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Analysis of Loss-of-Offsite-Power Events 1998–2013

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ABSTRACT

Loss of offsite power (LOOP) can have a major negative impact on a power plant's ability to achieve and maintain safe shutdown conditions. Risk analyses suggest that loss of all alternating current power contributes over 70% of the overall risk at some U.S. nuclear plants. LOOP event and subsequent restoration of offsite power are important inputs to plant probabilistic risk assessments. This report presents a statistical and engineering analysis of LOOP frequencies and durations at U.S. commercial nuclear power plants. The data used in this study are based on the operating experience during calendar years 1997 through 2013. Frequencies and durations were determined for four event categories: plant-centered, switchyard-centered, grid-related, and weather-related. The emergency diesel generator failure modes considered are failure to start, failure to load and run, and failure to run more than 1 hour. The component reliability estimates and the reliability data are trended for the most recent 10-year period while yearly estimates for reliability are provided for the entire active period. No statistically significant trends in LOOP frequencies over the 1997–2013 period are identified. There is a possibility that a significant trend in grid-related LOOP frequency exists that is not easily detected by a simple analysis. Statistically significant increases in recovery times after grid- and switchyard-related LOOPs are identified.

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ACRONYMS

CNID	constrained noninformative prior distribution
ECAR	East Central Area Reliability Coordination Agreement
EDG	emergency diesel generator
ERCOT	Electric Reliability Council of Texas
FRCC	Florida Reliability Coordinating Council
INL	Idaho National Laboratory
LOOP	loss of offsite power
MAAC	Mid-Atlantic Area Council
MAIN	Mid-America Interconnected Network
MAPP	Mid-Continent Area Power Pool
MCMC	Markov chain Monte-Carlo
MLE	maximum likelihood estimator
NERC	North American Electric Reliability Corporation
NPCC	Northeastern Power Coordinating Council
PRA	probabilistic risk assessment
rcry	reactor critical year
rsy	reactor shutdown year
SERC	Southeastern Electric Reliability Council
SPP	Southwest Power Pool
WECC	Western Electricity Coordinating Council

Analysis of Loss-of-Offsite-Power Events 1998–2013

The availability of alternating current power, which is normally supplied by offsite sources via the electrical grid, is essential for safe operation and accident recovery at commercial nuclear power plants. A loss-of-offsite-power (LOOP in this report; also referred to as LOSP) event 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 alternating current power contributes over 70% of the overall risk at some plants. Clearly, LOOP events and subsequent restoration of offsite power are important inputs to plant probabilistic risk assessments (PRAs). These inputs must reflect current industry performance so PRAs accurately estimate the risk from LOOP initiated scenarios.

This study is a statistical and engineering analysis of LOOP frequencies and durations at U.S. commercial nuclear reactors. LOOP data for calendar years 1986–2013 were collected and analyzed. The data cover both critical (at power) and shutdown operations at these plants.[a] 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. LOOP events at power, during which no plant trip was observed, are also excluded. Three other events were removed from analysis: the Lacrosse LOOP (1986 atypical plant design) and two Pilgrim salt-spray LOOPs (effective modifications made to minimize salt spray impacts).

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[a] “Plant” and “unit” are used interchangeably in this report.

1. LOOP FREQUENCY

LOOP industry frequencies were determined for four event categories: plant-centered, switchyard-centered, grid-related, and weather-related. These frequencies were then subdivided into results for critical and shutdown operation. Table 1 summarizes the results. Plant-specific LOOP frequencies for 1986–1996 are listed in Atwood et al. (1996); plat-specific frequencies for 1997–2004 are listed in Eide, Gentillon, and Wierman (2005).

Table 1. Plant-level LOOP frequencies.

Mode	LOOP Category	Data Period	Events	Reactor Critical or Shutdown Years	Maximum Likelihood Estimator	Frequency Units[a]
Critical Operation	Plant-centered	1997–2013	3	1567.9	1.91E−03	/rcry
	Switchyard-centered	1997–2013	22	1567.9	1.40E−02	/rcry
	Grid-related	1997–2013	18	1567.9	1.15E−02	/rcry
	Weather-related	1986–2013	12	2445.3	4.91E−03	/rcry
	All[b]		55	1701.7	3.23E−02	/rcry
Shutdown Operation	Plant-centered	1986–2013	23	471.6	4.88E−02	/rsy
	Switchyard-centered	1997–2013	13	192.2	6.76E−02	/rsy
	Grid-related	1986–2013	5	471.6	1.06E−02	/rsy
	Weather-related	1986–2013	17	471.6	3.60E−02	/rsy
	All[b]		58	355.8	1.63E−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, switchyard-centered LOOPs contribute 43% and grid-related LOOPs contribute 36% to the total critical operation LOOP frequency. The remaining two categories of LOOPs have frequency contributions of 16% (weather-related) and 6% (plant-centered).

For shutdown operation, switchyard-centered LOOPs again contribute 43% to the total shutdown LOOP frequency. Switchyard-centered LOOPs are dominated by maintenance and testing activities and by equipment failures. For the remaining categories, plant-centered LOOPs contribute 30%, weather-related 22%, and grid-related 6%.

Trend plots for each of the critical-operation event categories and all LOOPs combined are presented in Figures 1 through 5. The data supporting the plots are listed in Appendix A. The plots show trends over two periods: 1986–1996 and 1997–2013. As shown in the trend plots, the industry performance over this recent period is relatively constant. For plant-centered and switchyard-centered LOOPs, Figures 1 and 2 show that industry performance improved considerably over the period 1986–1996. Therefore, only the years 1997–2013 are used to determine industry frequencies representative of current performance.

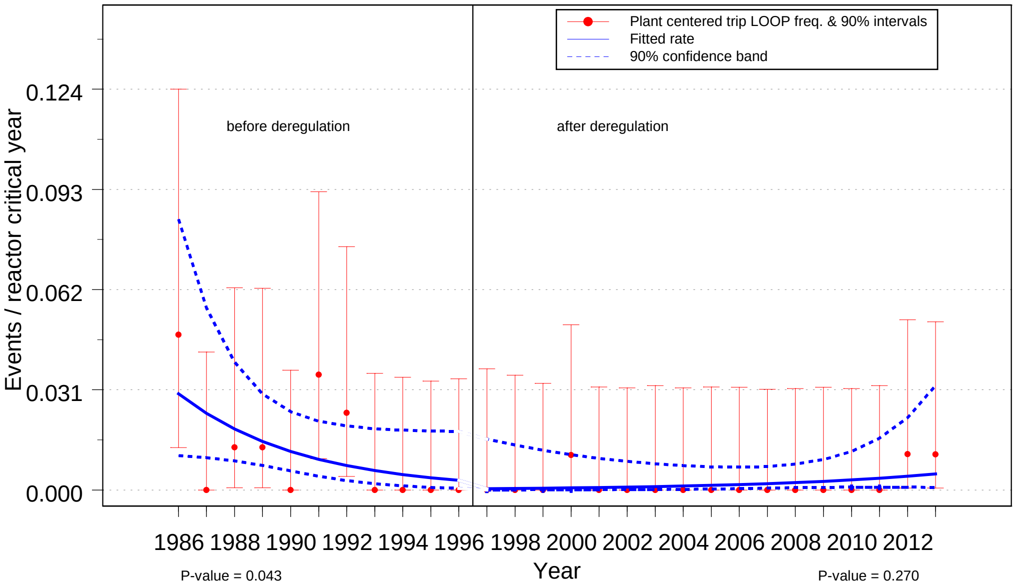


Figure 1. Trend plot of plant-centered LOOPs during critical operation.

