15E-03	3.89E-02	1.55E-02

Table 21. Plot data for HPCS EDG UA trend. Figure 8

FY/ Source	UA Hours	Critical Hours	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
2010 Update						8.05E-03	1.33E-02	1.06E-02
1998	156.9	29073.5	8.37E-03	7.19E-03	9.74E-03	8.42E-04	1.09E-02	4.62E-03
1999	781.8	53269.1	8.56E-03	7.47E-03	9.80E-03	1.54E-03	3.51E-02	1.35E-02
2000	932.7	64615.0	8.75E-03	7.76E-03	9.87E-03	7.12E-04	4.25E-02	1.42E-02
2001	427.3	64318.8	8.95E-03	8.05E-03	9.95E-03	9.05E-04	1.67E-02	6.65E-03
2002	443.5	65660.8	9.16E-03	8.34E-03	1.01E-02	5.22E-04	1.91E-02	6.80E-03
2003	795.9	64216.1	9.37E-03	8.60E-03	1.02E-02	5.50E-03	2.16E-02	1.24E-02
2004	848.0	66422.6	9.58E-03	8.84E-03	1.04E-02	3.55E-03	2.64E-02	1.27E-02
2005	635.1	63863.9	9.80E-03	9.04E-03	1.06E-02	1.94E-03	2.21E-02	9.65E-03
2006	524.1	66916.8	1.00E-02	9.20E-03	1.09E-02	2.12E-03	1.62E-02	7.74E-03
2007	593.1	64802.1	1.03E-02	9.33E-03	1.13E-02	3.72E-03	1.63E-02	9.07E-03
2008	779.2	65346.3	1.05E-02	9.43E-03	1.17E-02	9.81E-04	3.38E-02	1.22E-02
2009	506.8	64536.4	1.07E-02	9.51E-03	1.21E-02	1.12E-03	1.92E-02	7.74E-03
2010	1063.7	65868.9	1.10E-02	9.58E-03	1.26E-02	2.17E-03	4.03E-02	1.60E-02
2011	605.7	63380.6	1.12E-02	9.64E-03	1.31E-02	1.31E-03	2.51E-02	9.89E-03

Table 22. Plot data for EPS EDG unreliability trend. Figure 9

FY	Regression Curve Data Points			Plot Trend Error Bar Points		
	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	1.90E-02	1.55E-02	2.25E-02	1.21E-02	5.93E-02	2.49E-02
1999	2.04E-02	1.73E-02	2.35E-02	7.43E-03	3.53E-02	1.75E-02
2000	2.18E-02	1.90E-02	2.45E-02	1.19E-02	3.28E-02	1.95E-02
2001	2.31E-02	2.07E-02	2.56E-02	9.08E-03	3.59E-02	1.80E-02
2002	2.45E-02	2.23E-02	2.67E-02	1.42E-02	4.37E-02	2.46E-02
2003	2.59E-02	2.39E-02	2.78E-02	1.56E-02	5.73E-02	2.89E-02
2004	2.72E-02	2.54E-02	2.91E-02	1.34E-02	7.60E-02	2.85E-02
2005	2.86E-02	2.68E-02	3.05E-02	1.69E-02	4.78E-02	2.76E-02
2006	3.00E-02	2.80E-02	3.19E-02	1.49E-02	5.33E-02	2.79E-02
2007	3.13E-02	2.92E-02	3.35E-02	1.81E-02	5.92E-02	3.23E-02
2008	3.27E-02	3.03E-02	3.52E-02	2.11E-02	6.62E-02	3.64E-02
2009	3.41E-02	3.13E-02	3.69E-02	2.23E-02	5.98E-02	3.60E-02
2010	3.55E-02	3.23E-02	3.86E-02	2.09E-02	6.23E-02	3.49E-02
2011	3.68E-02	3.33E-02	4.03E-02	2.05E-02	5.74E-02	3.41E-02

