Analysis of Loss of Offsite Power Events

2007 Update

The availability of alternating current (ac) power is essential for safe operation and accident recovery at commercial nuclear power plants. Normally, ac power is supplied by offsite sources via the electrical grid. Loss of this offsite power can have a major negative impact on a power plant's ability to achieve and maintain safe shutdown conditions. Risk analyses performed for U.S. commercial nuclear power plants indicate that the loss of all ac power contributes over 70% of the overall risk at some plants. Clearly, loss of offsite power (LOOP, also referred to as LOSP) and subsequent restoration of offsite power are important inputs to plant probabilistic risk assessments (PRAs). These inputs must reflect current industry performance in order for PRAs to accurately estimate the risk from LOOP initiated scenarios.

This study is a statistical and engineering analysis of LOOP frequencies and durations at commercial nuclear reactors in the U.S. LOOP data for 1986–2007 were collected and analyzed. The data cover both critical (at power) and shutdown operations at these plants. Partial LOOP events, in which not all offsite power lines to the plant are lost or not all offsite power to safety buses is lost, are not covered in this report. In addition LOOP events at power, during which no plant trip was observed, are excluded.

1. LOOP FREQUENCY

LOOP industry frequencies were determined for four LOOP event categories: plant centered, switchyard centered, grid related, and weather related. In addition, these frequencies were subdivided into results for critical and shutdown operation. Table 1 summarizes these results (plant-specific LOOP frequencies are presented in Reference 1).

Table 1. Plant-level LOOP frequencies.

		Plant-Level LOOP Frequency				
Mode	LOOP Category	Data Period	Events	Reactor Critical or Shutdown Years	Maximum Likelihood Estimator (MLE)	Frequency Units[a]
Critical operation	Plant centered	1997–2007	2	985.2	2.03E-03	/rcry
	Switchyard centered	1997–2007	9	985.2	9.14E-03	/rcry
	Grid related	1997–2007	13	985.2	1.32E-02	/rcry
	Weather related	1986–2007	6	1862.4	3.22E-03	/rcry
	All		30	1087.7	2.76E-02	/rcry
Shutdown operation	Plant centered	1986–2007	20	406.8	4.92E-02	/rsy
	Switchyard centered	1997–2007	7	127.3	5.50E-02	/rsy
	Grid related	1986–2007	5	406.8	1.23E-02	/rsy
	Weather related	1986–2007	16	406.8	3.93E-02	/rsy
	All		48	308.1	1.56E-01	/rsy

a. The frequency units are per reactor critical year (/rcry) or per reactor shutdown year (/rsy).

For critical operation, grid-related LOOPs contribute 48% to the total critical operation LOOP frequency, while switchyard-centered LOOPs contribute 34%. The remaining two categories of LOOPs have frequency contributions of 11% (weather related) and 7% (plant centered). More than any other LOOP category, grid-related events have the potential to affect multiple plant units. The last three grid events affected eight plants, two plants, and three plants. This dependency is shown graphically in Figure 1. The two grid events prior to 2003 affected a single plant unit each.

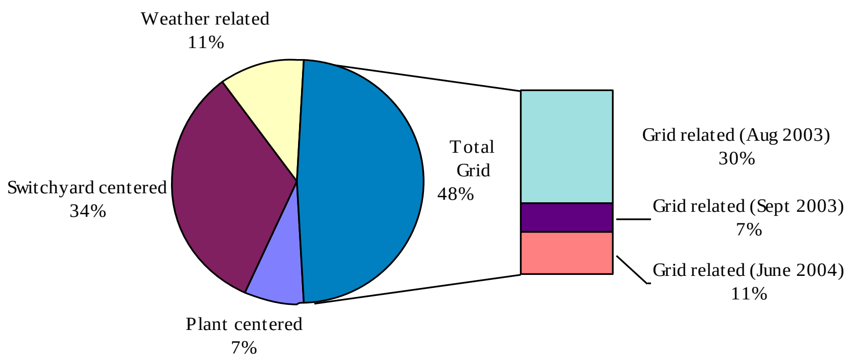


Figure 1. Distribution LOOP categories (per plant unit) during critical operation (1997 to 2007).

For shutdown operation, switchyard-centered LOOPs contribute 48% to the total shutdown LOOP frequency. Switchyard-centered LOOPs are dominated by maintenance and testing activities and by equipment failures. Plant-centered LOOPs contribute 26%, weather 20%, and grid 6%. These distributions are shown graphically in Figure 2.

Trend plots for all four LOOP event categories and all LOOPs combined during critical operation are presented in Figure 3 through Figure 7. The data supporting those figures are presented in Table 5 through Table 9. These figures show trends over two periods: 1986–1996 and 1997–2007. For plant-centered and switchyard-centered LOOPs, industry performance has improved considerably since 1986–1996. The corresponding trend analyses of the entire period indicate p-values close to 0.05, which is a typical statistical measure indicating existence of a significant[1] trend. Therefore, the baseline period for determining industry frequencies representative of current performance is 1997–2007.

[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).

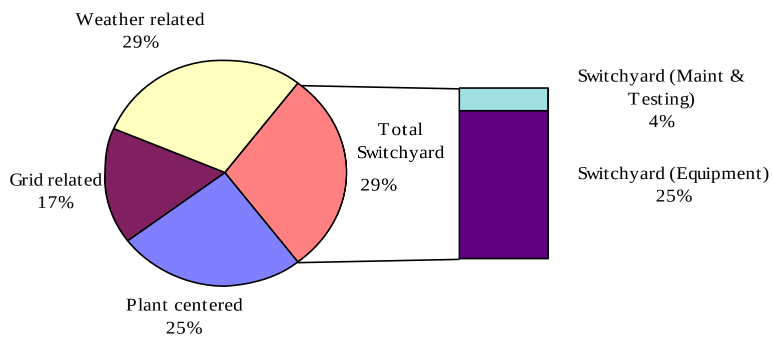


Figure 2. Distribution of LOOP categories (per plant unit) while shutdown (1997 to 2007).

As indicated in Figure 3 through Figure 7, the industry performance over this recent period is relatively constant. The 2004 analysis showed, for grid-related LOOPs, performance had worsened because of 2003 and 2004. The addition of three years data without new events has reduced the previous trend to a non-significant flat trend.

Distributions for the industry LOOP frequencies in Table 1 are presented in Table 2. Presented are the 5%, median, mean, 95%, maximum likelihood estimator (MLE), and shape (α) and scale (β) parameters for the gamma distributions. Empirical Bayes analysis was used to search for variability in the data using several grouping schemes: plant, site, various geographical areas, various electrical grid areas, year, and others. In cases where the empirical Bayes analyses identified more than one grouping with significant variability, a judgment call was made concerning which set of results to use. (See Appendixes B and C of Reference 1 for more information.)