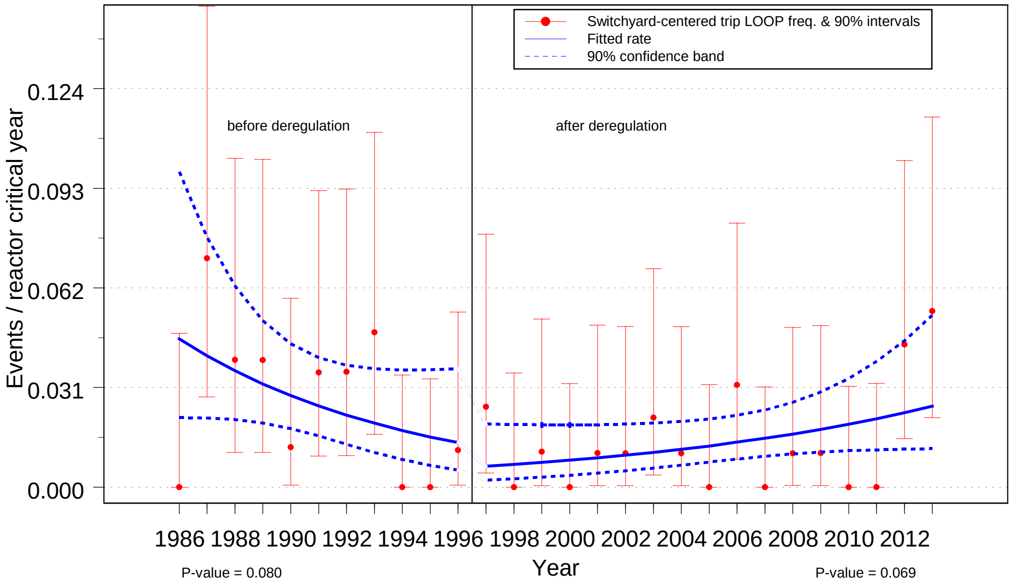
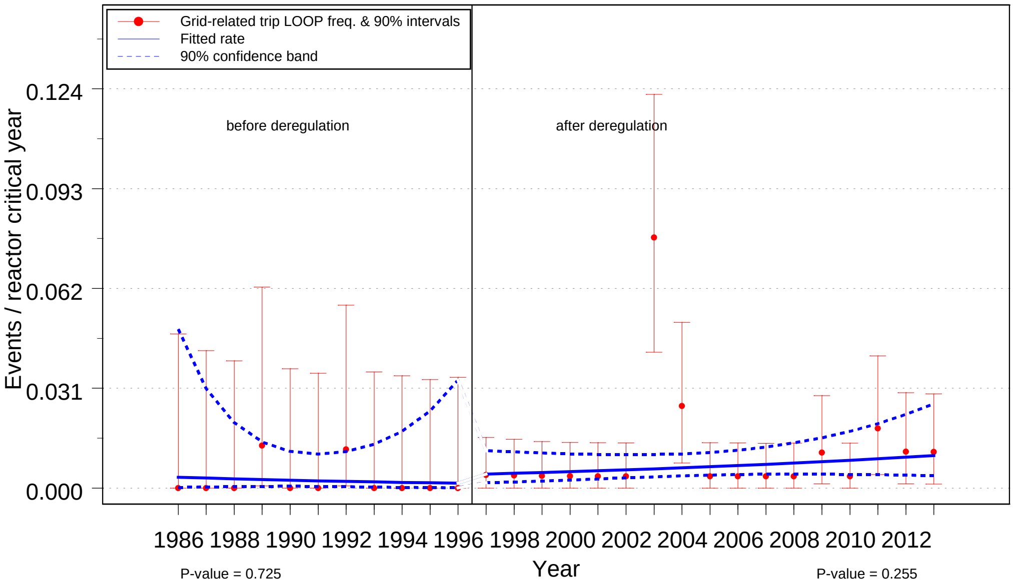


Figure 2. Trend plot of switchyard-centered LOOPs during critical operation.

More than any other LOOP category, grid-related events have the potential to affect multiple plant units. Three major grid events in August 2003, September 2003, and June 2004 affected eight plants, two plants, and three plants respectively (nearly three-fourths of the total). The other five events each affected a single critical plant. This poses challenges for simplistic modeling of event frequencies, which treats all events as independent.

An increasing trend was reported in the 2003 through 2007 versions of this report, but since 2008, these two spikes have been near the center of the 1997–2013 timeframe and cause the current analysis to report no significant trend (see Figure 3). However, the other five grid-related LOOPs since 1997 have occurred in 2009, 2011 (twice), 2012, and 2013, so an analysis that looked only at the most recent 10 years, or that counted the 2003–2004 LOOPs as three events rather than thirteen, would report a significant adverse trend in grid-related LOOPs. Many researchers looking at the broader electric utility field have reported such adverse trends in grid reliability over the past 10 to 15 years.

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 below.



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 3. Trend plot of grid-related LOOPs during critical operation.

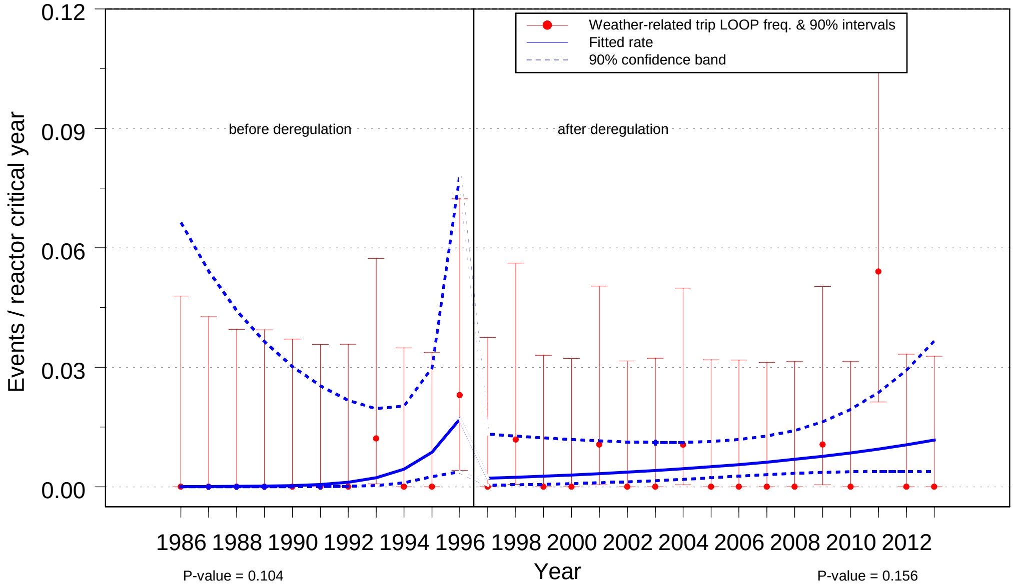
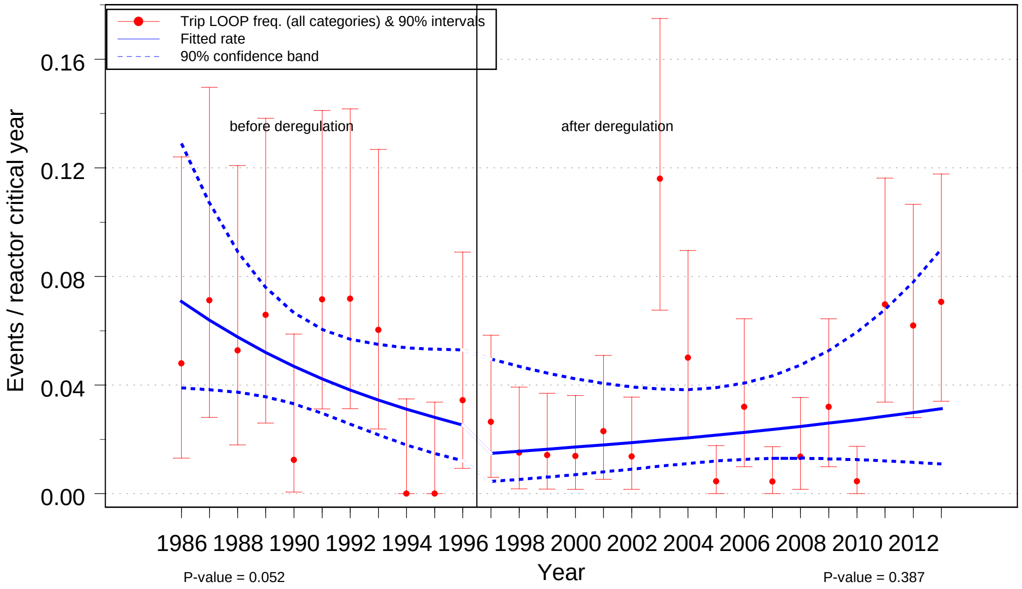


