Analysis of Loss of Offsite Power Events

2010 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 calendar years 1986–2010 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 included 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	1997–2010	2	1294.0	1.55E-03	/rcry
	Switchyard-centered	1997–2010	13	1294.0	1.00E-02	/rcry
	Grid-related	1997–2010	14	1294.0	1.08E-02	/rcry
	Weather-related	1986–2010	8	2171.4	3.68E-03	/rcry
	All[b]		37	1421.4	2.60E-02	/rcry
Shutdown operation	Plant-centered	1986–2010	23	435.9	5.28E-02	/rsy
	Switchyard-centered	1997–2010	10	156.5	6.39E-02	/rsy
	Grid-related	1986–2010	5	435.9	1.15E-02	/rsy
	Weather-related	1986–2010	16	435.9	3.67E-02	/rsy
	All[b]		54	316.6	1.65E-01	/rsy

a. The frequency units are per reactor critical year (/rcry) or per reactor shutdown year (/rsy).
b. In the "All" rows, the events and rate estimators are summed across LOOP categories. The

years are calculated so that the counts divided by the years equal the rates.

For critical operation, grid-related LOOPs contribute 46% to the total critical operation LOOP frequency, while switchyard-centered LOOPs contribute 38%. The remaining two categories of LOOPs have frequency contributions of 15% (weather-related) and 6% (plant-centered). More than any other LOOP category, grid-related events have the potential to affect multiple plant units. The last three major grid events affected eight plants, two plants, and three plants. This dependency is shown graphically in Figure 1. The two grid events prior to 1996 affected a single plant unit each.

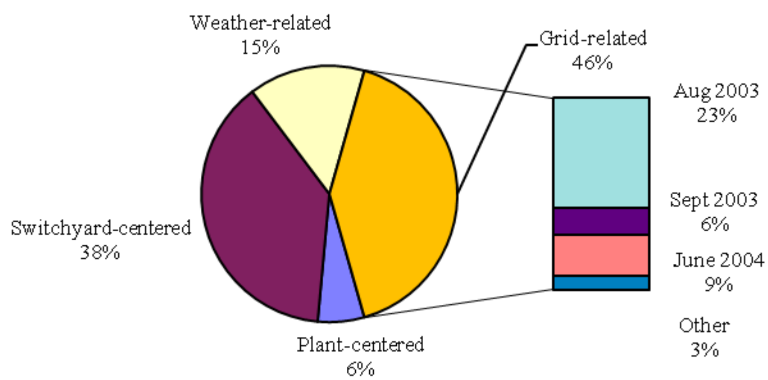


Figure 1. Distribution LOOP categories (per plant unit) during critical operation (1997 to 2010).

For shutdown operation, switchyard-centered LOOPs contribute 26% to the total shutdown LOOP frequency. Switchyard-centered LOOPs are dominated by maintenance and testing activities and by equipment failures. Plant-centered LOOPs contribute 25%, weather 25%, and grid 14%. 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 10 through Table 14. These figures show trends over two periods: 1986–1996 and 1997–2010. 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 1997–2010.

[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).

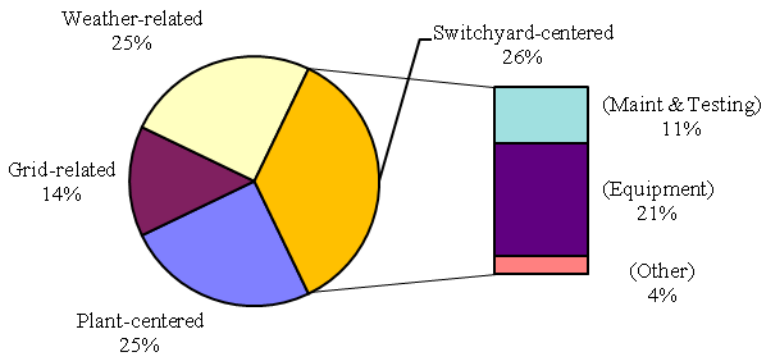


Figure 2. Distribution of LOOP categories (per plant unit) while shutdown (1997 to 2010).

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 four 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. Variation was modeled in some cases, as discussed further below.

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. Past data support the separation of these two modes of operation for grid and weather-related LOOPs, but current data show fewer differences. The decision was made to split the data for all modes because of the different plant operating conditions and the different demands on the emergency power system associated with the two operational modes.

Another overall consideration was the period of time to use for each estimate. 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. For the shutdown data, differences in switchyard LOOP occurrence frequencies remain apparent (p-value=0.0016) and only the data since deregulation are used.

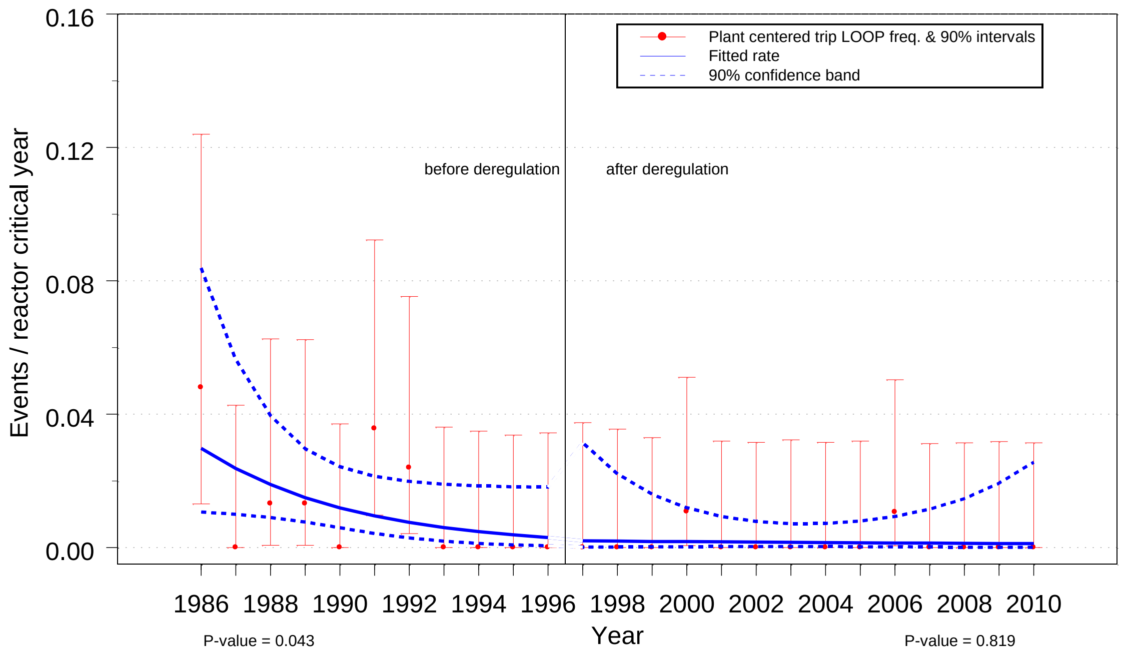


Figure 3. Trend plot of LOOP frequency for 1986–1996 and 1997–2010. Plant-centered LOOPs: trend plot of industry performance during critical operation.