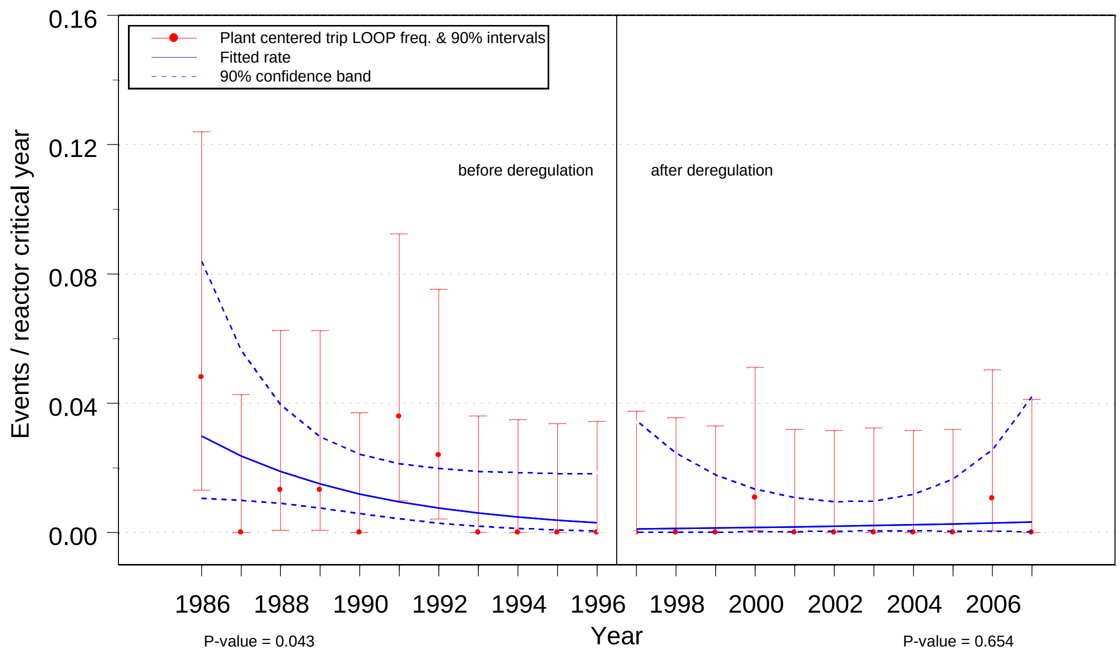


Figure 3. Trend plot of LOOP frequency for 1986–1996 and 1997–2007. Plant-centered LOOPs: trend plot of industry performance during critical operation.

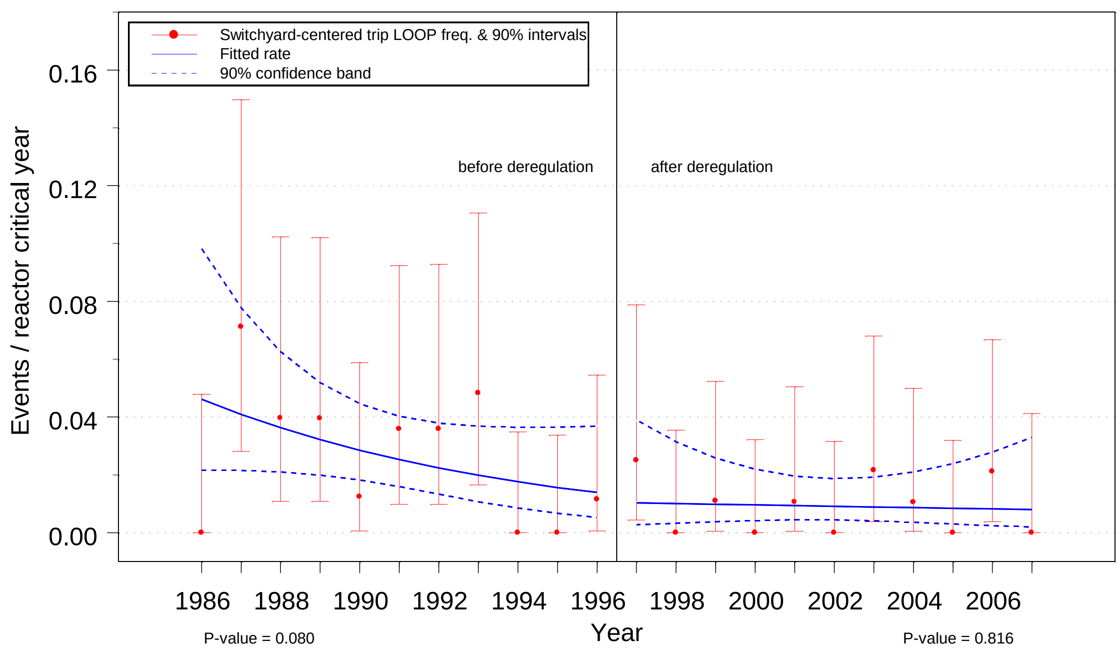
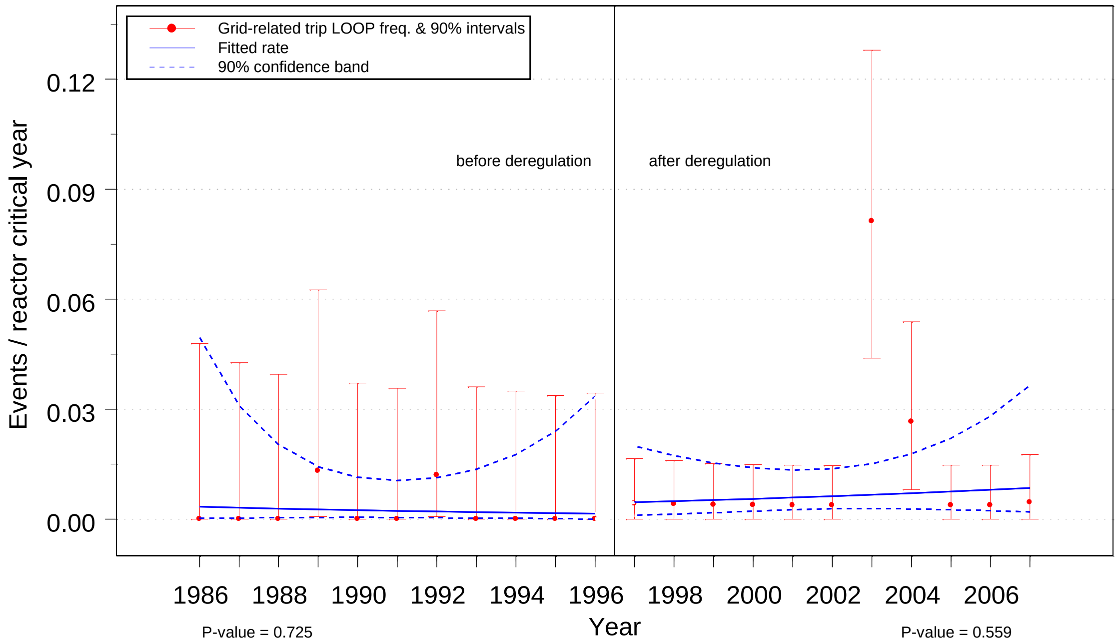


Figure 4. Trend plot of LOOP frequency for 1986–1996 and 1997–2007. Switchyard-centered LOOPs: trend plot of industry performance during critical operation.