Figure 4. Trend plot of weather-related LOOPs during critical operation.



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 all LOOPs combined during critical operation.

Table 2. *Plant-level LOOP frequency distributions.*[a]

Mode	LOOP Category	5%	Median (50%)	Mean	95%	MLE	Gamma Shape Parameter (α)	Gamma Scale Parameter (β, years)	Variation Modeled
Critical Operation	Plant-centered	6.91E−04	2.02E−03	2.23E−03	4.49E−03	1.91E−03	3.50	1567.90	Homogeneous
	Switchyard-centered	2.34E−03	1.17E−02	1.41E−02	3.40E−02	1.40E−02	1.90	134.44	Year
	Grid-related	1.04E−06	2.76E−03	1.17E−02	5.39E−02	1.15E−02	0.29	25.12	Plant
	Weather-related	6.38E−09	5.48E−04	5.08E−03	2.61E−02	4.91E−03	0.20	39.95	Plant (year also significant)[b]
	All	6.95E−03	2.50E−02	3.24E−02	8.33E−02	—	1.56	48.18	Simulation[c]
Shutdown Operation	Plant-centered	2.38E−03	3.36E−02	4.88E−02	1.47E−01	4.88E−02	0.98	20.06	Plant
	Switchyard-centered	2.76E−04	3.20E−02	7.02E−02	2.70E−01	6.76E−02	0.50	7.12	Season, InterCon (CNID)[d]
	Grid-related	4.85E−03	1.10E−02	1.17E−02	2.09E−02	1.06E−02	5.50	471.60	Homogeneous
	Weather-related	6.59E−08	4.32E−03	3.76E−02	1.92E−01	3.60E−02	0.21	5.53	Plant
	All	3.03E−02	1.29E−01	1.68E−01	4.44E−01	—	1.44	8.58	Simulation[c]

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

b. Plant and year both statistically significant. But the α = 0.2 for plant variation is more diffuse than a CNID prior with α = 0.5 would be.

c. α and β were estimated by matching the mean and 95th percentile. The Markov chain Monte-Carlo median was 1.52E−01 and the 5th percentile was 8.05E−02.

d. Season and InterCon both statistically significant, therefore CNID prior with α = 0.5 used.

To develop LOOP distributions for use in PRAs, the first consideration was the issue of whether critical operation 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 several years ago 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. This method has once again been used in the 2013 update.

Another overall consideration was the period of time to use for each estimate. For the critical operation data, data since deregulation (which began around 1997) 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. 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.

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-squared tests are approximated by simulation. Where the statistical tests show variation and associated empirical Bayes distributions are identified, the variation is modeled. In cases where the empirical Bayes analyses identifies more than one grouping scheme with significant variability, the practice in previous years was to model the single most significant source of variability even though this underestimated the total variability in the data set. In this report, a stricter interpretation of the guidance in Appendix B of Atwood et al. (1996) has been taken; when more than one significant source of variation is identified, a constrained noninformative prior distribution (CNID) is used.

Combining the data for the total LOOP rate is done by sampling the four distributions identified for each subcategory, identifying the mean, median, and 5th and 95th percentiles of the sum of those four distributions by simulation, and then finding the gamma distribution that matches the mean and 95th percentile of that distribution. The uncertainty distribution of the overall LOOP rate is not a gamma distribution, but matching the 95th percentile of the actual distribution has been found to be an effective procedure for modeling non-gamma-distributed random variables in SAPHIRE and is also recommended in Raughley and Lanik (2003).

For specific modeling of additional variation, the grid-related data were found to differ with regard to several possible breakdowns (site, grid, year, etc.) Differences in data from the 10 North American Electric Reliability Corporation (NERC) “reliability councils” (Figure 6) were selected as representative of this variation.[a] In the modeling described above, separate data were input for each reliability council. Table 3 reports the number of grid-related LOOPs in each of the 10 reliability councils. The large differences among reliability councils are due in large part to the three large grid-related events in 2003 and 2004 that affected multiple plants in the same reliability council.

For shutdown operation, all the historic data were used for all but the switchyard-related LOOPs. Here, the occurrences since deregulation were significantly fewer than the occurrence rate in the earlier period (p-value = 0.0001) so the 1997–2013 data were used. Additional variation was modeled for plant-centered LOOPs (plant differences) and weather-related loops (grid differences).

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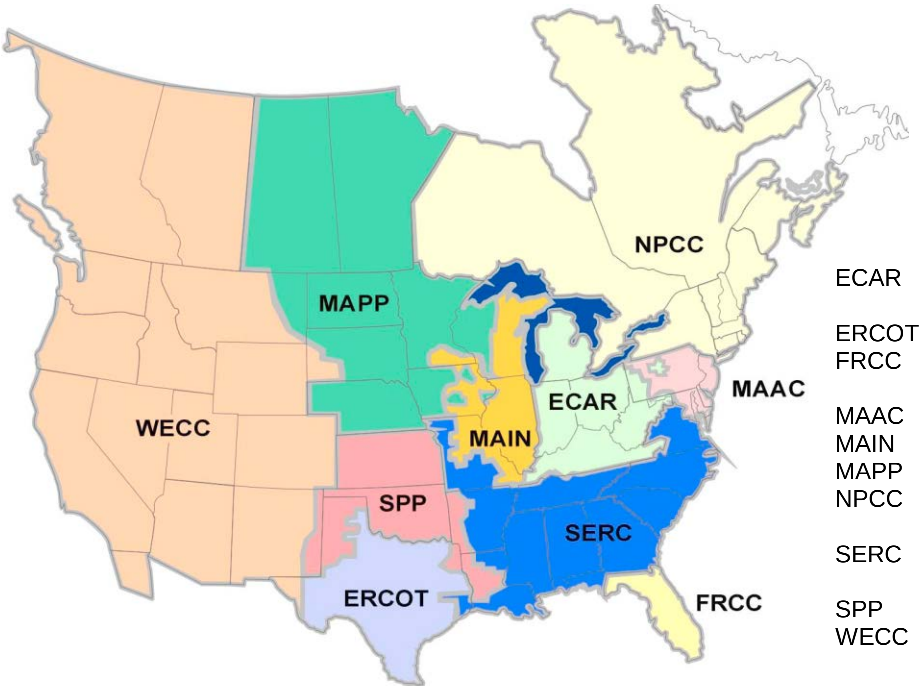
[a] The NERC now uses eight reliability councils (NERC 2015). For consistency with older data, events are split according to the previous 10 councils (see Figure 6).