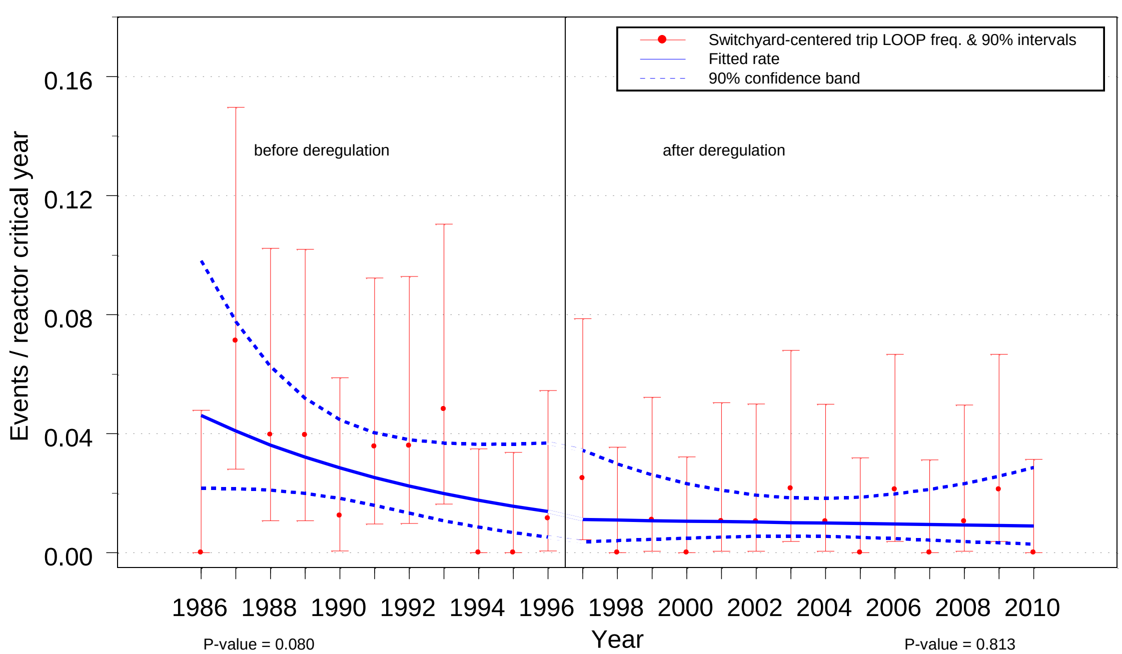
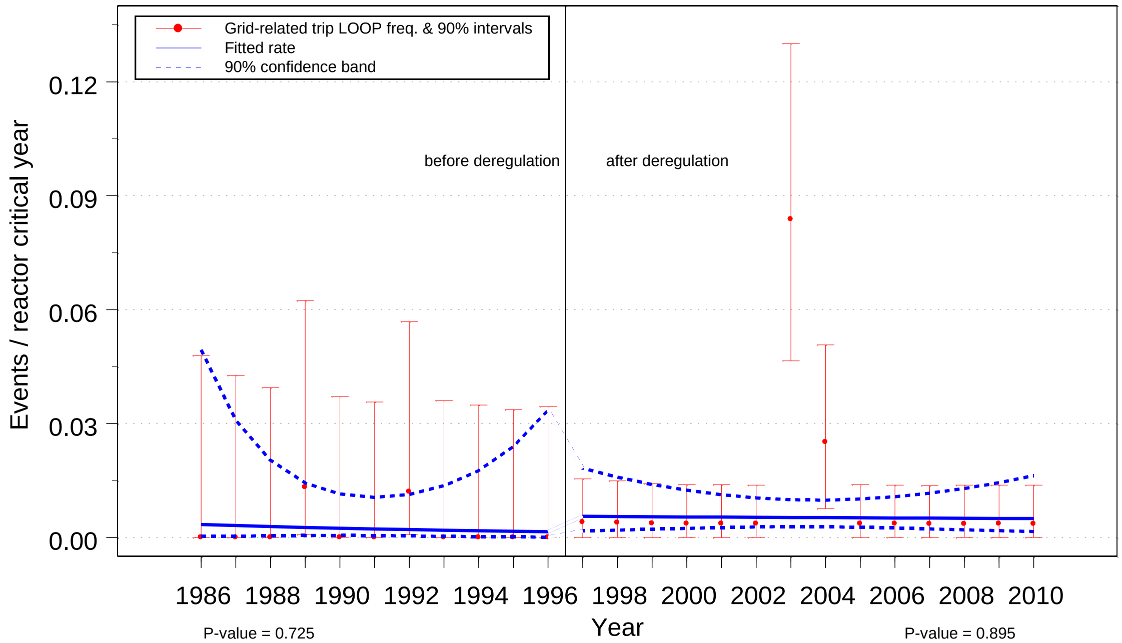


Figure 4. Trend plot of LOOP frequency for 1986–1996 and 1997–2010. Switchyard-centered LOOPs: trend plot of industry performance during critical operation.



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 1997–2010. Grid-related LOOPs: trend plot of industry performance during critical operation.

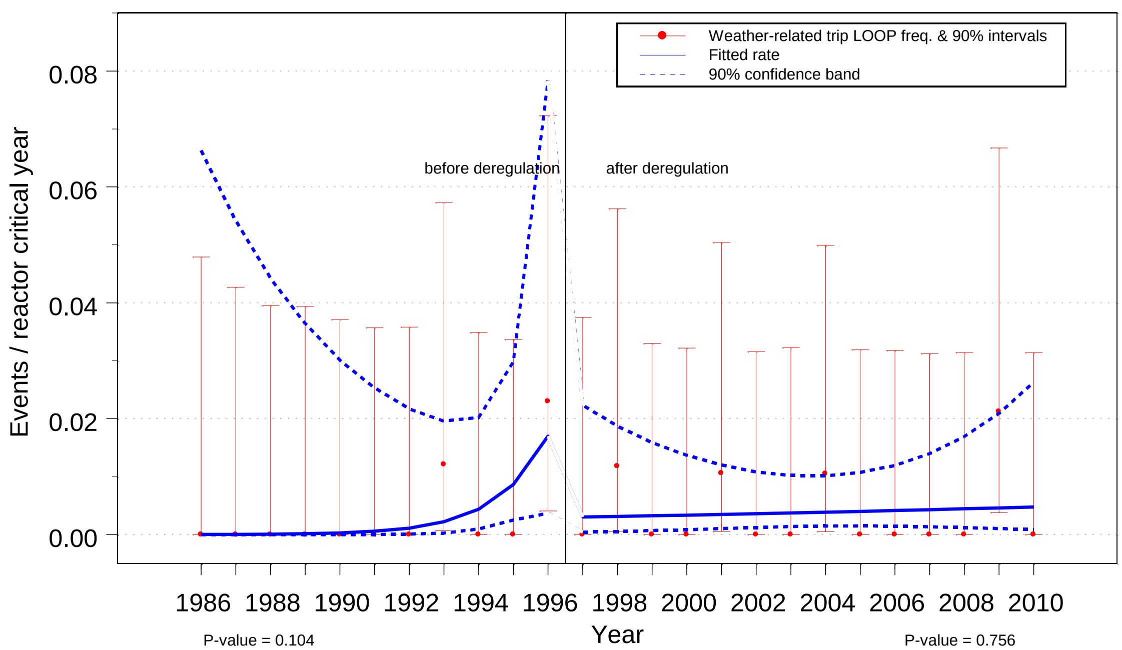
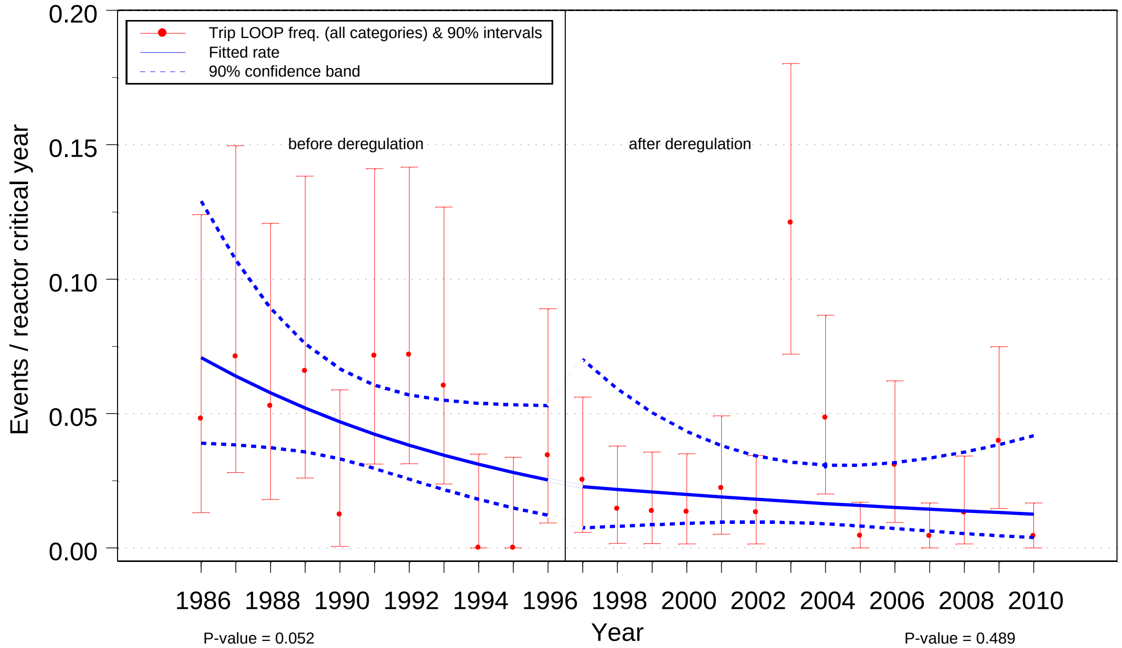


Figure 6. Trend plot of LOOP frequency for 1986–1996 and 1997–2010. Weather-related LOOPs: trend plot of industry performance during critical operation.