Note: *The confidence interval for 2003 does not account for the dependence of the events and is, therefore, too narrow (by an undetermined amount).*

Figure 5. Trend plot of LOOP frequency for 1986–1996 and 1997–2007. Grid-related LOOPs: trend plot of industry performance during critical operation.

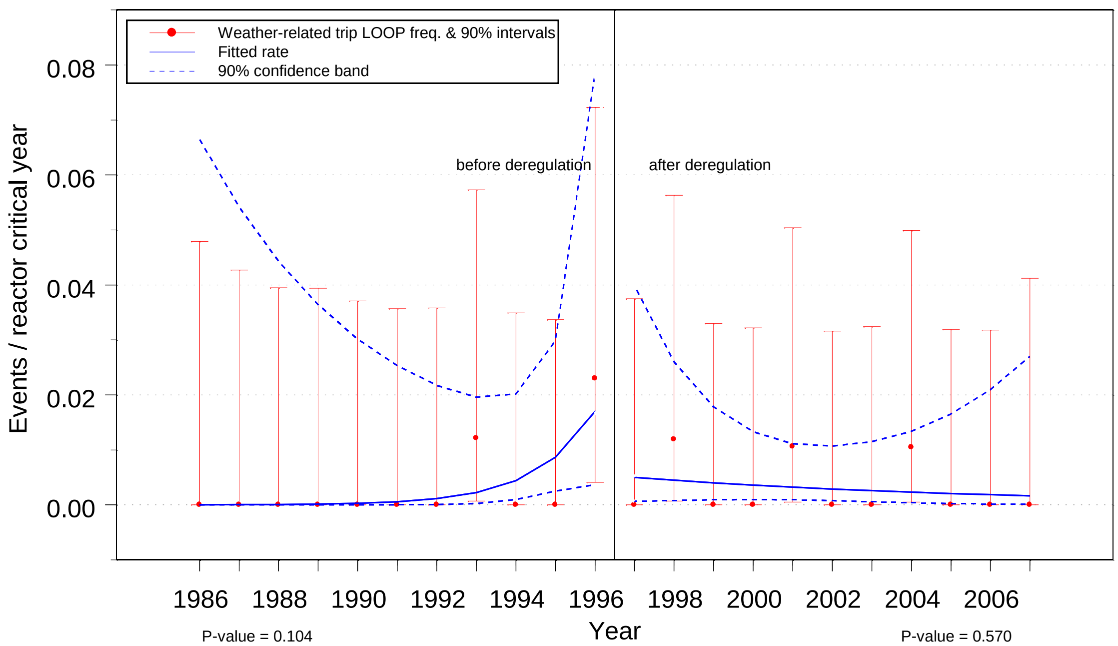
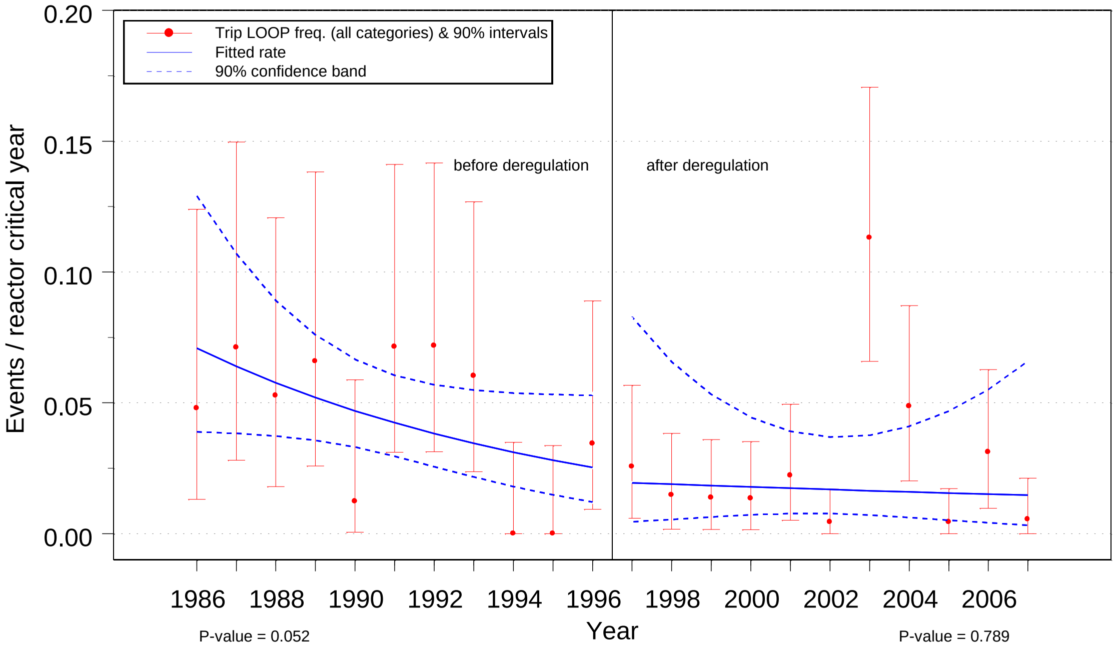


Figure 6. Trend plot of LOOP frequency for 1986–1996 and 1997–2007. Weather-related LOOPs: trend plot of industry performance during critical operation.



Note: *The confidence interval for 2003 does not account for the dependence of the events and is therefore too narrow (by an undetermined amount).*

Figure 7. Trend plot of LOOP frequency for 1986–1996 and 1997–2007. All LOOPs combined: trend plot of industry performance during critical operation.

To develop LOOP distributions for use in PRAs, the first consideration was the issue of whether critical operations data should be separated from shutdown operation data. The data support the separation of these two modes of operation for grid and weather-related LOOPs (with p-values 0.04 and 0.05, respectively). The decision was made to split the data for all modes because of the different plant operating conditions, and different demands on the emergency power system, associated with the two operational modes.

In this study, Bayesian methods are used to derive distributions describing industry-level occurrence rates for use in PRAs, The methods account for uncertainties coming from the random nature of the data and from between-group variation. They also support the combining of data to describe the total LOOP rate. The methods start by specifying diffuse, broad gamma prior distributions for each rate being considered. These distributions are tuned in a Bayesian “Markov chain Monte-Carlo” (MCMC) simulation process. Poisson event counts that might occur from particular rates, based on specified historical years of critical operation, are described in the model. The observed event counts are specified. In the “Metropolis-Hasting” step, values from a given iteration of the simulation are accepted if they improve the likelihood for the constellation of sampling and parameter distributions under consideration. After a “burn-in” period, the parameter distributions describing the gamma distributions for the occurrence rates under study become stable. The resulting posterior distributions are sampled to determine the mean and other characteristics of the occurrence rates. Industry-level rates are monitored since they are the sum of the plant-centered, switchyard-centered, grid-related, and weather-related occurrence rates.

For the critical operation data, data since deregulation was used for all the LOOP categories as in the previous study, except for the weather-related occurrences. Here, there was no statistical evidence to suggest splitting the overall period of data (since 1986). It is believed that weather is independent of deregulation. With regard to specific modeling of additional variation, the grid data were found to differ with regard to several possible breakdowns (site, grid, year, etc.) Differences in data from the 10 “Reliability Councils” were selected as representative of this variation. In the modeling described above, separate data were input for each Reliability Council. In each iteration of the simulation (for which over 900,000 iterations were performed after the burn-in period) a reliability council was selected at random, with a weighting based on each council’s proportion of critical operation time, to provide input for the grid contribution to the total LOOP.