ECAR = East Central Area Reliability Coordination Agreement
ERCOT = Electric Reliability Council of Texas
FRCC = Florida Reliability Coordinating Council
MAAC = Mid-Atlantic Area Council
MAIN = Mid-America Interconnected Network
MAPP = Mid-Continent Area Power Pool
NPCC = Northeastern Power Coordinating Council
SERC = Southeastern Electric Reliability Council
SPP = Southwest Power Pool
WECC = Western Electricity Coordinating Council.

Figure 6. NERC reliability council regions.

Table 3. Grid-related LOOP frequencies by reliability council (1997–2013).

Reliability Council[a]	Events	Reactor Critical Years	5%	Median	Mean	95%	MLE	Gamma Shape Parameter (α)	Gamma Scale Parameter (β, years)
ECAR	2	111.9	3.73E−03	1.38E−02	1.55E−02	3.39E−02	1.79E−02	2.90	187.18
ERCOT	0	62.3	1.39E−04	4.35E−03	6.56E−03	2.19E−02	0	0.90	137.61
FRCC	0	71.4	1.23E−04	4.08E−03	6.15E−03	2.06E−02	0	0.90	146.70
MAAC	4	203.9	6.46E−03	1.64E−02	1.76E−02	3.31E−02	1.96E−02	4.90	279.21
MAIN	0	228.1	3.02E−05	1.98E−03	2.98E−03	1.06E−02	0	0.90	303.35
MAPP	0	88.9	9.89E−05	3.65E−03	5.50E−03	1.87E−02	0	0.90	164.14
NPCC	7	167.1	1.37E−02	3.12E−02	3.26E−02	5.81E−02	4.19E−02	7.90	242.39
SERC	2	471.3	1.30E−03	4.71E−03	5.31E−03	1.15E−02	0	2.90	546.60
SPP	0	45.9	1.75E−04	4.95E−03	7.45E−03	2.46E−02	0	0.90	121.14
WECC	3	116.9	5.93E−03	1.86E−02	2.03E−02	4.17E−02	2.57E−02	3.90	192.20
Total	18	1567.7							

a. ECAR = East Central Area Reliability Coordination Agreement
ERCOT = Electric Reliability Council of Texas
FRCC = Florida Reliability Coordinating Council
MAAC = Mid-Atlantic Area Council
MAIN = Mid-America Interconnected Network
MAPP = Mid-Continent Area Power Pool
NPCC = Northeastern Power Coordinating Council
SERC = Southeastern Electric Reliability Council
SPP = Southwest Power Pool
WECC = Western Electricity Coordinating Council.

2. METHODS

This section has been added to provide additional information about the methods used to derive a satisfactory “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.

Atwood et al. (1996) derived the total LOOP frequency by summing the plant-centered, grid-related, switchyard-centered, and weather-related frequencies. Because 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, Idaho National Laboratory (INL) staff have searched for a more appropriate method to arrive at the total LOOP frequency. From 2009 to 2012, INL staff used an alternative method outlined below.

Markov chain Monte-Carlo, Metropolis-Hasting, and “burn-in” methods 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, INL staff have the most experience with WinBUGS and OpenBugs. WINBUGS is widely used in the statistical community.

The use of hierarchical Bayes methods are described in Section 8.3 of the *Handbook of Parameter Estimation for Probabilistic Risk Assessment* (Atwood et al. 2003). 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 Handbook applies directly, except that a more diffuse prior on beta [gamma(0.0001,0.0001) instead of gamma(0.0625,0.0625)] was used here. 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 distribution. Then, to get the overall LOOP rate, simulate and monitor

$$\lambda_{LOOP} = \lambda_P + \lambda_S + \lambda_{G,Reliabilty\ Council} + \lambda_W \tag{1}$$

for the critical operation data and

$$\lambda_{LOOP} = \lambda_{P,plant} + \lambda_S + \lambda_G + \lambda_{W,grid} \tag{2}$$

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, hierarchical Bayes 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. Up to 2012, INL staff believed that these new estimates were more appropriate than the estimates previously supplied in Atwood et al. (1996) and the two previous updates. The issue is once again under discussion by the INL statistics staff, and for the 2013 update, the methods of Atwood et al. (1996) have once again been employed.

3. 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 data for both operating modes. In addition, no significant differences exist within each LOOP category between the 1986–1996 and 1997–2013 data periods so the entire 1986–2013 period is applicable. This assumption will have to be revisited in the future; grid- and switchyard-related LOOP durations show a significant adverse trend since 1997, though the pre- and post-deregulation means are similar.

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

$$f(t) = \frac{1}{t\sqrt{2\pi}\sigma} e^{-\frac{1}{2}\left[\frac{\ln(t)-\mu}{\sigma}\right]} \tag{3}$$

$$F(t) = \Phi\left[\frac{\ln(t)-\mu}{\sigma}\right] \tag{4}$$

where

t = offsite power recovery time

σ = standard deviation of natural logarithms of data

μ = mean 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 Atwood et al. (1996). Note that the mean and median of the lognormal distributions, reported in the bottom two rows of Table 4, can be calculated from μ and σ, as $\exp(\mu + \sigma^2/2)$ and $\exp(\mu)$ respectively.

The corresponding curves are presented in Figure 7. Statistical analyses indicated that the critical operation and shutdown operation LOOP data were similar for each LOOP category so the duration information in Figure 7 is applicable to both types of operation.

Table 4. Lognormal fit parameters.[a]

	Plant-centered	Switchyard-centered	Grid-related	Weather-related	CombinedPlant-andSwitchyard-centered[b]
p-value	>0.16	>0.25	>0.25	>0.25	>0.12
Mu (μ)	−0.5507	−0.0184	0.6799	1.2849	−0.1771
Standard Error of μ	−0.2473	0.1715	0.2932	0.4449	0.1430
Sigma (σ)	1.4418	1.5344	1.2087	2.0869	1.5269
Standard Error of σ	0.1748	0.1213	0.2073	0.3146	0.1011
Curve Fit 95% (h)	6.179	12.251	14.414	111.936	10.325
Curve Fit Mean (h)	1.630	3.186	4.098	31.899	2.687
Curve Fit Median (h)	0.577	0.982	1.974	3.614	0.838

a. One LaCrosse and two Pilgrim events were excluded from these analyses. See Appendix A, Table A-1 of Atwood et al. (1996) for more information.

b. For plant risk models that combine the plant-centered and switchyard-centered LOOPs, this column should be used.

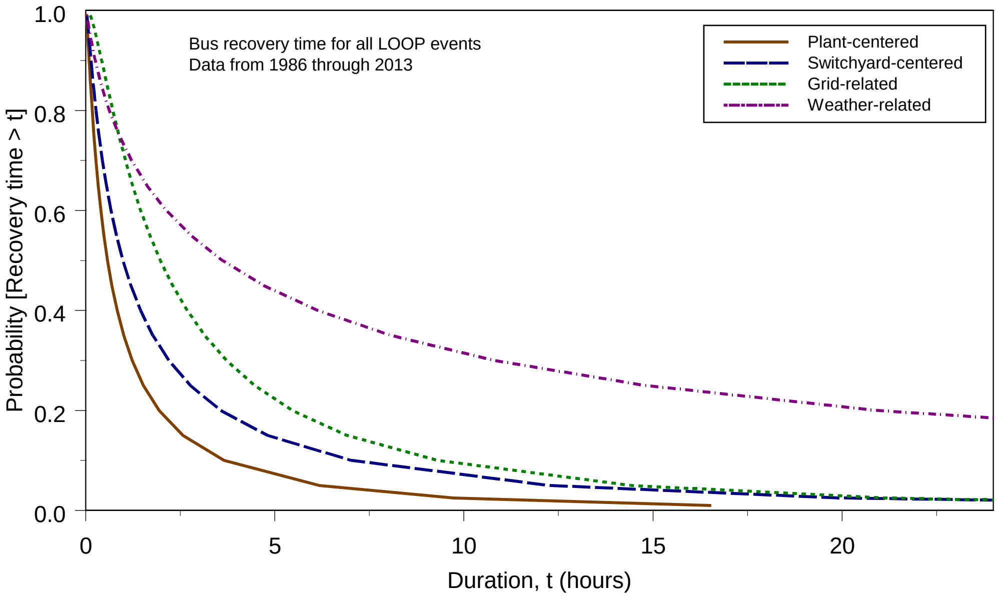


Figure 7. Probability of exceedance versus duration curves.