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 1997–2010. All LOOPs combined: trend plot of industry performance during critical operation.

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 searching for variability in the data using several grouping schemes: plant, site, various geographical areas, electrical grid areas, year, and others. The variability is sought for each separate LOOP frequency estimate using chi-squared tests and empirical Bayes analyses. In a SAS procedure, exact chi-square tests are approximated by simulation. Where the statistical tests show variation and empirical Bayes distributions describing that variation are identified, the variation is modeled. In cases where the empirical Bayes analyses identified more than one grouping scheme 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.)

The process of combining of the data for the total LOOP rate begins by specifying diffuse, broad gamma prior distributions for each rate being considered (see Section 8). 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.

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" (Figure 8) 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. The results of the evaluation of variation by NERC reliability council for grid events are shown in Table 3. The NERC reliability council acronyms are defined in Section 7.

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).

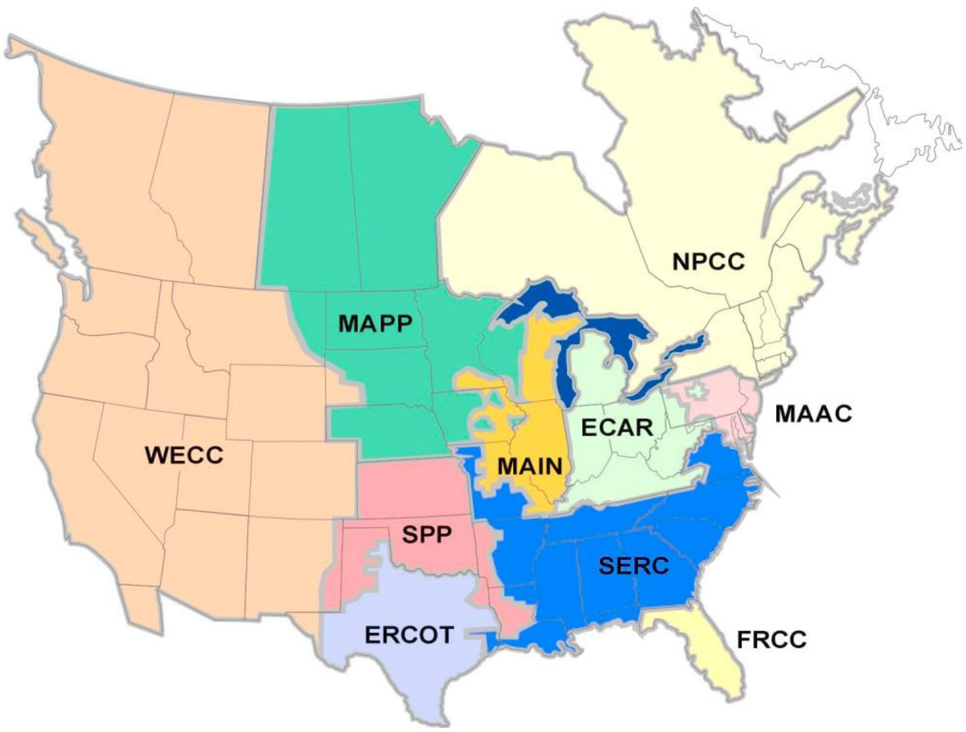


Figure 8. NERC reliability council regions. (Map based on http://www.nerc.com/regional/nercmapcolor.jpg.)

Table 2. Plant-level LOOP frequency distributions.

Mode	LOOP Category	Plant-Level LOOP Frequency Distribution [a]							
		5%	Median (50%)	Mean	95%	MLE	Gamma Shape Parameter (α)	Gamma Scale Parameter (β, years)	Variation Modeled
Critical operation	Plant-centered	4.43E-04	1.68E-03	1.93E-03	4.28E-03	1.55E-03	2.5	1294.0	Homogeneous
	Switchyard-centered	6.24E-03	1.02E-02	1.04E-02	1.55E-02	1.00E-02	13.5	1294.0	Homogeneous
	Grid-related	1.17E-05	4.37E-03	1.22E-02	5.09E-02	1.08E-02	0.40	32.4	Reliability council
	Weather-related	2.00E-03	3.76E-03	3.91E-03	6.35E-03	3.68E-03	8.5	2171.4	Homogeneous
	All	1.28E-02	2.11E-02	2.71E-02	6.23E-02	2.61E-02	2.82	104.1	MCMC Simulation
Shutdown operation	Plant-centered	2.45E-03	3.54E-02	5.16E-02	1.56E-01	5.28E-02	0.97	18.8	Plant
	Switchyard-centered	3.70E-02	6.50E-02	6.71E-02	1.04E-01	6.39E-02	10.5	156.5	Homogeneous
	Grid-related	5.25E-03	1.19E-02	1.26E-02	2.26E-02	1.15E-02	5.5	435.9	Homogeneous
	Weather-related	3.08E-04	2.05E-02	4.02E-02	1.47E-01	3.67E-02	0.57	14.2	Grid
	All	7.98E-02	1.49E-01	1.69E-01	3.28E-01	1.65E-01	4.21	24.91	MCMC Simulation

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

Table 3. Grid-related LOOP frequencies by reliability council.

Reliability Council	Events	Reactor Critical Years	5%	Median	Mean	95%	Maximum Likelihood Estimator (MLE)	Gamma Shape Parameter (α)	Gamma Scale Parameter (β, years)
ECAR	2	90.4	3.96E-03	1.69E-02	1.95E-02	4.47E-02	2.21E-02	2.40	122.8
ERCOT	0	51.7	1.96E-06	1.68E-03	4.70E-03	2.04E-02	0	0.40	84.2
FRCC	0	61.9	1.64E-06	1.50E-03	4.20E-03	1.83E-02	0	0.40	94.3
MAAC	2	167.9	2.56E-03	1.03E-02	1.20E-02	2.70E-02	1.19E-02	2.40	200.3
MAIN	0	186.4	4.46E-07	6.47E-04	1.81E-03	8.02E-03	0	0.40	218.8
MAPP	0	75.6	1.31E-06	1.31E-03	3.66E-03	1.60E-02	0	0.40	108.0
NPCC	7	136.6	1.94E-02	4.18E-02	4.38E-02	7.61E-02	5.12E-02	7.40	169.0
SERC	0	386.6	1.87E-07	3.38E-04	9.44E-04	4.22E-03	0	0.40	419.0
SPP	0	38.4	2.58E-06	2.00E-03	5.59E-03	2.41E-02	0	0.40	70.8
WECC	3	98.7	7.18E-03	2.34E-02	2.59E-02	5.41E-02	3.04E-02	3.40	131.1

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 1997–2010 data periods, so the entire 1986–2010 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 4. 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 4. Lognormal fit parameters [a].

	Plant-centered	Switchyard-centered	Grid-related	Weather-related	Combined Plant and Switchyard-centered [b]
p-value	>0.1655	>0.25	>0.25	>0.25	>0.1073
Mu (μ)	-0.615	-0.339	0.414	0.996	-0.428
Sigma (σ)	1.408	1.361	1.013	2.046	1.382
Curve Fit 95% (h)	5.482	6.682	8.011	78.395	6.336
Curve Fit Mean (h)	1.457	1.798	2.528	21.957	1.695
Curve Fit Median (h)	0.540	0.712	1.513	2.708	0.652
Curve Fit 5% (h)	0.053	0.076	0.286	0.094	0.067
Error Factor (95%/median)	10.14	9.38	5.29	28.94	9.72

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 9. Statistical analyses indicated that the critical operation and shutdown operation LOOP data were similar for each LOOP category, so the duration information in Figure 9 is applicable to both types of operation.