For shutdown operation, all the historic data was used as in the previous study, except for the switchyard-related LOOPs. Here, the occurrences since deregulation were significantly fewer than the occurrence rate in the earlier period (p-value 0.0001). Additional variation was modeled for the shutdown plant-centered LOOPs (plant differences) and for the shutdown weather-related loops (grid differences).

Table 2. Plant-level LOOP frequency distributions.

Mode	LOOP Category	5%	Median (50%)	Mean	95%	MLE	Gamma Shape Parameter (α)	Gamma Scale Parameter (β, years)	Variation Modeled
		Plant-Level LOOP Frequency Distribution [a]							
Critical operation	Plant centered	5.82E-04	2.21E-03	2.54E-03	5.62E-03	2.03E-03	2.50	982.34	Homogeneous
	Switchyard centered	5.14E-03	9.31E-03	9.64E-03	1.53E-02	9.14E-03	9.50	984.92	Homogeneous
	Grid related	3.02E-05	5.76E-03	1.82E-02	7.30E-02	1.32E-02	0.52	28.61	Reliability Council
	Weather related	1.58E-03	3.32E-03	3.49E-03	6.01E-03	3.22E-03	6.49	1859.98	Homogeneous
	Industry	1.21E-02	2.29E-02	3.39E-02	8.90E-02	2.76E-02	1.76	52.03	MCMC Simulation
Shutdown operation	Plant centered	7.10E-04	8.44E-02	1.90E-01	7.31E-01	4.92E-02	0.5	2.6	Plant
	Switchyard centered	2.86E-02	5.63E-02	5.89E-02	9.81E-02	5.50E-02	7.5	127.3	Homogeneous
	Grid related	5.64E-03	1.27E-02	1.35E-02	2.42E-02	1.23E-02	5.5	407.1	Grid
	Weather related	3.76E-04	2.64E-02	6.03E-02	2.62E-01	3.93E-02	0.4	6.0	Grid
	Industry	7.72E-02	2.22E-01	3.22E-01	8.94E-01	1.56E-01	1.2	3.8	MCMC Simulation

a. The frequency units for 5%, median, mean, and 95% are per reactor critical year (/rcry) or per reactor shutdown year (/rsy).

2. LOOP DURATION AND RECOVERY

Probability of exceedance versus duration curves were generated for each of the four LOOP categories: plant centered, switchyard centered, grid related, and weather related. No significant differences exist between the critical operation and shutdown operation data within the distinct LOOP categories, so curves were generated combining both types of data. In addition, no significant differences exist within each LOOP category between the 1986–1996 and 1997–2007 data periods, so the entire 1986–2007 period is applicable.

The lognormal density and cumulative distribution functions used in this report are the following:

$$f(t) = \frac{1}{t\sqrt{2\pi}\sigma} e^{-\frac{1}{2}\left[\frac{\ln(t)-\mu}{\sigma}\right]} \quad (1)$$

$$F(t) = \Phi\left[\frac{\ln(t)-\mu}{\sigma}\right] \quad (2)$$

where

t	=	offsite power recovery time
μ	=	mean of natural logarithms of data
σ	=	standard deviation of natural logarithms of data
Φ	=	error function.

The values that should be used for these equations are shown in Table 3. The definitions of the lognormal μ and σ parameters in Equations 1 and 2 are those found in Microsoft® Excel and the curve fitting software described in Appendix B of Reference 1.

Table 3. Lognormal fit parameters[a].

	Plant Centered	Switchyard Centered	Grid Related	Weather Related	Combined Plant and Switchyard Centered [b]
p-value	>0.16	>=0.25	>=0.25	>=0.25	>0.09
Mu (μ)	-0.688	-0.348	0.441	0.998	-0.466
Sigma (σ)	1.368	1.269	1.045	2.094	1.318
Curve Fit 95% (h)	4.77	5.73	8.04	86.85	5.48
Curve Fit Mean (h)	1.28	1.59	2.54	24.91	1.50
Curve Fit Median (h)	0.50	0.70	1.52	2.74	0.63
Curve Fit 5% (h)	0.05	0.09	0.29	0.09	0.07
Error Factor (95%/median)	9.49	8.18	5.30	31.71	8.74

a. The LaCrosse and two Pilgrim events were excluded from these analyses. See Appendix A, Table A-1 of Reference 1 for more information.
b. For plant risk models that combine the plant-centered and switchyard-centered LOOPs, this column should be used.

The corresponding curves are presented in Figure 8. Statistical analyses indicated that the critical operation and shutdown operation LOOP data were similar for each LOOP category, so the duration information in Figure 8 is applicable to both types of operation.