LOOP duration data for critical and shutdown operation over the entire period 1986–2013 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 1997–2013 data. However, if all of the LOOP data are combined, a statistically significant increasing trend in durations is observed over the period 1986–1996. The 1997–2013 duration data also exhibit a significant increasing trend, driven by the grid- and switchyard-based events. The results of this trending analysis are presented in Figure 8. The detailed results for the grid- and switchyard-based events are present in Figures 9 and 10. No significant trends in plant-centered or weather-related durations since 1997 were found.

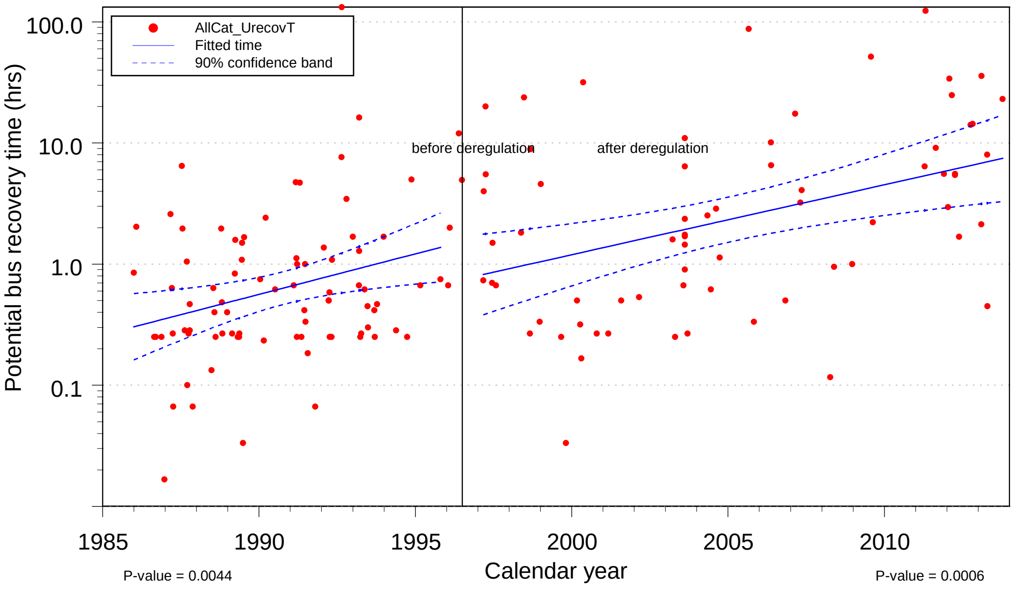


Figure 8. Trend plot of LOOP duration for 1986–1996 and 1997–2013 for critical and shutdown operation.

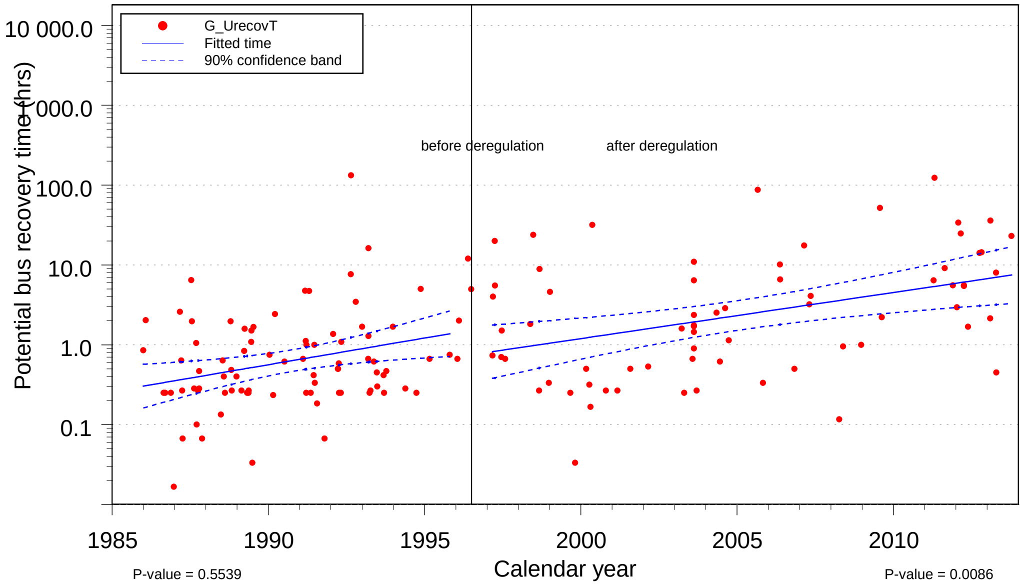


Figure 9. Trend plot of grid-based LOOP duration for 1986–1996 and 1997–2013.

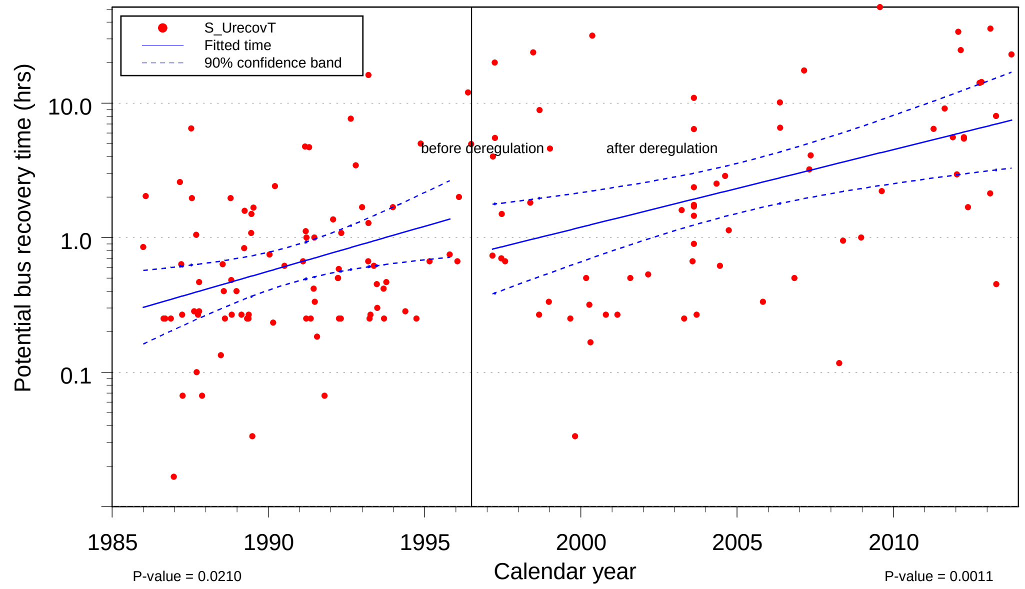


Figure 10. Trend plot of switchyard-based LOOP duration for 1986–1996 and 1997–2013.