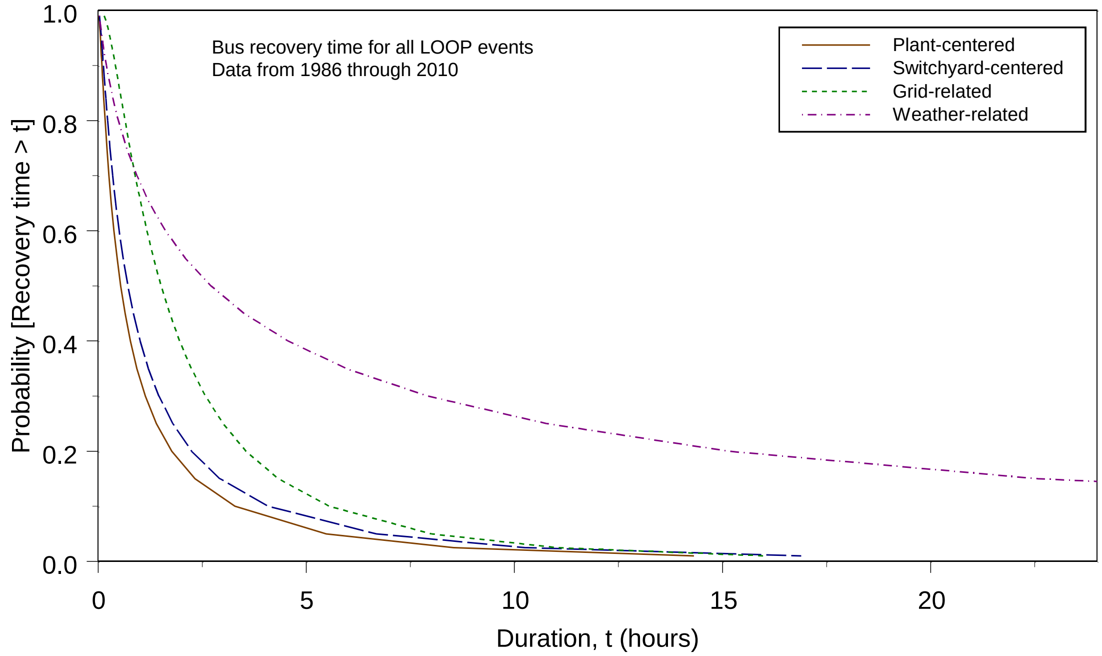
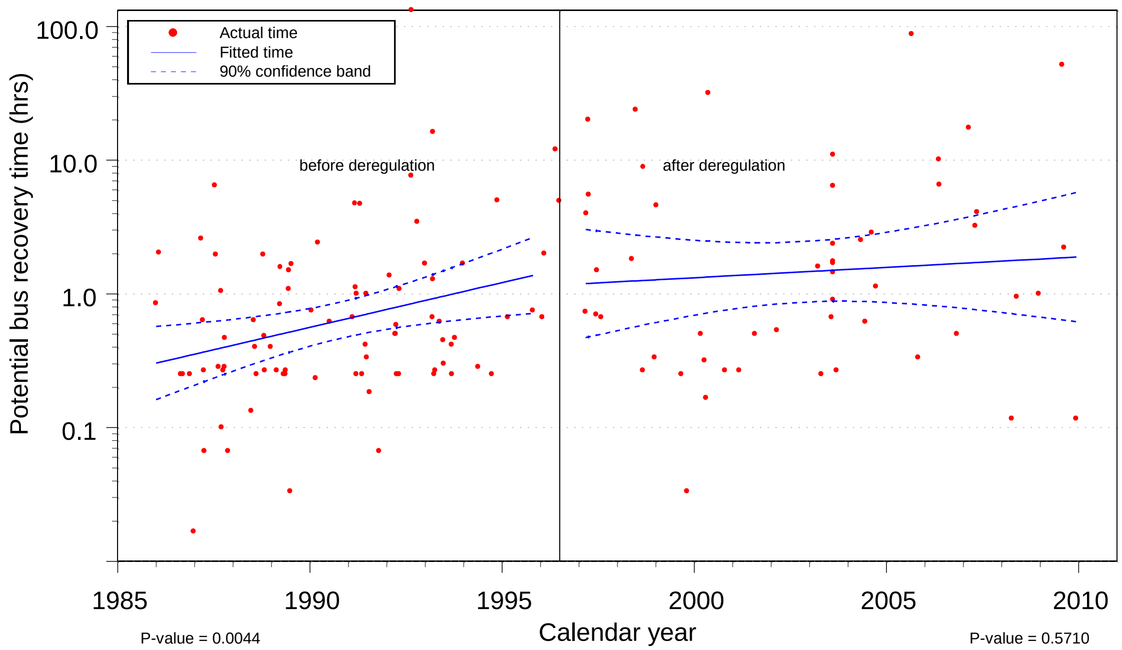


Figure 9. Probability of exceedance versus duration curves.

LOOP duration data for critical and shutdown operation over the entire period 1986–2010 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 1997–2010 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 1997–2010 duration data do not exhibit a significant trend. The results of this trending analysis are presented in Figure 10. Finally, if the entire period 1986–2010 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 1997–2010 is not statistically significant (p-value for the slope is 0.55).*

Figure 10. Trend plot of LOOP duration for 1986–1996 and 1997–2010 for critical and shutdown operation.

3. EMERGENCY DIESEL GENERATOR REPAIR TIMES

Section 5, of Volume 2, in Reference 1 presents the probability of exceedance for emergency diesel generators (EDGs) repair times (one of two EDGs) based on the unplanned outage times provided by the reactor oversight program (ROP). This section provides an update of that analysis using monthly-unplanned demands from July 2003 to December 2010 from the Equipment Performance and Information Exchange (EPIX) database.

For each train in the Mitigating Systems Performance Index (MSPI) Program, monthly entries of planned outage hours, unplanned outage hours, and plant critical hours are provided from July 2003 through the present. Only outages that occurred while the plant was in critical operation are included in the EPIX database. Table 5 shows the mean and median of the raw unplanned UA data (with zero entries removed) and the shape parameters of the Weibull distribution fit to this data for the single EDG case and a simulation of the easier to repair EDG (of two). The simulation models plant personnel choosing to repair the easier to repair EDG (shorter repair time) 80% of the time. The simulation uses the distribution of the single EDG for both EDGs. A Weibull distribution (best fitting distribution) is fit to the simulated results.

Table 6 shows the non-recovery probabilities calculated for selected critical times using the repair time distribution times shown in Table 5. Figure 11 shows a graphic comparison of the two sets of results.

Table 5. EDG unplanned repair time distribution parameters.

Parameter	Single EDG Values	Two EDG Values
Mean	20.64	14.45
Median	10.20	5.54
Weibull (α)	0.69	0.64
Weibull (β)	17.65	10.31

Table 6. EDG non-recovery probability for selected times.