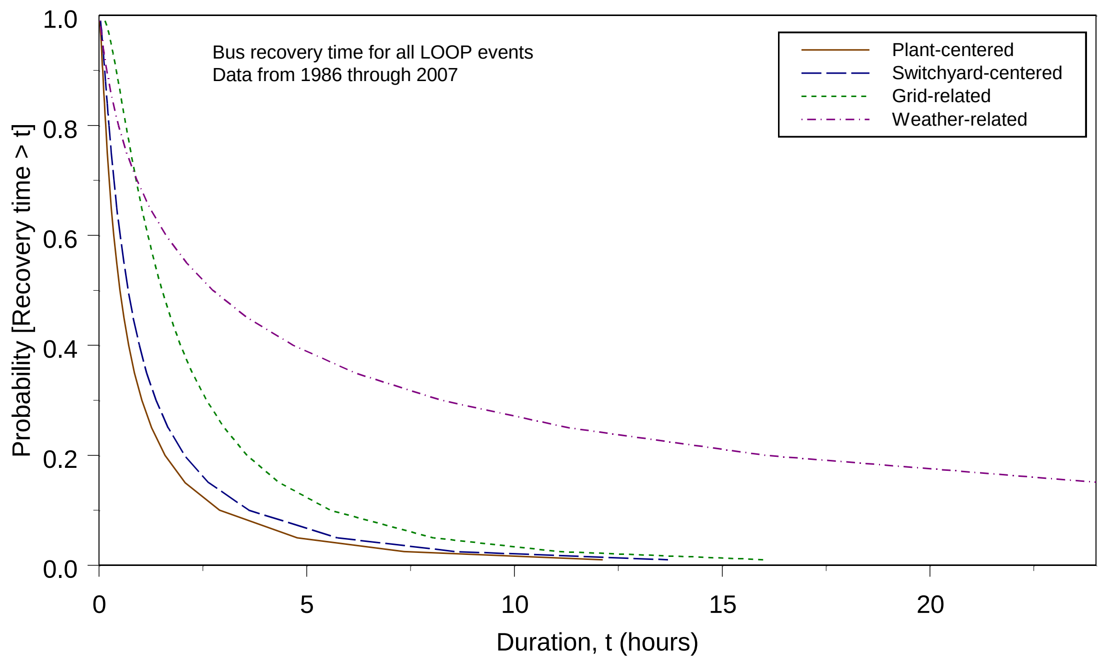
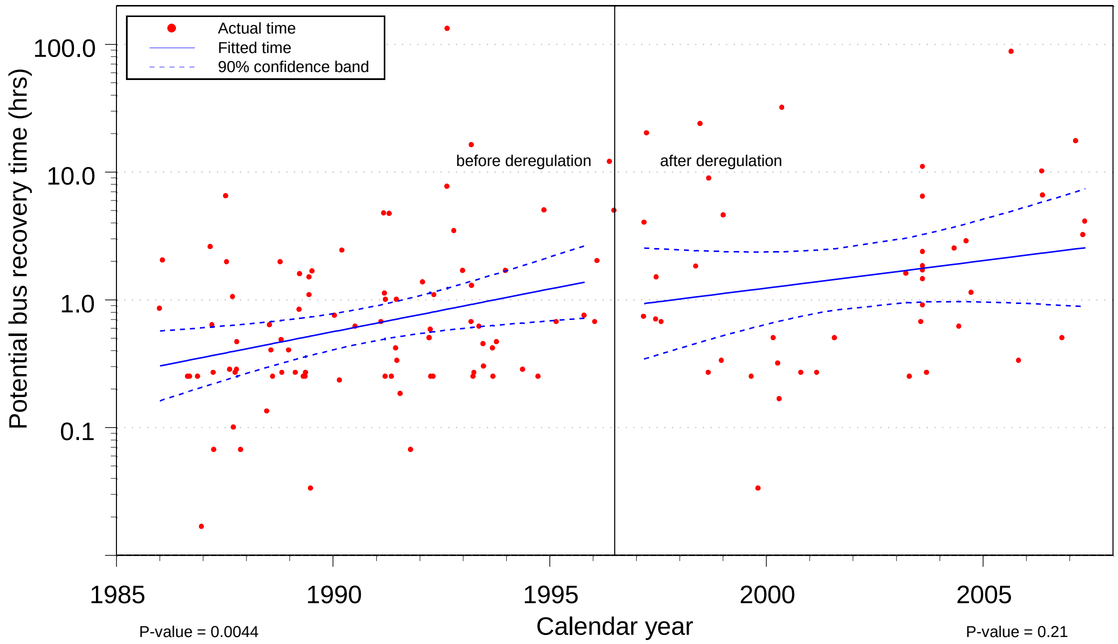


Figure 8. Probability of exceedance versus duration curves.

LOOP duration data for critical and shutdown operation over the entire period 1986–2007 were used to generate probability of exceedance versus duration curves for each of the four LOOP categories. Statistical analyses indicated that within each category, there was not a statistically significant difference between the 1986–1996 data and the 1997–2007 data. However, if all of the LOOP data are combined, a statistically significant increasing trend in durations is observed over the period 1986–1996. In contrast, the 1997–2007 duration data do not exhibit a significant trend. The results of this trending analysis are presented in Figure 9. Finally, if the entire period 1986–2007 is considered, there is no statistically significant trend in LOOP durations.



Note: *The increasing trend over 1986–1996 is statistically significant (p-value for the slope is 0.004), while the slightly increasing trend over 1997–2007 is not statistically significant (p-value for the slope is 0.21).*

Figure 9. Trend plot of LOOP duration for 1986–1996 and 1997–2007 for critical and shutdown operation.

3. SEASONAL EFFECTS

NUREG-1784 (Reference 2) indicated that more recent LOOPs (switchyard centered and grid related) occur mostly during the five summer months (defined in that document as May through September). The LOOP data used for the present study were reviewed to determine if this seasonal effect exists within the four categories of LOOPs. Higher summer frequencies were found for four of the four categories for critical operation. The frequencies for shutdown operation during the summer are higher for three of the four categories.

This section analyzes each LOOP category over the periods 1986–1996 and 1997–2007 in order to identify seasonal differences between the two periods. Results for critical and shutdown operation are presented in Table 4. The results indicate no major seasonal effects on the shutdown overall LOOP frequency for either period. However, the critical operation LOOPs over the more recent period, 1997–2007, indicate a large seasonal difference in the overall LOOP frequency. This seasonal difference for the more recent period for critical operation results mainly from grid-related and switchyard-centered LOOPs. All three grid disturbance events (August 14, 2003, event contributing eight LOOPs; September 15, 2003, event contributing two LOOPs; and June 14, 2004, event contributing three LOOPs) occurred during the summer months. In addition, seven switchyard-centered LOOPs occurred during the summer months, while only one occurred during the non-summer months.

Table 4. Plant-level LOOP events by season.

		1986–1996				1997–2007				
		Summer		Non-summer		Summer		Non-summer		
Mode	LOOP Category	Events	MLE	Events	MLE	Events	MLE	Events	MLE	Frequency Units[a]
Critical operation	Plant centered	4	1.05E-02	6	1.21E-02	1	2.30E-03	1	1.82E-03	/rcry
	Switchyard centered	11	2.89E-02	12	2.42E-02	8	1.84E-02	1	1.82E-03	/rcry
	Grid related	2	5.26E-03	0	0.00E+00	13	2.99E-02	0	0.00E+00	/rcry
	Weather related	2	5.26E-03	1	2.01E-03	2	4.60E-03	1	1.82E-03	/rcry
	All	19	4.99E-02	19	3.83E-02	24	5.52E-02	3	5.45E-03	/rcry
	Reactor Critical Years (rcry)	380.5	—	496.7	—	434.4	—	550.3	—	—
Shutdown operation	Plant centered	6	5.87E-02	8	4.51E-02	2	5.04E-02	4	4.57E-02	/rsy
	Switchyard centered	11	1.08E-01	20	1.13E-01	1	2.52E-02	6	6.85E-02	/rsy
	Grid related	1	9.78E-03	0	0.00E+00	3	7.56E-02	1	1.14E-02	/rsy
	Weather related	2	1.96E-02	7	3.95E-02	4	1.01E-01	3	3.43E-02	/rsy
	All	20	1.96E-01	35	1.98E-01	10	2.52E-01	14	1.60E-01	/rsy
	Reactor Shutdown Years (rsy)	102.3	—	177.2	—	39.7	—	87.59	—	—

a. The frequency units are per reactor critical year (/rcry) or per reactor shutdown year (/rsy).

4. ENGINEERING ANALYSIS OF LOOP DATA

This section reviews the LOOP events from an engineering perspective. The objective is to provide additional qualitative insights with respect to the LOOP events. Events were segregated according to specific causes. A breakdown of the equipment failures is presented in Figure 10, in which transformers dominate the results. Figure 11 presents a breakdown of human error events, in which maintenance activities contribute the largest fraction. Finally, Figure 12 shows the breakdown of weather-related LOOP events.