4. EMERGENCY DIESEL GENERATOR REPAIR TIMES

Volume 2 of Atwood et al. (1996) presents information about the reliability of emergency diesel generators (EDGs.) Section 4 of Atwood et al. (1996) breaks down the unreliability of EDGs into four components: failure to start, failure to run for the first hour, failure to run in subsequent hours, and unavailability due to the component being offline (e.g., for routine maintenance) at the time of a demand. A detailed analysis of EDG unreliability trends is now provided in a standalone report. The most recent version of this report is Schroeder (2015), published in January 2015, reflecting field experience through calendar year 2013.

Section 5 of Atwood et al., (1996) presents information about EDG repair times. As noted in this report, there are very few data regarding recovery times in actual emergency situations. This question is approached by examining how many hours of unplanned unavailability have been reported for each EDG each month from 2004 to 2013 in the Mitigating Systems Performance Index data.

Atwood et al. (1996) fitted a Weibull distribution to the repair time data, and this same approach has been replicated in LOOP updates for several years. The best-fitting Weibull distribution to the 1206 reported unavailability durations was found by maximum likelihood to have shape parameter 0.697±.014 and scale parameter 19.15±0.81. This corresponds to a mean repair time of 24.3 hours with a standard deviation of 35.8 hours. The estimated probability of exceedance for any desired repair time using the Weibull model can be found in Excel using formula “= 1 − CDF(time,0.697,19.15,TRUE).” Selected exceedance probabilities are reported below in Table 5.

INL staff are currently investigating whether a Weibull distribution remains the best way to model the repair time distribution, and whether a trend in repair times exists over the past 10 years. (Preliminary results suggest that a lognormal distribution agrees more closely with the repair time data between 1 and 55 hours but does not model very short repair times well.)

Table 5. Probability of exceeding selected EDG repair times

Recovery Time (hr)	Weibull Model	Raw Mitigating Systems Performance Index Data
1	0.880	0.903
2	0.813	0.841
3	0.759	0.793
4	0.715	0.744
5	0.675	0.695
6	0.641	0.655
11.33		0.500
11.35	0.500	
12	0.486	0.475
24	0.311	0.262
36	0.212	0.182
48	0.150	0.120
56.6		0.100
63.4	0.100	

5. SPECIAL TOPICS

5.1 Seasonal Effects

Raughley and Lanik (2003) indicate that the more recent LOOPs (switchyard-centered and grid-related) occur mostly during the five summer months (May through September). This section analyzes each LOOP category over the periods 1986–1996 and 1997–2013 to identify seasonal differences between the two periods. Results for critical and shutdown operation are presented in Table 6. 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, 1997–2012, 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.

Table 6. *Plant-level LOOP events by season.*

		1986-1996				1997-2013				
		Summer (May–Sept.)		Non-summer		Summer (May–Sept.)		Non-summer		
Mode	**LOOP Category**	**Events**	**Mean Frequency**	**Events**	**Mean Frequency**	**Events**	**Mean Frequency**	**Events**	**Mean Frequency**	**Frequency Units**[a]
Critical Operation	Plant-centered	4	1.18E−02	6	1.31E−02	1	2.21E-03	2	2.81E-03	/rcry
	Switchyard-centered	11	3.01E-02	12	2.53E-02	11	1.69E-02	11	1.29E-02	/rcry
	Grid-related	2	6.54E−03	0	1.01E−03	17	2.58E-02	1	1.69E-03	/rcry
	Weather-related	2	6.54E−03	1	3.03E−03	3	5.15E-03	6	7.31E-03	/rcry
	All	19	5.10E−02	19	3.94E−02	32	4.79E-02	20	2.31E-02	/rcry
	Reactor critical years (rcry)	382.5		494.9		679.1		888.7		—
Shutdown Operation	Plant-centered	7	7.29E−02	9	5.38E−02	2	4.30E-02	5	4.10E-02	/rsy
	Switchyard-centered	11	1.12E-01	20	1.16E-01	2	4.30E-02	11	8.58E-02	/rsy
	Grid-related	1	1.46E−02	0	2.83E−03	3	6.02E-02	1	1.12E-02	/rsy
	Weather-related	2	2.43E−02	7	4.25E−02	4	7.73E-02	4	3.36E-02	/rsy
	All	21	2.09E−01	36	2.07E−01	11	1.98E-01	21	1.60E-01	/rsy
	Reactor shutdown years (rsy)	102.8		176.5		58.2		134.1		—

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

5.2 Multi-Unit Site Considerations

Among the 170 LOOP plant-level events considered in this study, there were 16 occurrences involving more than one plant at a site resulting from the same event (33 plant-centered events over a 24-hr period) and 137 single-LOOP occurrences. The multi-unit events are listed in chronological order in Table 7. Thirteen of these events involved two plants, one event (Palo Verde on June 14, 2004) involved all three plants at the site, and one event (Browns Ferry on April 27, 2011) caused the trip of two of the three units.

The analysis in this chapter has not yet been updated to include the multi-unit LOOP caused by lightning at LaSalle on April 17, 2013 (i.e., "1986–2012" in the title of Table 7 is not a typographical error).

Table 7. LOOP events (1986–2012) 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
2	Peach Bottom	7/29/1988	2	2	Switchyard-centered	Shutdown Operation
3	Turkey Point	8/24/1992	2	2	Weather-related	Shutdown Operation[a]
4	Sequoyah	12/31/1992	2	2	Switchyard-centered	Critical Operation
5	Brunswick	3/16–3/17/1993	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/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[a]
13	Catawba	5/20/2006	2	2	Switchyard-centered	Critical Operation
14	Surry	4/16/2011	2	2	Weather-related	Critical Operation
15	Browns Ferry	4/27/2011	3	2	Weather-related	Critical Operation[b]
16	North Anna	8/23/2011	2	2	Grid-related	Critical Operation
	Total		**34**	**33**		

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

b. This event was treated as though all three units experienced a LOOP, although a 161-kV offsite power line remained available for Browns Ferry 3. The unit responded as though it, too, had experience a LOOP.

Of the single-unit LOOPs, 78 occurred at sites with more than one plant. For LOOP purposes, Fitzpatrick and Nine Mile Point 1 are considered a dual-unit site and Nine Mile Point 2 is a single-unit site. The three-unit sites (starting with the data in 1986) are Browns Ferry, Oconee, Palo Verde, San Onofre, Millstone, and Hope Creek/Salem (considered a three-unit site for LOOP purposes). Currently, San Onofre and Millstone are two-unit sites. Since 1986, there have been 31 two-unit sites (30 still operating) and 34 single-unit sites (28 still operating).

Table 8 contains conditional probabilities of other plants at a multi-plant site experiencing a LOOP given a LOOP at a particular plant being analyzed. The table has two sections: one for LOOP-category "specific" estimates and one for general LOOP estimates based on plant state. Separate methods were used to develop the estimates for the two sections. In the first part of the table, events were tallied based on whether multiple LOOPs occurred. However, not all the observed single-LOOP events contribute because the "given" condition is on a specific plant. For example, consider a two-unit plant. On average, only half of the single-unit LOOPs would affect Unit 2. For those particular demands, the fact that Unit 1 did not have a LOOP represents a success. The other single-unit demands (the single-unit demands on Unit 1) would not be relevant because they do not deal with Unit 2 and are not part of the given conditions. Making the condition "specific" thus reduces the number of successes used to estimate the failure probability. For three-unit sites, one-third of the single-LOOP events were counted as successes for the probability of the other units failing. Fractional demands appear in the table because of these considerations.

One other detail of this update is that it includes the first observed LOOP at a multi-unit site that did not fully affect all units at that site. The "unaffected unit" did experience the LOOP, but one 161-kV offsite power source remained in service. Until more events that cause a LOOP at some but not all units occur, the calculations will not attempt to factor in the remaining active unit. This event was treated as a LOOP at all three units to simplify the probability estimates.