Time (h)	One EDG	Two EDGs
0	1.000	1.000
0.5	0.918	0.867
1	0.871	0.800
1.5	0.833	0.749
2	0.801	0.706
3	0.745	0.636
4	0.698	0.581
5	0.658	0.534
6	0.622	0.494
7	0.590	0.459
8	0.560	0.428
9	0.534	0.400
10	0.509	0.375
11	0.486	0.352
12	0.465	0.332
13	0.445	0.313
14	0.426	0.296
15	0.409	0.280
16	0.393	0.265
17	0.377	0.252
18	0.363	0.239
19	0.349	0.227
20	0.336	0.216
21	0.324	0.206
22	0.312	0.196
23	0.301	0.187
24	0.290	0.179

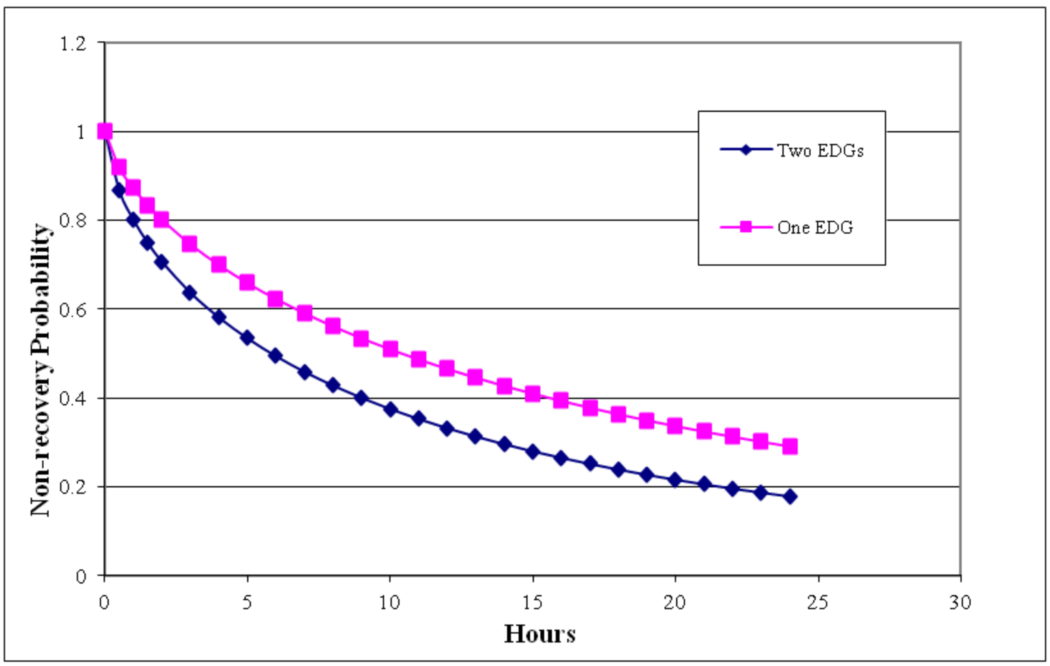


Figure 11. Plot of non-recovery probabilities based on the two sets of data.

4. SPECIAL TOPICS

4.1 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 (1997–2010) were found for all of the four categories for critical operation. The frequencies for shutdown operation (1997–2010) during the summer are higher for three of the four categories.

This section analyzes each LOOP category over the periods 1986–1996 and 1997–2010 in order to identify seasonal differences between the two periods. Results for critical and shutdown operation are presented in Table 8. 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, 1997–2010, 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 major 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.

4.2 Multi-Unit Site Considerations

Among the 158 LOOP plant level events considered in this study for frequency and duration analyses (177 total events; removing 16 LOOP s with no trip, the Lacrosse LOOP [1986 atypical plant design], and two Pilgrim salt spray LOOPs removed [effective modifications made to minimize salt spray impacts]), there were 13 occurrences (27 LOOP events) involving more than one plant at a site resulting from the same event (over a period of 24 hours). These events are listed in chronological order in Table 7. Twelve involved two plants, while one (Palo Verde on June 14, 2004) involved all three plants at the site.

The remaining 131 events were single plant events. Of the 104 presently operating plants, there are 28 single-plant sites, 32 dual-plant sites (Fitzpatrick and Nine Mile Point 1 are considered dual-unit for LOOP purposes), and four three-plant sites. (The three-plant sites are Browns Ferry, Oconee, Palo Verde, and Hope Creek/Salem [considered three-unit for LOOP purposes].)

Conditional probabilities of other plants at a multi-plant site experiencing a LOOP, given a LOOP at one of the plants at the site, are presented in Table 9. These conditional probabilities range from 2.4E-2 for plant-centered LOOPs to 3.2E-1 for grid-related LOOPs. Because all of the 13 events listed in Table 7 affected all plants at a site, the probabilities listed in Table 9 are considered to apply to all other plants at the site. For example, if a site has three plants and one plant experiences a grid-related LOOP while at power, then the probability that the other two plants also experience the same grid-related LOOP is 0.32 from Table 9.

Table 7. LOOP events (1986-2010) that affected more than one plant at a site.

Event	Site	Date	Number of Plants at Site	Number of Plants Affected	LOOP Category	Mode
1	Calvert Cliffs	7/23/1987	2	2	Switchyard Centered	Critical Operation

Event	Site	Date	Number of Plants at Site	Number of Plants Affected	LOOP Category	Mode
2	Peach Bottom	7/29/1988	2	2	Switchyard Centered	Shutdown Operation
3	Turkey Point	8/24/1992	2	2	Weather Related	Shutdown Operation (note a)
4	Sequoyah	12/31/1992	2	2	Switchyard Centered	Critical Operation
5	Brunswick	03/16-17/1993	2	2	Weather Related	Shutdown Operation
6	Beaver Valley	10/12/1993	2	2	Switchyard Centered	Critical Operation/ Shutdown Operation
7	Prairie Island	6/29/1996	2	2	Weather Related	Critical Operation
8	Fitzpatrick and Nine Mile Point 1	8/14/2003	2	2	Grid Related	Critical Operation
9	Indian Point	8/14/2003	2	2	Grid Related	Critical Operation
10	Peach Bottom	9/15/2003	2	2	Grid Related	Critical Operation
11	Palo Verde	6/14/2004	3	3	Grid Related	Critical Operation
12	St. Lucie	9/25/2004	2	2	Weather Related	Shutdown Operation (note a)
13	Catawba	5/20/2006	2	2	Switchyard Centered	Critical Operation

a. In these cases, the plants shut down in anticipation of bad weather. The weather events subsequently resulted in LOOPs at the plants.

Table 8. Plant-level LOOP events by season.

		1986-1996				1997-2010				
		Summer (May-Sept.)		Non-summer		Summer (May-Sept.)		Non-summer		
Mode	**LOOP Category**	Events	Mean Frequency[a]	Events	Mean Frequency[a]	Events	Mean Frequency[a]	Events	Mean Frequency[a]	Frequency Units[b]
Critical operation	Plant-centered	4	1.18E-02	6	1.31E-02	1	2.67E-03	1	2.05E-03	/rcry
	Switchyard-centered	11	3.01E-02	12	2.53E-02	10	1.87E-02	3	4.78E-03	/rcry
	Grid-related	2	6.54E-03	0	1.01E-03	13	2.41E-02	1	2.05E-03	/rcry
	Weather-related	2	6.54E-03	1	3.03E-03	4	8.02E-03	1	2.05E-03	/rcry
	All	19	5.10E-02	19	3.94E-02	28	5.08E-02	6	8.87E-03	/rcry
	Reactor critical years (rcry)	382.5		494.9		561.3		732.7		—
Shutdown operation	Plant-centered	7	7.29E-02	9	5.38E-02	2	5.37E-02	5	5.00E-02	/rsy
	Switchyard-centered	11	1.12E-01	20	1.16E-01	2	5.37E-02	8	7.73E-02	/rsy
	Grid-related	1	1.46E-02	0	2.83E-03	3	7.51E-02	1	1.36E-02	/rsy
	Weather-related	2	2.43E-02	7	4.25E-02	4	9.66E-02	3	3.18E-02	/rsy
	All	21	2.09E-01	36	2.07E-01	11	2.47E-01	17	1.59E-01	/rsy
	Reactor shutdown years (rsy)	102.8		176.5		46.6		109.9		—

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

Table 9. Conditional probability of all plants at a site experiencing a LOOP given a LOOP at one of the plants.

LOOP Category	**LOOP Events at Multi-Plant Sites Affecting all Plants at the Site**	**Total Number of LOOP Events at Multi-Plant Sites**	**Conditional Probability of All Plants at a Multi-Plant Site Experiencing a LOOP Given a LOOP at One of the Plants at the Site (note a)**				**Beta Distribution Parameters**	
			5%	**Median**	**Mean**	**95%**	**α**	**β**
Grid Centered	4	13	1.38E-01	3.13E-01	3.21E-01	5.34E-01	4.5	9.5
Plant Centered	0	20	9.71E-05	1.12E-02	2.38E-02	9.05E-02	0.5	20.5
Switchyard Centered	5	47	4.99E-02	1.09E-01	1.15E-01	1.98E-01	5.5	42.5
Weather Related	4	12	1.51E-01	3.38E-01	3.46E-01	5.69E-01	4.5	8.5
All Categories	13	92	9.00E-02	1.43E-01	1.45E-01	2.09E-01	13.5	79.5

a. The mean is a Bayesian update using a Jeffreys prior. Mean = (0.5 + events)/(1 + total events). The beta distribution is a CNID.