Table 23. Plot data for HPCS EDG unreliability trend. Figure 10

FY	Regression Curve Data Points			Plot Trend Error Bar Points		
	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	1.92E-02	1.66E-02	2.23E-02	9.29E-03	1.95E-02	1.32E-02
1999	1.95E-02	1.71E-02	2.23E-02	2.48E-02	5.79E-02	3.69E-02
2000	1.98E-02	1.77E-02	2.23E-02	9.02E-03	5.07E-02	2.25E-02
2001	2.02E-02	1.82E-02	2.24E-02	9.42E-03	2.51E-02	1.52E-02
2002	2.05E-02	1.87E-02	2.24E-02	1.17E-02	3.04E-02	1.81E-02
2003	2.08E-02	1.91E-02	2.26E-02	1.31E-02	2.94E-02	2.01E-02
2004	2.11E-02	1.95E-02	2.29E-02	1.48E-02	3.76E-02	2.40E-02
2005	2.15E-02	1.98E-02	2.32E-02	2.05E-02	4.12E-02	2.84E-02
2006	2.18E-02	2.01E-02	2.37E-02	1.05E-02	2.46E-02	1.61E-02
2007	2.22E-02	2.02E-02	2.43E-02	1.23E-02	2.49E-02	1.77E-02
2008	2.25E-02	2.03E-02	2.49E-02	8.44E-03	4.10E-02	1.96E-02
2009	2.29E-02	2.03E-02	2.57E-02	1.18E-02	2.99E-02	1.85E-02
2010	2.32E-02	2.04E-02	2.65E-02	3.11E-02	6.92E-02	4.52E-02
2011	2.36E-02	2.03E-02	2.73E-02	1.13E-02	3.52E-02	2.01E-02

Table 24. Plot data for EPS and HPCS EDG start demands trend. Figure 11

FY/ Source	Demands	Reactor Years	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	4397	95.0	4.58E+01	4.42E+01	4.76E+01	4.51E+01	4.74E+01	4.63E+01
1999	4371	95.0	4.59E+01	4.44E+01	4.74E+01	4.49E+01	4.72E+01	4.60E+01
2000	4148	95.3	4.60E+01	4.46E+01	4.73E+01	4.24E+01	4.47E+01	4.35E+01
2001	4156	95.0	4.60E+01	4.49E+01	4.73E+01	4.26E+01	4.49E+01	4.37E+01
2002	4517	95.0	4.61E+01	4.51E+01	4.72E+01	4.64E+01	4.87E+01	4.75E+01
2003	4471	95.0	4.62E+01	4.52E+01	4.72E+01	4.59E+01	4.82E+01	4.71E+01
2004	4586	95.3	4.63E+01	4.54E+01	4.72E+01	4.70E+01	4.93E+01	4.81E+01
2005	4528	95.0	4.63E+01	4.54E+01	4.73E+01	4.65E+01	4.88E+01	4.77E+01
2006	4434	95.0	4.64E+01	4.55E+01	4.74E+01	4.55E+01	4.78E+01	4.67E+01
2007	4465	95.0	4.65E+01	4.54E+01	4.76E+01	4.58E+01	4.82E+01	4.70E+01
2008	4529	95.3	4.66E+01	4.54E+01	4.78E+01	4.64E+01	4.87E+01	4.75E+01
2009	4309	95.0	4.66E+01	4.53E+01	4.80E+01	4.42E+01	4.65E+01	4.54E+01
2010	4391	95.0	4.67E+01	4.52E+01	4.83E+01	4.51E+01	4.74E+01	4.62E+01
2011	4334	95.0	4.68E+01	4.51E+01	4.85E+01	4.45E+01	4.68E+01	4.56E+01

Table 25. Plot data for EPS and HPCS EDG load and run ≤1-hour demands trend. Figure 12

FY/ Source	Demands	Reactor Years	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	3963	95.0	4.12E+01	4.05E+01	4.18E+01	4.06E+01	4.28E+01	4.17E+01
1999	3869	95.0	4.11E+01	4.05E+01	4.16E+01	3.97E+01	4.18E+01	4.07E+01
2000	3888	95.3	4.10E+01	4.05E+01	4.15E+01	3.97E+01	4.19E+01	4.08E+01
2001	3830	95.0	4.09E+01	4.04E+01	4.13E+01	3.93E+01	4.14E+01	4.03E+01
2002	3835	95.0	4.07E+01	4.03E+01	4.11E+01	3.93E+01	4.14E+01	4.04E+01
2003	3845	95.0	4.06E+01	4.03E+01	4.10E+01	3.94E+01	4.16E+01	4.05E+01
2004	3927	95.3	4.05E+01	4.02E+01	4.09E+01	4.01E+01	4.23E+01	4.12E+01
2005	3929	95.0	4.04E+01	4.01E+01	4.08E+01	4.03E+01	4.24E+01	4.14E+01
2006	3825	95.0	4.03E+01	4.00E+01	4.07E+01	3.92E+01	4.13E+01	4.03E+01
2007	3797	95.0	4.02E+01	3.98E+01	4.06E+01	3.89E+01	4.10E+01	4.00E+01
2008	3852	95.3	4.01E+01	3.97E+01	4.06E+01	3.94E+01	4.15E+01	4.04E+01
2009	3716	95.0	4.00E+01	3.95E+01	4.05E+01	3.81E+01	4.02E+01	3.91E+01
2010	3833	95.0	3.99E+01	3.93E+01	4.05E+01	3.93E+01	4.14E+01	4.03E+01
2011	3762	95.0	3.98E+01	3.92E+01	4.04E+01	3.85E+01	4.07E+01	3.96E+01