For the second section of Table 8, probabilities are simulated for each of the four LOOP categories using the beta distributions in the first section of the table. Then LOOP frequencies for each LOOP category are simulated for critical operations using the four gamma distributions in the top part of Table 2. A weighted average LOOP probability for critical operations is calculated, with weights based on the LOOP frequencies. More specifically, the average is the sum over the four LOOP categories of the simulated multiple-LOOP probability for a category multiplied by the simulated frequency for that category divided by the sum of the frequencies. The simulation was repeated 100,000 times. The results were fitted to a beta distribution using the "Univariate" SAS procedure, which fits the distribution by seeking parameters that maximize the likelihood of getting the simulated data. The same method was used to calculate the distribution for shutdown operations, except that the weights for the probabilities were computed using samples from the gamma distributions in the bottom half of Table 2.

The conditional probabilities for the other units experiencing a LOOP at a multiple-unit site given a LOOP at a particular site range from 6.8E−02 for plant-centered LOOPs to 6.9E−01 for grid-related LOOPs. The probabilities are considered to apply to all multiple-unit sites. For example, if a site has three plants and one plant experiences a grid-related LOOP, then a point estimate of the probability that the other two plants also experience the same grid-related LOOP is 0.69 from the table. The estimates in the second section of the table are only to be used when the risk model does not distinguish the individual LOOP categories.

Table 8. *Conditional probability of all plants at a site experiencing a LOOP given a LOOP at the specific plant being analyzed.*

LOOP Category	**Number of LOOP Events Affecting all Plants at a Multi-Plant Site**	**Number of "Specific" LOOP Events at Multi-Plant Sites**	**Conditional Probability of All Plants at a Multi-Plant Site Experiencing a LOOP Given a LOOP at a Particular Plant at the Site**				**Beta Distribution Parameters**	
			5%	**Median**	**Mean**	**95%**	**α**	**β**
By LOOP Category[a]								
Plant-centered	0	8.33	1.28E−04	4.21E−02	6.82E−02	2.67E−01	0.69	9.40
Switchyard-centered	5	27.67	8.69E−02	1.86E−01	1.93E−01	3.25E−01	5.69	23.74
Grid-related	5	6.50	3.84E−01	7.05E−01	6.89E−01	9.26E−01	5.69	2.57
Weather-related	6	8	4.10E−01	6.99E−01	6.85E−01	9.08E−01	6.69	3.07
By Plant Mode[b]								
All categories, critical operation	12[c]	27.33[c]	9.36E−02	2.35E−01	2.39E−01	4.20E−01	10.67	33.99
All categories, shutdown operation	4	23.17	2.23E−01	3.81E−01	3.82E−01	5.54E−01	18.68	30.15

a. In the first four rows, the mean is the mean from a Bayesian update of the Jeffreys non-informative prior $\frac{(0.5+events)}{(1+total\ events)}$. The total events are fractional. A single-LOOP event is considered as, on the average, a demand of 0.5 for each unit at a two-unit site and as a demand of 0.333 for each unit at a three-unit site. Since the "given" unit is one unit, the fractional demands are summed instead of the actual counts for single-unit LOOPs. The remaining LOOPs affected all the units at a site, including the specific unit. The data are generally not homogeneous. In accordance with the methodology of Atwood et al. (1996) (Volume 1, Appendix C), CNID beta distributions were selected to represent the uncertainties.

b. All-category distributions were obtained by simulation using the category-specific distributions in the first rows of this table weighted by the plant mode-specific LOOP occurrence frequencies in Table 2. The simulation results were fitted to smooth distributions using the "univariate" SAS Procedure.

c. The event with one plant operating and one in shutdown operations was treated as operating for this count.

6. 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. Figure 11 is a breakdown of equipment failures and shows that transformers dominate the results. Figure 12 presents a breakdown of human error events, in which maintenance activities contribute the largest fraction. Finally, Figure 13 shows lightning caused the most weather-related LOOP events.

These data have been aggregated from 1986 to the present, with seven new events added for calendar year 2013. The question of whether the breakdown has changed over time has not been investigated recently. One of the 2013 extreme weather events was coded in the database as “snow and wind.” This has been counted as a snow event, not a high wind event, for the purposes of Figure 13 rather than creating a new column or double-counting this event.

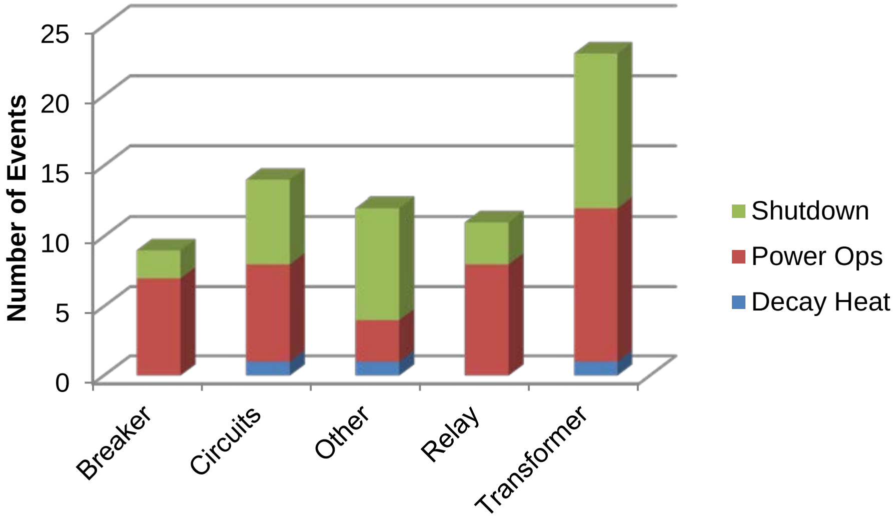


Figure 11. LOOP due to equipment failure by cause, 1986–2013.

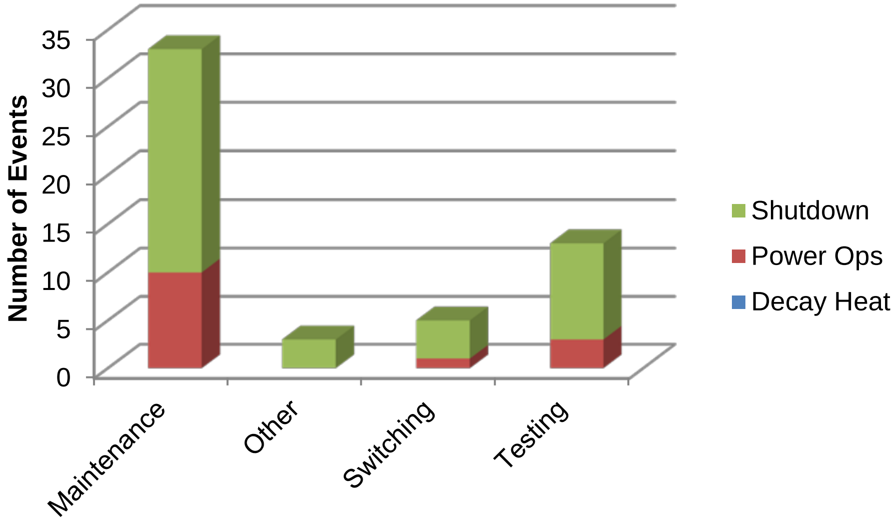


Figure 12. LOOP due to human error by type, 1986–2013.