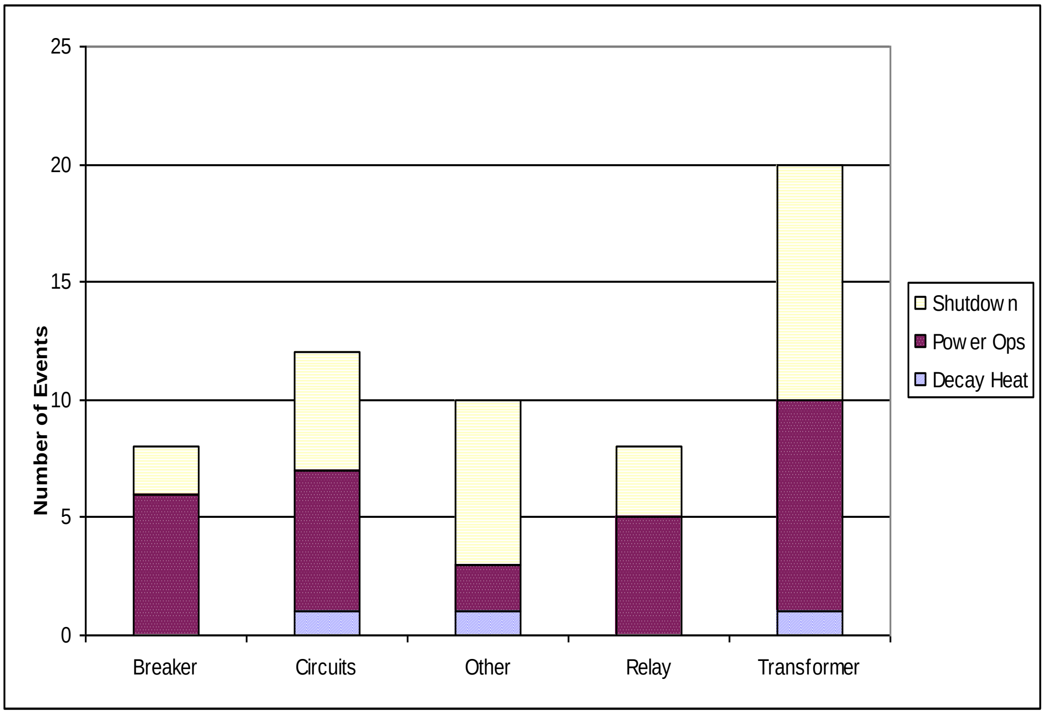


Figure 10. LOOP due to equipment failure by cause, 1986–2007.

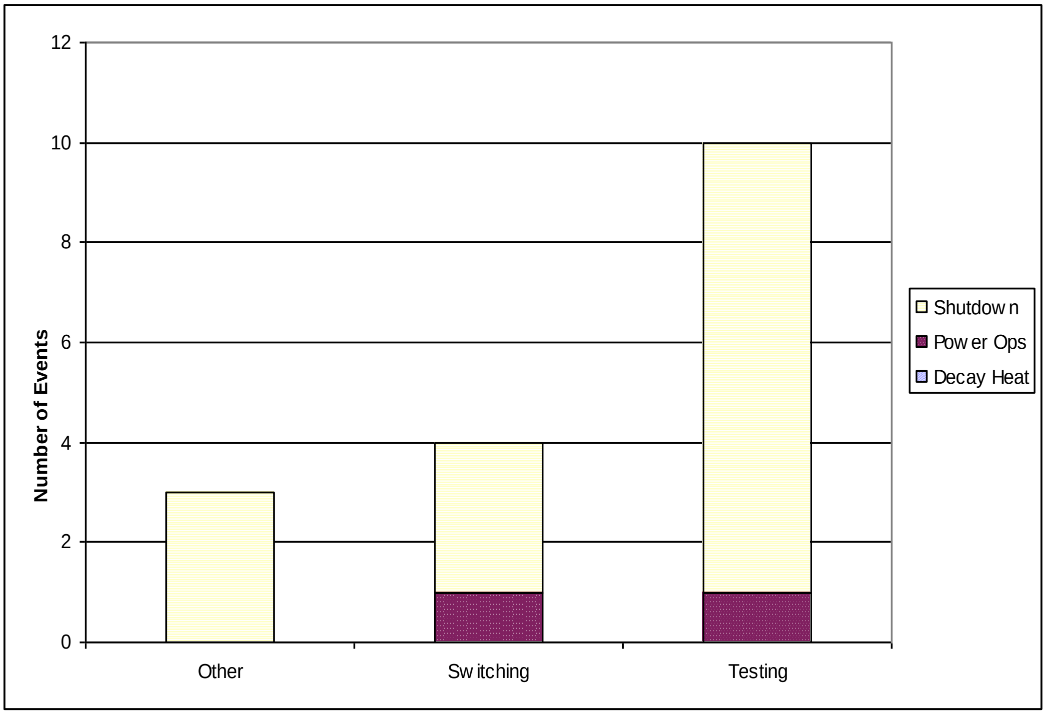


Figure 11. LOOP due to human error by type, 1986–2007.

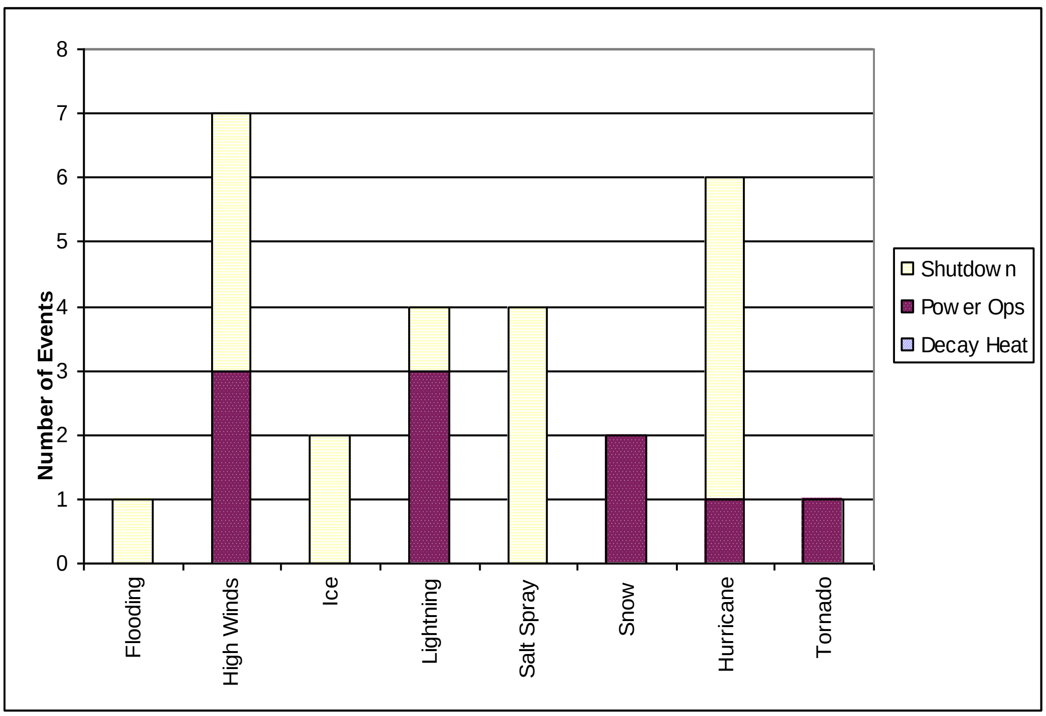


Figure 12. LOOP due to weather by cause, 1986–2007.