Table 26. Plot data for EPS and HPCS EDG run hours (greater than 1H) trend. Figure 13

FY/ Source	Run Hours	Reactor Years	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	7080	95.0	8.36E+01	7.54E+01	9.25E+01	7.31E+01	7.60E+01	7.45E+01
1999	7203	95.0	8.44E+01	7.71E+01	9.25E+01	7.44E+01	7.73E+01	7.58E+01
2000	7997	95.3	8.53E+01	7.87E+01	9.25E+01	8.24E+01	8.55E+01	8.39E+01
2001	8370	95.0	8.62E+01	8.02E+01	9.26E+01	8.65E+01	8.97E+01	8.81E+01
2002	8951	95.0	8.71E+01	8.17E+01	9.28E+01	9.26E+01	9.59E+01	9.42E+01
2003	8963	95.0	8.80E+01	8.31E+01	9.32E+01	9.27E+01	9.60E+01	9.43E+01
2004	9063	95.3	8.89E+01	8.43E+01	9.38E+01	9.35E+01	9.68E+01	9.51E+01
2005	9822	95.0	8.98E+01	8.52E+01	9.47E+01	1.02E+02	1.05E+02	1.03E+02
2006	8968	95.0	9.08E+01	8.58E+01	9.59E+01	9.28E+01	9.60E+01	9.44E+01
2007	9231	95.0	9.17E+01	8.63E+01	9.75E+01	9.55E+01	9.88E+01	9.72E+01
2008	8340	95.3	9.27E+01	8.65E+01	9.92E+01	8.60E+01	8.91E+01	8.76E+01
2009	8247	95.0	9.36E+01	8.66E+01	1.01E+02	8.52E+01	8.84E+01	8.68E+01
2010	8155	95.0	9.46E+01	8.67E+01	1.03E+02	8.43E+01	8.74E+01	8.58E+01
2011	8986	95.0	9.56E+01	8.66E+01	1.05E+02	9.30E+01	9.62E+01	9.46E+01

Table 27. Plot data for EPS and HPCS EDG FTS events trend. Figure 14

FY/ Source	Failures	Reactor Years	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	16	95.0	1.42E-01	1.02E-01	1.97E-01	1.06E-01	2.40E-01	1.67E-01
1999	13	95.0	1.41E-01	1.05E-01	1.89E-01	8.19E-02	2.03E-01	1.37E-01
2000	10	95.3	1.39E-01	1.07E-01	1.81E-01	5.86E-02	1.65E-01	1.06E-01
2001	11	95.0	1.38E-01	1.10E-01	1.74E-01	6.64E-02	1.78E-01	1.17E-01
2002	15	95.0	1.37E-01	1.11E-01	1.68E-01	9.78E-02	2.28E-01	1.57E-01
2003	19	95.0	1.36E-01	1.13E-01	1.64E-01	1.30E-01	2.77E-01	1.98E-01
2004	13	95.3	1.34E-01	1.13E-01	1.61E-01	8.17E-02	2.03E-01	1.37E-01
2005	16	95.0	1.33E-01	1.11E-01	1.59E-01	1.06E-01	2.40E-01	1.67E-01
2006	11	95.0	1.32E-01	1.09E-01	1.60E-01	6.64E-02	1.78E-01	1.17E-01
2007	7	95.0	1.31E-01	1.06E-01	1.62E-01	3.68E-02	1.27E-01	7.61E-02
2008	14	95.3	1.30E-01	1.02E-01	1.65E-01	8.96E-02	2.15E-01	1.47E-01
2009	8	95.0	1.29E-01	9.82E-02	1.69E-01	4.40E-02	1.40E-01	8.62E-02
2010	16	95.0	1.28E-01	9.41E-02	1.73E-01	1.06E-01	2.40E-01	1.67E-01
2011	15	95.0	1.26E-01	8.99E-02	1.78E-01	9.78E-02	2.28E-01	1.57E-01