5. 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 12, in which transformers dominate the results. Figure 13 presents a breakdown of human error events, in which maintenance activities contribute the largest fraction. Finally, Figure 14 shows the breakdown of weather-related LOOP events.

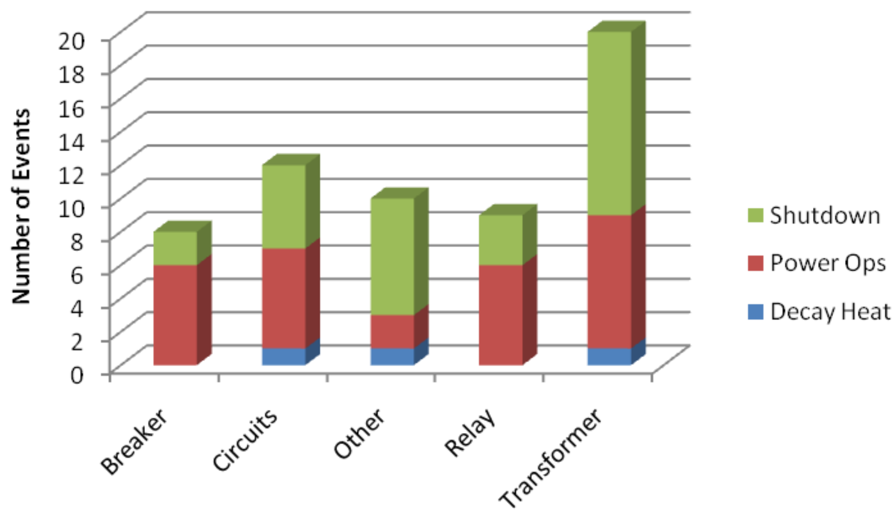


Figure 12. LOOP due to equipment failure by cause, 1986–2010.

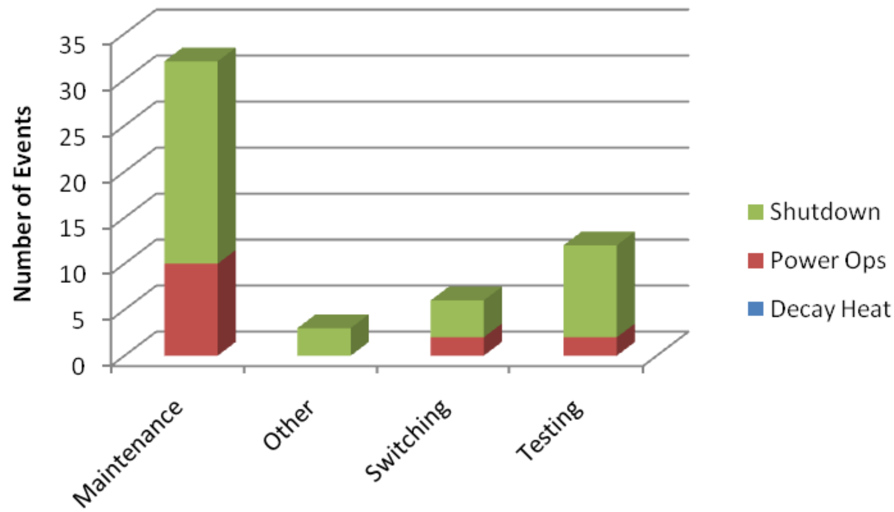


Figure 13. LOOP due to human error by type, 1986–2010.

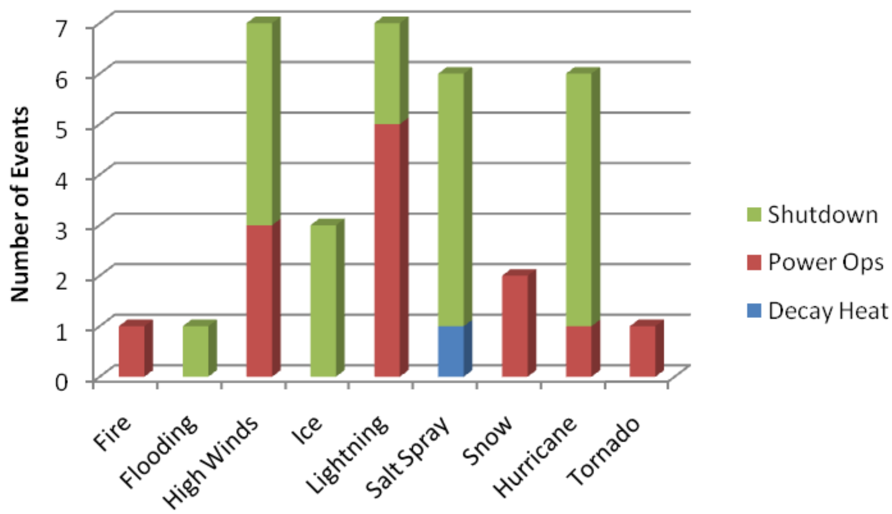


Figure 14. LOOP due to weather by cause, 1986–2010.

6. DATA TABLES

Table 10. Plot data of LOOP frequency for 1986–1996 and 1997–2010. 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	9.88E-03	2.45E-02	6.08E-02
1987	0.00E+00	0.00E+00	4.27E-02	9.07E-03	2.07E-02	4.72E-02
1988	6.77E-04	1.32E-02	6.26E-02	8.24E-03	1.74E-02	3.70E-02
1989	6.75E-04	1.32E-02	6.24E-02	7.39E-03	1.47E-02	2.93E-02
1990	0.00E+00	0.00E+00	3.71E-02	6.51E-03	1.24E-02	2.37E-02
1991	9.74E-03	3.57E-02	9.24E-02	5.62E-03	1.05E-02	1.95E-02
1992	4.25E-03	2.39E-02	7.53E-02	4.74E-03	8.84E-03	1.65E-02
1993	0.00E+00	0.00E+00	3.61E-02	3.91E-03	7.46E-03	1.42E-02
1994	0.00E+00	0.00E+00	3.49E-02	3.16E-03	6.29E-03	1.25E-02
1995	0.00E+00	0.00E+00	3.37E-02	2.51E-03	5.31E-03	1.12E-02
1996	0.00E+00	0.00E+00	3.44E-02	1.96E-03	4.48E-03	1.02E-02
1997	0.00E+00	0.00E+00	3.75E-02	1.27E-04	2.00E-03	3.14E-02
1998	0.00E+00	0.00E+00	3.55E-02	1.67E-04	1.92E-03	2.21E-02
1999	0.00E+00	0.00E+00	3.30E-02	2.13E-04	1.84E-03	1.59E-02
2000	5.52E-04	1.08E-02	5.11E-02	2.64E-04	1.77E-03	1.19E-02
2001	0.00E+00	0.00E+00	3.19E-02	3.10E-04	1.70E-03	9.30E-03
2002	0.00E+00	0.00E+00	3.16E-02	3.41E-04	1.63E-03	7.80E-03
2003	0.00E+00	0.00E+00	3.23E-02	3.43E-04	1.57E-03	7.14E-03
2004	0.00E+00	0.00E+00	3.16E-02	3.14E-04	1.50E-03	7.19E-03
2005	0.00E+00	0.00E+00	3.19E-02	2.64E-04	1.44E-03	7.90E-03
2006	5.44E-04	1.06E-02	5.03E-02	2.07E-04	1.39E-03	9.30E-03
2007	0.00E+00	0.00E+00	3.12E-02	1.54E-04	1.33E-03	1.15E-02
2008	0.00E+00	0.00E+00	3.14E-02	1.11E-04	1.28E-03	1.47E-02
2009	0.00E+00	0.00E+00	3.14E-02	1.11E-04	1.28E-03	1.47E-02
2010	0.00E+00	0.00E+00	3.18E-02	7.80E-05	1.23E-03	1.93E-02