5. DATA TABLES

Table 5. Plot data of LOOP frequency for 1986–1996 and 1997–2007. Plant-centered LOOPs: trend plot of industry performance during critical operation. Figure 3.

FY	Plot Trend Error Bar Points			Regression Curve Data Points		
	Lower (5%)	MLE	Upper (95%)	Lower (5%)	MLE	Upper (95%)
1986	1.31E-02	4.80E-02	1.24E-01	1.06E-02	2.98E-02	8.39E-02
1987	0.00E+00	0.00E+00	4.27E-02	9.99E-03	2.37E-02	5.63E-02
1988	6.77E-04	1.32E-02	6.26E-02	9.01E-03	1.89E-02	3.95E-02
1989	6.75E-04	1.32E-02	6.24E-02	7.60E-03	1.50E-02	2.96E-02
1990	0.00E+00	0.00E+00	3.71E-02	5.89E-03	1.19E-02	2.42E-02
1991	9.74E-03	3.58E-02	9.24E-02	4.23E-03	9.49E-03	2.13E-02
1992	4.25E-03	2.39E-02	7.53E-02	2.88E-03	7.55E-03	1.98E-02
1993	0.00E+00	0.00E+00	3.61E-02	1.91E-03	6.01E-03	1.89E-02
1994	0.00E+00	0.00E+00	3.49E-02	1.24E-03	4.78E-03	1.85E-02
1995	0.00E+00	0.00E+00	3.37E-02	7.92E-04	3.80E-03	1.82E-02
1996	0.00E+00	0.00E+00	3.44E-02	5.04E-04	3.02E-03	1.81E-02
1997	0.00E+00	0.00E+00	3.75E-02	3.66E-05	1.13E-03	3.46E-02
1998	0.00E+00	0.00E+00	3.55E-02	6.39E-05	1.25E-03	2.45E-02
1999	0.00E+00	0.00E+00	3.30E-02	1.09E-04	1.39E-03	1.78E-02
2000	5.52E-04	1.08E-02	5.11E-02	1.79E-04	1.55E-03	1.34E-02
2001	0.00E+00	0.00E+00	3.19E-02	2.77E-04	1.73E-03	1.08E-02
2002	0.00E+00	0.00E+00	3.16E-02	3.87E-04	1.92E-03	9.53E-03
2003	0.00E+00	0.00E+00	3.24E-02	4.69E-04	2.14E-03	9.75E-03
2004	0.00E+00	0.00E+00	3.16E-02	4.80E-04	2.38E-03	1.18E-02
2005	0.00E+00	0.00E+00	3.19E-02	4.25E-04	2.65E-03	1.65E-02
2006	5.44E-04	1.06E-02	5.03E-02	3.40E-04	2.95E-03	2.55E-02
2007	0.00E+00	0.00E+00	4.12E-02	2.57E-04	3.28E-03	4.20E-02

Table 6. Plot data of LOOP frequency for 1986–1996 and 1997–2007. Switchyard-centered LOOPs: trend plot of industry performance during critical operation, Figure 4.

FY	Plot Trend Error Bar Points			Regression Curve Data Points		
	Lower (5%)	MLE	Upper (95%)	Lower (5%)	MLE	Upper (95%)
1986	0.00E+00	0.00E+00	4.79E-02	2.16E-02	4.61E-02	9.81E-02
1987	2.81E-02	7.12E-02	1.50E-01	2.15E-02	4.09E-02	7.77E-02
1988	1.08E-02	3.96E-02	1.02E-01	2.10E-02	3.63E-02	6.26E-02
1989	1.08E-02	3.95E-02	1.02E-01	1.99E-02	3.22E-02	5.18E-02
1990	6.36E-04	1.24E-02	5.88E-02	1.82E-02	2.85E-02	4.46E-02
1991	9.74E-03	3.58E-02	9.24E-02	1.59E-02	2.53E-02	4.03E-02
1992	9.78E-03	3.59E-02	9.28E-02	1.33E-02	2.24E-02	3.79E-02
1993	1.65E-02	4.83E-02	1.10E-01	1.07E-02	1.99E-02	3.68E-02
1994	0.00E+00	0.00E+00	3.49E-02	8.55E-03	1.76E-02	3.64E-02
1995	0.00E+00	0.00E+00	3.37E-02	6.72E-03	1.56E-02	3.65E-02
1996	5.89E-04	1.15E-02	5.45E-02	5.24E-03	1.39E-02	3.68E-02
1997	4.45E-03	2.50E-02	7.88E-02	2.75E-03	1.03E-02	3.89E-02
1998	0.00E+00	0.00E+00	3.55E-02	3.24E-03	1.01E-02	3.14E-02
1999	5.65E-04	1.10E-02	5.23E-02	3.74E-03	9.83E-03	2.58E-02
2000	0.00E+00	0.00E+00	3.22E-02	4.19E-03	9.59E-03	2.19E-02
2001	5.46E-04	1.06E-02	5.05E-02	4.47E-03	9.35E-03	1.95E-02
2002	0.00E+00	0.00E+00	3.16E-02	4.45E-03	9.11E-03	1.87E-02
2003	3.84E-03	2.16E-02	6.80E-02	4.11E-03	8.88E-03	1.92E-02
2004	5.40E-04	1.05E-02	5.00E-02	3.58E-03	8.66E-03	2.10E-02
2005	0.00E+00	0.00E+00	3.19E-02	2.99E-03	8.44E-03	2.38E-02
2006	3.77E-03	2.12E-02	6.67E-02	2.44E-03	8.23E-03	2.78E-02
2007	0.00E+00	0.00E+00	4.12E-02	1.95E-03	8.03E-03	3.30E-02

Table 7. Plot data of LOOP frequency for 1986–1996 and 1997–2007. Grid-related LOOPs: trend plot of industry performance during critical operation. Figure 5.