Table 28. Plot data for EPS EDG FTLR events trend. Figure 15

FY/ Source	Failures	Reactor Years	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	20	95.0	1.38E-01	9.92E-02	1.92E-01	1.39E-01	2.90E-01	2.09E-01
1999	10	95.0	1.40E-01	1.04E-01	1.88E-01	5.91E-02	1.66E-01	1.07E-01
2000	12	95.3	1.43E-01	1.10E-01	1.85E-01	7.42E-02	1.91E-01	1.27E-01
2001	8	95.0	1.45E-01	1.15E-01	1.83E-01	4.42E-02	1.41E-01	8.66E-02
2002	19	95.0	1.47E-01	1.20E-01	1.81E-01	1.31E-01	2.78E-01	1.99E-01
2003	16	95.0	1.50E-01	1.25E-01	1.80E-01	1.06E-01	2.41E-01	1.68E-01
2004	15	95.3	1.52E-01	1.28E-01	1.81E-01	9.80E-02	2.29E-01	1.58E-01
2005	11	95.0	1.55E-01	1.31E-01	1.83E-01	6.67E-02	1.79E-01	1.17E-01
2006	16	95.0	1.57E-01	1.32E-01	1.88E-01	1.06E-01	2.41E-01	1.68E-01
2007	21	95.0	1.60E-01	1.32E-01	1.94E-01	1.48E-01	3.02E-01	2.19E-01
2008	17	95.3	1.63E-01	1.31E-01	2.02E-01	1.14E-01	2.53E-01	1.78E-01
2009	18	95.0	1.65E-01	1.29E-01	2.12E-01	1.23E-01	2.66E-01	1.88E-01
2010	15	95.0	1.68E-01	1.27E-01	2.22E-01	9.82E-02	2.29E-01	1.58E-01
2011	13	95.0	1.71E-01	1.25E-01	2.34E-01	8.23E-02	2.04E-01	1.38E-01

Table 29. Plot data for EPS EDG FTR>1H events trend. Figure 16

FY/ Source	Failures	Reactor Years	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	3	95.0	3.35E-02	2.26E-02	4.97E-02	1.09E-02	7.05E-02	3.51E-02
1999	1	95.0	3.88E-02	2.72E-02	5.53E-02	1.76E-03	3.92E-02	1.50E-02
2000	5	95.3	4.49E-02	3.26E-02	6.17E-02	2.29E-02	9.83E-02	5.50E-02
2001	4	95.0	5.19E-02	3.91E-02	6.88E-02	1.67E-02	8.48E-02	4.51E-02
2002	6	95.0	6.00E-02	4.68E-02	7.70E-02	2.95E-02	1.12E-01	6.51E-02
2003	8	95.0	6.94E-02	5.59E-02	8.63E-02	4.35E-02	1.38E-01	8.52E-02
2004	9	95.3	8.03E-02	6.63E-02	9.72E-02	5.06E-02	1.51E-01	9.50E-02
2005	13	95.0	9.29E-02	7.83E-02	1.10E-01	8.09E-02	2.01E-01	1.35E-01
2006	9	95.0	1.07E-01	9.15E-02	1.26E-01	5.07E-02	1.51E-01	9.52E-02
2007	14	95.0	1.24E-01	1.06E-01	1.46E-01	8.87E-02	2.13E-01	1.45E-01
2008	15	95.3	1.44E-01	1.21E-01	1.71E-01	9.64E-02	2.25E-01	1.55E-01
2009	15	95.0	1.66E-01	1.37E-01	2.01E-01	9.66E-02	2.25E-01	1.55E-01
2010	15	95.0	1.92E-01	1.55E-01	2.39E-01	9.66E-02	2.25E-01	1.55E-01
2011	22	95.0	2.22E-01	1.73E-01	2.85E-01	1.53E-01	3.09E-01	2.26E-01

9. REFERENCES

1.   U.S. NRC, *Component Reliability Data Sheets Update 2010*, January 2012,
      http://nrcoe.inl.gov/resultsdb/publicdocs/AvgPerf/ComponentReliabilityDataSheets2010.pdf

2.   S.A. Eide, et al, *Industry-Average Performance for Components and Initiating Events at U.S. Commercial Nuclear Power Plants*, U.S. Nuclear Regulatory Commission, NUREG/CR-6928, February 2007.

3.   C.L. Atwood, et al. *Handbook of Parameter Estimation for Probabilistic Risk Assessment*, NUREG/CR-6823, September 2003.