Table 11. Plot data of LOOP frequency for 1986–1996 and 1997–2010. 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	1.99E-02	3.65E-02	6.69E-02
1987	2.81E-02	7.12E-02	1.50E-01	1.94E-02	3.40E-02	5.97E-02
1988	1.08E-02	3.96E-02	1.02E-01	1.88E-02	3.17E-02	5.34E-02
1989	1.08E-02	3.95E-02	1.02E-01	1.82E-02	2.95E-02	4.78E-02
1990	6.36E-04	1.24E-02	5.88E-02	1.76E-02	2.75E-02	4.30E-02
1991	9.74E-03	3.57E-02	9.24E-02	1.69E-02	2.56E-02	3.89E-02
1992	9.78E-03	3.59E-02	9.27E-02	1.61E-02	2.39E-02	3.53E-02
1993	1.65E-02	4.82E-02	1.10E-01	1.53E-02	2.22E-02	3.23E-02
1994	0.00E+00	0.00E+00	3.49E-02	1.44E-02	2.07E-02	2.97E-02
1995	0.00E+00	0.00E+00	3.37E-02	1.35E-02	1.93E-02	2.76E-02
1996	5.89E-04	1.15E-02	5.45E-02	1.25E-02	1.80E-02	2.58E-02
1997	4.45E-03	2.50E-02	7.88E-02	3.63E-03	1.12E-02	3.44E-02
1998	0.00E+00	0.00E+00	3.55E-02	4.04E-03	1.10E-02	2.99E-02
1999	5.65E-04	1.10E-02	5.23E-02	4.46E-03	1.08E-02	2.62E-02
2000	0.00E+00	0.00E+00	3.22E-02	4.87E-03	1.06E-02	2.32E-02
2001	5.46E-04	1.06E-02	5.05E-02	5.23E-03	1.05E-02	2.10E-02
2002	5.41E-04	1.05E-02	5.00E-02	5.49E-03	1.03E-02	1.93E-02
2003	3.84E-03	2.16E-02	6.80E-02	5.57E-03	1.01E-02	1.84E-02
2004	5.40E-04	1.05E-02	5.00E-02	5.46E-03	9.97E-03	1.82E-02
2005	0.00E+00	0.00E+00	3.19E-02	5.16E-03	9.80E-03	1.86E-02
2006	3.77E-03	2.12E-02	6.67E-02	4.73E-03	9.64E-03	1.97E-02
2007	0.00E+00	0.00E+00	3.12E-02	4.25E-03	9.49E-03	2.12E-02
2008	5.37E-04	1.05E-02	4.97E-02	3.75E-03	9.33E-03	2.32E-02
2009	3.77E-03	2.12E-02	6.67E-02	3.28E-03	9.18E-03	2.57E-02
2010	0.00E+00	0.00E+00	3.14E-02	2.85E-03	9.03E-03	2.86E-02

Table 12. Plot data of LOOP frequency for 1986–1996 and 1997–2010. 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	1.51E-05	3.99E-03	1.54E-02	2.15E-03	4.29E-03	8.58E-03
1987	1.43E-05	3.76E-03	1.45E-02	2.25E-03	4.31E-03	8.25E-03
1988	1.37E-05	3.61E-03	1.39E-02	2.36E-03	4.33E-03	7.95E-03
1989	1.23E-03	1.08E-02	2.83E-02	2.47E-03	4.35E-03	7.66E-03
1990	1.33E-05	3.48E-03	1.34E-02	2.58E-03	4.38E-03	7.41E-03
1991	1.30E-05	3.40E-03	1.31E-02	2.69E-03	4.40E-03	7.18E-03
1992	1.17E-03	1.02E-02	2.68E-02	2.80E-03	4.42E-03	6.98E-03
1993	1.31E-05	3.43E-03	1.32E-02	2.90E-03	4.44E-03	6.80E-03
1994	1.29E-05	3.36E-03	1.29E-02	2.99E-03	4.46E-03	6.67E-03
1995	1.26E-05	3.29E-03	1.27E-02	3.06E-03	4.48E-03	6.57E-03
1996	1.28E-05	3.33E-03	1.28E-02	3.12E-03	4.51E-03	6.51E-03
1997	1.54E-05	4.01E-03	1.54E-02	1.70E-03	5.56E-03	1.82E-02
1998	1.49E-05	3.88E-03	1.49E-02	1.91E-03	5.51E-03	1.58E-02
1999	1.43E-05	3.69E-03	1.42E-02	2.14E-03	5.46E-03	1.39E-02
2000	1.40E-05	3.64E-03	1.40E-02	2.37E-03	5.41E-03	1.24E-02
2001	1.39E-05	3.61E-03	1.39E-02	2.57E-03	5.36E-03	1.12E-02
2002	1.38E-05	3.58E-03	1.38E-02	2.73E-03	5.32E-03	1.04E-02
2003	4.65E-02	8.38E-02	1.30E-01	2.81E-03	5.27E-03	9.89E-03
2004	7.62E-03	2.51E-02	5.07E-02	2.78E-03	5.22E-03	9.80E-03
2005	1.39E-05	3.61E-03	1.39E-02	2.66E-03	5.18E-03	1.01E-02
2006	1.39E-05	3.60E-03	1.38E-02	2.46E-03	5.13E-03	1.07E-02
2007	1.37E-05	3.55E-03	1.37E-02	2.22E-03	5.09E-03	1.16E-02
2008	1.38E-05	3.57E-03	1.37E-02	1.98E-03	5.04E-03	1.29E-02
2009	1.39E-05	3.60E-03	1.38E-02	1.74E-03	5.00E-03	1.44E-02
2010	1.38E-05	3.57E-03	1.37E-02	1.51E-03	4.96E-03	1.62E-02

Table 13. Plot data of LOOP frequency for 1986–1996 and 1997–2010. 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	2.55E-04	1.73E-03	1.17E-02
1987	0.00E+00	0.00E+00	4.27E-02	3.02E-04	1.83E-03	1.11E-02
1988	0.00E+00	0.00E+00	3.95E-02	3.56E-04	1.95E-03	1.06E-02
1989	0.00E+00	0.00E+00	3.94E-02	4.20E-04	2.07E-03	1.01E-02
1990	0.00E+00	0.00E+00	3.71E-02	4.95E-04	2.19E-03	9.71E-03
1991	0.00E+00	0.00E+00	3.57E-02	5.81E-04	2.33E-03	9.31E-03
1992	0.00E+00	0.00E+00	3.58E-02	6.80E-04	2.47E-03	8.96E-03
1993	6.19E-04	1.21E-02	5.72E-02	7.94E-04	2.62E-03	8.66E-03
1994	0.00E+00	0.00E+00	3.49E-02	9.21E-04	2.78E-03	8.40E-03
1995	0.00E+00	0.00E+00	3.37E-02	1.06E-03	2.95E-03	8.21E-03
1996	4.08E-03	2.30E-02	7.23E-02	1.22E-03	3.13E-03	8.08E-03
1997	0.00E+00	0.00E+00	3.75E-02	4.12E-04	3.03E-03	2.23E-02
1998	6.08E-04	1.18E-02	5.62E-02	5.26E-04	3.14E-03	1.87E-02
1999	0.00E+00	0.00E+00	3.30E-02	6.65E-04	3.25E-03	1.59E-02
2000	0.00E+00	0.00E+00	3.22E-02	8.30E-04	3.37E-03	1.37E-02
2001	5.46E-04	1.06E-02	5.05E-02	1.01E-03	3.49E-03	1.20E-02
2002	0.00E+00	0.00E+00	3.16E-02	1.20E-03	3.61E-03	1.08E-02
2003	0.00E+00	0.00E+00	3.23E-02	1.37E-03	3.74E-03	1.02E-02
2004	5.40E-04	1.05E-02	5.00E-02	1.48E-03	3.87E-03	1.01E-02
2005	0.00E+00	0.00E+00	3.19E-02	1.51E-03	4.01E-03	1.07E-02
2006	0.00E+00	0.00E+00	3.18E-02	1.45E-03	4.16E-03	1.19E-02
2007	0.00E+00	0.00E+00	3.12E-02	1.33E-03	4.31E-03	1.40E-02
2008	0.00E+00	0.00E+00	3.14E-02	1.18E-03	4.46E-03	1.69E-02
2009	3.77E-03	2.12E-02	6.67E-02	1.02E-03	4.62E-03	2.09E-02
2010	0.00E+00	0.00E+00	3.14E-02	8.70E-04	4.78E-03	2.63E-02