FY	Plot Trend Error Bar Points			Regression Curve Data Points		
	Lower (5%)	MLE	Upper (95%)	Lower (5%)	MLE	Upper (95%)
1986	0.00E+00	0.00E+00	4.79E-02	2.31E-04	3.38E-03	4.95E-02
1987	0.00E+00	0.00E+00	4.27E-02	3.15E-04	3.12E-03	3.09E-02
1988	0.00E+00	0.00E+00	3.95E-02	4.08E-04	2.88E-03	2.03E-02
1989	6.75E-04	1.32E-02	6.24E-02	4.91E-04	2.65E-03	1.43E-02
1990	0.00E+00	0.00E+00	3.71E-02	5.27E-04	2.45E-03	1.14E-02
1991	0.00E+00	0.00E+00	3.57E-02	4.86E-04	2.26E-03	1.05E-02
1992	6.14E-04	1.20E-02	5.68E-02	3.86E-04	2.08E-03	1.13E-02
1993	0.00E+00	0.00E+00	3.61E-02	2.73E-04	1.92E-03	1.36E-02
1994	0.00E+00	0.00E+00	3.49E-02	1.79E-04	1.77E-03	1.76E-02
1995	0.00E+00	0.00E+00	3.37E-02	1.12E-04	1.64E-03	2.39E-02
1996	0.00E+00	0.00E+00	3.44E-02	6.80E-05	1.51E-03	3.35E-02
1997	1.66E-05	4.30E-03	1.65E-02	1.06E-03	4.60E-03	1.99E-02
1998	1.60E-05	4.14E-03	1.59E-02	1.38E-03	4.89E-03	1.73E-02
1999	1.52E-05	3.93E-03	1.51E-02	1.76E-03	5.20E-03	1.53E-02
2000	1.50E-05	3.86E-03	1.49E-02	2.19E-03	5.53E-03	1.40E-02
2001	1.49E-05	3.83E-03	1.47E-02	2.58E-03	5.88E-03	1.34E-02
2002	1.48E-05	3.81E-03	1.46E-02	2.86E-03	6.25E-03	1.37E-02
2003	4.40E-02	8.13E-02	1.28E-01	2.93E-03	6.64E-03	1.51E-02
2004	8.12E-03	2.66E-02	5.38E-02	2.81E-03	7.06E-03	1.78E-02
2005	1.49E-05	3.83E-03	1.47E-02	2.56E-03	7.51E-03	2.20E-02
2006	1.48E-05	3.82E-03	1.47E-02	2.27E-03	7.98E-03	2.80E-02
2007	1.76E-05	4.58E-03	1.76E-02	1.97E-03	8.48E-03	3.64E-02

Table 8. Plot data of LOOP frequency for 1986–1996 and 1997–2007. Weather-related LOOPs: trend plot of industry performance during critical operation, Figure 6.

FY	Plot Trend Error Bar Points			Regression Curve Data Points		
	Lower (5%)	MLE	Upper (95%)	Lower (5%)	MLE	Upper (95%)
1986	0.00E+00	0.00E+00	4.79E-02	5.72E-09	1.95E-05	6.64E-02
1987	0.00E+00	0.00E+00	4.27E-02	2.72E-08	3.84E-05	5.41E-02
1988	0.00E+00	0.00E+00	3.95E-02	1.29E-07	7.55E-05	4.43E-02
1989	0.00E+00	0.00E+00	3.94E-02	6.07E-07	1.49E-04	3.64E-02
1990	0.00E+00	0.00E+00	3.71E-02	2.84E-06	2.93E-04	3.01E-02
1991	0.00E+00	0.00E+00	3.57E-02	1.31E-05	5.76E-04	2.53E-02
1992	0.00E+00	0.00E+00	3.58E-02	5.92E-05	1.13E-03	2.17E-02
1993	6.19E-04	1.21E-02	5.72E-02	2.54E-04	2.23E-03	1.96E-02
1994	0.00E+00	0.00E+00	3.49E-02	9.54E-04	4.39E-03	2.02E-02
1995	0.00E+00	0.00E+00	3.37E-02	2.50E-03	8.65E-03	2.99E-02
1996	4.08E-03	2.30E-02	7.23E-02	3.70E-03	1.70E-02	7.84E-02
1997	0.00E+00	0.00E+00	3.75E-02	6.28E-04	5.00E-03	3.98E-02
1998	6.08E-04	1.19E-02	5.62E-02	7.72E-04	4.48E-03	2.60E-02
1999	0.00E+00	0.00E+00	3.30E-02	9.02E-04	4.01E-03	1.78E-02
2000	0.00E+00	0.00E+00	3.22E-02	9.72E-04	3.59E-03	1.33E-02
2001	5.46E-04	1.06E-02	5.05E-02	9.32E-04	3.22E-03	1.11E-02
2002	0.00E+00	0.00E+00	3.16E-02	7.80E-04	2.88E-03	1.07E-02
2003	0.00E+00	0.00E+00	3.24E-02	5.81E-04	2.58E-03	1.15E-02
2004	5.40E-04	1.05E-02	5.00E-02	3.99E-04	2.31E-03	1.34E-02
2005	0.00E+00	0.00E+00	3.19E-02	2.61E-04	2.07E-03	1.65E-02
2006	0.00E+00	0.00E+00	3.18E-02	1.65E-04	1.86E-03	2.09E-02
2007	0.00E+00	0.00E+00	4.12E-02	1.03E-04	1.66E-03	2.70E-02

Table 9. Plot data of LOOP frequency for 1986–1996 and 1997–2007. All LOOPs combined: trend plot of industry performance during critical operation., Figure 7.

FY	Plot Trend Error Bar Points			Regression Curve Data Points		
	Lower (5%)	MLE	Upper (95%)	Lower (5%)	MLE	Upper (95%)
1986	1.31E-02	4.80E-02	1.24E-01	3.89E-02	7.09E-02	1.29E-01
1987	2.81E-02	7.12E-02	1.50E-01	3.83E-02	6.39E-02	1.07E-01
1988	1.80E-02	5.28E-02	1.21E-01	3.73E-02	5.77E-02	8.91E-02
1989	2.59E-02	6.58E-02	1.38E-01	3.57E-02	5.20E-02	7.59E-02
1990	6.36E-04	1.24E-02	5.88E-02	3.31E-02	4.69E-02	6.66E-02
1991	3.11E-02	7.15E-02	1.41E-01	2.96E-02	4.24E-02	6.05E-02
1992	3.13E-02	7.18E-02	1.42E-01	2.56E-02	3.82E-02	5.69E-02
1993	2.38E-02	6.03E-02	1.27E-01	2.17E-02	3.45E-02	5.49E-02
1994	0.00E+00	0.00E+00	3.49E-02	1.80E-02	3.11E-02	5.38E-02
1995	0.00E+00	0.00E+00	3.37E-02	1.48E-02	2.81E-02	5.32E-02
1996	9.39E-03	3.44E-02	8.90E-02	1.21E-02	2.53E-02	5.29E-02
1997	5.84E-03	2.56E-02	5.66E-02	4.57E-03	1.94E-02	8.28E-02
1998	1.72E-03	1.47E-02	3.82E-02	5.44E-03	1.89E-02	6.57E-02
1999	1.62E-03	1.38E-02	3.60E-02	6.36E-03	1.84E-02	5.32E-02
2000	1.58E-03	1.35E-02	3.53E-02	7.19E-03	1.79E-02	4.44E-02
2001	5.11E-03	2.23E-02	4.95E-02	7.72E-03	1.74E-02	3.91E-02
2002	1.74E-05	4.43E-03	1.70E-02	7.74E-03	1.69E-02	3.69E-02
2003	6.59E-02	1.13E-01	1.71E-01	7.17E-03	1.64E-02	3.76E-02
2004	2.02E-02	4.87E-02	8.73E-02	6.21E-03	1.60E-02	4.10E-02
2005	1.75E-05	4.47E-03	1.72E-02	5.14E-03	1.55E-02	4.68E-02
2006	9.63E-03	3.12E-02	6.27E-02	4.14E-03	1.51E-02	5.50E-02
2007	2.16E-05	5.52E-03	2.12E-02	3.27E-03	1.47E-02	6.58E-02

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