Table 14. Plot data of LOOP frequency for 1986–1996 and 1997–2010. 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	1.41E-02	4.57E-02	9.18E-02	1.96E-02	4.29E-02	9.37E-02
1987	2.71E-02	6.52E-02	1.17E-01	1.97E-02	4.08E-02	8.48E-02
1988	1.85E-02	5.01E-02	9.42E-02	1.97E-02	3.89E-02	7.68E-02
1989	2.53E-02	6.10E-02	1.09E-01	1.96E-02	3.70E-02	6.97E-02
1990	1.85E-03	1.58E-02	4.12E-02	1.96E-02	3.52E-02	6.35E-02
1991	3.00E-02	6.63E-02	1.14E-01	1.94E-02	3.35E-02	5.80E-02
1992	3.01E-02	6.65E-02	1.14E-01	1.92E-02	3.19E-02	5.32E-02
1993	2.36E-02	5.67E-02	1.01E-01	1.88E-02	3.04E-02	4.91E-02
1994	1.97E-05	5.00E-03	1.92E-02	1.84E-02	2.90E-02	4.56E-02
1995	1.91E-05	4.86E-03	1.87E-02	1.78E-02	2.76E-02	4.27E-02
1996	1.07E-02	3.46E-02	6.95E-02	1.71E-02	2.62E-02	4.03E-02
1997	5.79E-03	2.53E-02	5.61E-02	7.41E-03	2.28E-02	7.01E-02
1998	1.70E-03	1.45E-02	3.79E-02	8.02E-03	2.18E-02	5.91E-02
1999	1.60E-03	1.37E-02	3.57E-02	8.60E-03	2.08E-02	5.03E-02
2000	1.57E-03	1.34E-02	3.50E-02	9.11E-03	1.99E-02	4.33E-02
2001	5.07E-03	2.22E-02	4.91E-02	9.47E-03	1.90E-02	3.80E-02
2002	1.55E-03	1.32E-02	3.44E-02	9.60E-03	1.81E-02	3.42E-02
2003	7.23E-02	1.21E-01	1.80E-01	9.41E-03	1.73E-02	3.19E-02
2004	2.01E-02	4.84E-02	8.66E-02	8.89E-03	1.65E-02	3.08E-02
2005	1.74E-05	4.44E-03	1.71E-02	8.11E-03	1.58E-02	3.08E-02
2006	9.56E-03	3.09E-02	6.22E-02	7.18E-03	1.51E-02	3.17E-02
2007	1.71E-05	4.35E-03	1.67E-02	6.23E-03	1.44E-02	3.34E-02
2008	1.54E-03	1.31E-02	3.42E-02	5.32E-03	1.38E-02	3.56E-02
2009	1.47E-02	3.98E-02	7.49E-02	4.51E-03	1.32E-02	3.84E-02
2010	1.72E-05	4.38E-03	1.68E-02	3.79E-03	1.26E-02	4.17E-02

7. ACRONYMS

ac	alternating current
ASP	accident sequence precursor
CNID	constrained noninformative distribution
EB	empirical Bayes
ECAR	East Central Area Reliability Coordination Agreement
EPRI	Electric Power Research Institute
ERCOT	Electric Reliability Council of Texas
FRCC	Florida Reliability Coordinating Council
INL	Idaho National Laboratory
LER	licensee event report
LOOP	loss of offsite power
LOOP-IE	loss of offsite power initiating event
LOOP-IE-C	loss of offsite power initiating event consequential
LOOP-IE-I	loss of offsite power initiating event initial
LOOP-IE-NC	loss of offsite power initiating event not consequential
LOOP-NT	loss of offsite power no trip
LOSP	loss of offsite power
MAAC	Mid-Atlantic Area Council
MAIN	Mid-America Interconnected Network
MAPP	Mid-Continent Area Power Pool
NERC	North American Electric Reliability Council
NPCC	Northeastern Power Coordinating Council
NPP	commercial nuclear power plant
PRA	probabilistic risk assessment
rcry	reactor critical year
rcy	reactor calendar year
rsy	reactor shutdown year
SBO	station blackout
SERC	Southeastern Electric Reliability Council
SPAR	standardized plant analysis risk
SPP	Southwest Power Pool
WECC	Western Electricity Coordinating Council

8. METHODS

This section has been added to provide additional information about the methods used to derive a satisfactory 'Total LOOP Frequency'. Reference 1 derived the total LOOP frequency by summing the plant-centered, grid-related, switchyard-centered, and weather-related frequencies. Since each of these essentially added 0.5 LOOP events (CNID update), the total LOOP frequency was 2.0 LOOP events larger than actual counts. Since that report was prepared, the staff at the INL has searched for a more appropriate method to arrive at the total LOOP frequency.

It should be noted that this discussion applies only to the total LOOP frequency and does not apply to the individual LOOP frequencies for the plant-centered, grid-related, switchyard-centered, and weather-related categories.

"Markov chain Monte-Carlo" (MCMC), Metropolis-Hasting, and "burn-in," are generally most applicable to the use of WinBUGS or its newer incarnation, OpenBugs. While there are likely to be other tools for these calculations, the staff at the INL has the most experience with WinBUGS and OpenBugs. WINBUGS is widely used in the statistical community.

The use of "hierarchical Bayes" (HB) methods are described in Section 8.3 of the *Handbook of Parameter Estimation for Probabilistic Risk Assessment* (HOPE) NUREG/CR-6823 (Reference 3). This update implements a procedure nearly identical to the procedure discussed in Section 8.3.4. Figure 8.8 on page 8-16 of the HOPE manual applies directly, except that we use a more diffuse prior on beta [gamma(0.0001,0.0001) instead of gamma(0.0625,0.0625)]. [Note that, for both of these "flat" distributions, the mean is relatively high: 1.0, but the gamma distribution parameters are expected to be relatively high].

For the LOOP data analysis, this procedure is applied for each frequency that was fitted with an empirical Bayes (EB) distribution. Then, to get the overall LOOP rate, simulate and monitor

Lambda(LOOP)=Lambda(P) +Lambda(S)+Lambda(G, Reliability Council)+Lambda(W) for the critical operation data and

Lambda(LOOP)=Lambda(P, plant) +Lambda(S)+Lambda(G)+Lambda(W, grid) for the shutdown data.

In each of these estimates, the appropriate inputs apply (based on critical operation data or on shutdown data). Where estimates from specific groups apply, particular groups are sampled in each iteration of the simulation in proportion to their contribution to the total critical operation or shutdown time.

In the 2007 and 2008 LOOP updates, HB methods were not used. Separate diffuse priors were tracked and tuned for each group for each of the three estimates for which variation is considered. For some of the groups such as plants with sparse data, the priors remained diffuse and the associated means remained relatively high. The resulting overall LOOP occurrences rates were higher than the rates cited in the current LOOP Update. The staff at the INL believes that these new estimates are more appropriate than the estimates previously supplied in Reference 1 and the two previous updates.

9. REFERENCES

1. S.A. Eide et al., *Reevaluation of Station Blackout Risk at Nuclear Power Plants*, U.S. Nuclear Regulatory Commission, NUREG/CR-6890, December 2005.
2. W. S. Raughley, and G. F. Lanik, *Operating Experience Assessment—Effects of Grid Events on Nuclear Power Plant Performance*, U.S. Nuclear Regulatory Commission, NUREG-1784, December 2003.
3. Atwood, C.L., et al., 2003,, *Handbook of Parameter Estimation for Probabilistic Risk Assessment (HOPE)*, Nuclear Regulatory Commission, NUREG/CR-6823, September 2003.