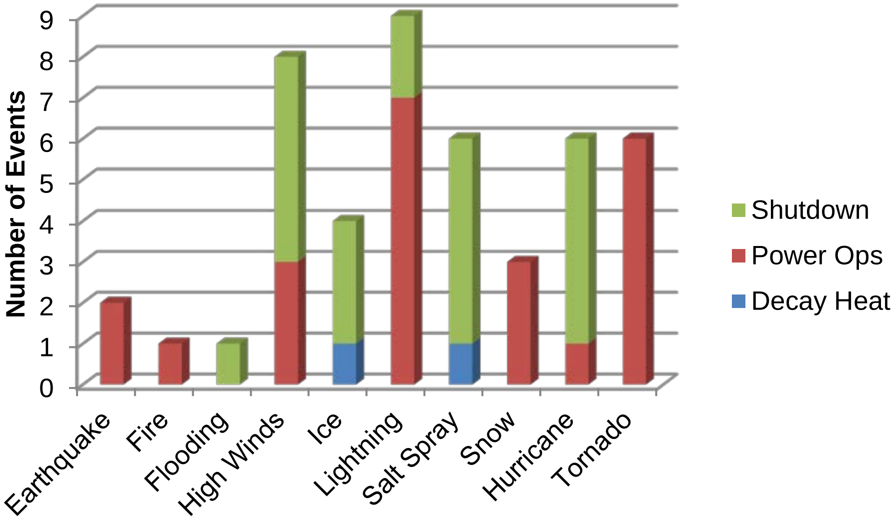


Figure 13. LOOP due to weather by cause, 1986–2013.

7. REFERENCES

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Appendix A
Data Tables

Appendix A
Data Tables

Table A-1. Plot data for plant-centered trend plot (Figure 1)

	Plot Trend Error Bar Points			Regression Curve Data Points		
FY	**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	8.38E−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	3.57E−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	6.00E−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	1.13E−05	4.22E−04	1.57E−02
1998	0.00E+00	0.00E+00	3.55E−02	1.75E−05	4.93E−04	1.39E−02
1999	0.00E+00	0.00E+00	3.30E−02	2.69E−05	5.75E−04	1.23E−02
2000	5.52E−04	1.08E−02	5.11E−02	4.12E−05	6.71E−04	1.09E−02
2001	0.00E+00	0.00E+00	3.19E−02	6.27E−05	7.82E−04	9.76E−03
2002	0.00E+00	0.00E+00	3.16E−02	9.46E−05	9.13E−04	8.81E−03
2003	0.00E+00	0.00E+00	3.23E−02	1.41E−04	1.06E−03	8.05E−03
2004	0.00E+00	0.00E+00	3.16E−02	2.06E−04	1.24E−03	7.48E−03
2005	0.00E+00	0.00E+00	3.19E−02	2.95E−04	1.45E−03	7.12E−03
2006	0.00E+00	0.00E+00	3.18E−02	4.08E−04	1.69E−03	7.02E−03
2007	0.00E+00	0.00E+00	3.12E−02	5.37E−04	1.97E−03	7.25E−03
2008	0.00E+00	0.00E+00	3.14E−02	6.64E−04	2.30E−03	7.98E−03
2009	0.00E+00	0.00E+00	3.18E−02	7.65E−04	2.69E−03	9.42E−03
2010	0.00E+00	0.00E+00	3.14E−02	8.24E−04	3.13E−03	1.19E−02
2011	0.00E+00	0.00E+00	3.23E−02	8.37E−04	3.65E−03	1.60E−02
2012	5.70E−04	1.11E−02	5.27E−02	8.14E−04	4.26E−03	2.23E−02
2013	5.62E−04	1.10E−02	5.20E−02	7.68E−04	4.97E−03	3.22E−02

Table A-2. Plot data for switchyard-centered trend plot (Figure 2)

	Plot Trend Error Bar Points			Regression Curve Data Points		
FY	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	3.62E−02	6.26E−02
1989	1.08E−02	3.95E−02	1.02E−01	1.99E−02	3.21E−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	3.57E−02	9.24E−02	1.59E−02	2.53E−02	4.03E−02
1992	9.78E−03	3.59E−02	9.27E−02	1.33E−02	2.24E−02	3.79E−02
1993	1.65E−02	4.82E−02	1.10E−01	1.07E−02	1.99E−02	3.68E−02
1994	0.00E+00	0.00E+00	3.49E−02	8.54E−03	1.76E−02	3.64E−02
1995	0.00E+00	0.00E+00	3.37E−02	6.71E−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	2.18E−03	6.53E−03	1.96E−02
1998	0.00E+00	0.00E+00	3.55E−02	2.59E−03	7.10E−03	1.95E−02
1999	5.65E−04	1.10E−02	5.23E−02	3.08E−03	7.73E−03	1.94E−02
2000	0.00E+00	0.00E+00	3.22E−02	3.65E−03	8.41E−03	1.94E−02
2001	5.46E−04	1.06E−02	5.05E−02	4.31E−03	9.15E−03	1.94E−02
2002	5.41E−04	1.05E−02	5.00E−02	5.06E−03	9.95E−03	1.96E−02
2003	3.84E−03	2.16E−02	6.80E−02	5.90E−03	1.08E−02	1.99E−02
2004	5.40E−04	1.05E−02	5.00E−02	6.82E−03	1.18E−02	2.04E−02
2005	0.00E+00	0.00E+00	3.19E−02	7.78E−03	1.28E−02	2.11E−02
2006	8.67E−03	3.18E−02	8.22E−02	8.73E−03	1.40E−02	2.23E−02
2007	0.00E+00	0.00E+00	3.12E−02	9.61E−03	1.52E−02	2.40E−02
2008	5.37E−04	1.05E−02	4.97E−02	1.03E−02	1.65E−02	2.64E−02
2009	5.44E−04	1.06E−02	5.03E−02	1.09E−02	1.80E−02	2.96E−02
2010	0.00E+00	0.00E+00	3.14E−02	1.13E−02	1.96E−02	3.38E−02
2011	0.00E+00	0.00E+00	3.23E−02	1.16E−02	2.13E−02	3.91E−02
2012	1.52E−02	4.44E−02	1.02E−01	1.18E−02	2.32E−02	4.56E−02
2013	2.16E−02	5.48E−02	1.15E−01	1.19E−02	2.52E−02	5.35E−02

Table A-3. Plot data for grid-related trend plot (Figure 3)

	Plot Trend Error Bar Points			**Regression Curve Data Points**		
FY	**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	4.94E−02
1987	0.00E+00	0.00E+00	4.27E−02	3.14E−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	5.26E−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	5.67E−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	6.79E−05	1.51E−03	3.35E−02
1997	1.58E−05	4.09E−03	1.57E−02	1.65E−03	4.37E−03	1.16E−02
1998	1.53E−05	3.94E−03	1.52E−02	1.89E−03	4.60E−03	1.12E−02
1999	1.46E−05	3.76E−03	1.44E−02	2.17E−03	4.85E−03	1.09E−02
2000	1.43E−05	3.70E−03	1.42E−02	2.46E−03	5.11E−03	1.06E−02
2001	1.42E−05	3.67E−03	1.41E−02	2.79E−03	5.39E−03	1.04E−02
2002	1.41E−05	3.64E−03	1.40E−02	3.12E−03	5.68E−03	1.03E−02
2003	4.21E−02	7.78E−02	1.22E−01	3.45E−03	5.98E−03	1.04E−02
2004	7.79E−03	2.55E−02	5.15E−02	3.75E−03	6.30E−03	1.06E−02
2005	1.42E−05	3.67E−03	1.41E−02	4.00E−03	6.64E−03	1.10E−02
2006	1.42E−05	3.66E−03	1.41E−02	4.18E−03	7.00E−03	1.17E−02
2007	1.40E−05	3.61E−03	1.39E−02	4.29E−03	7.37E−03	1.27E−02
2008	1.41E−05	3.63E−03	1.40E−02	4.32E−03	7.77E−03	1.40E−02
2009	1.27E−03	1.10E−02	2.87E−02	4.30E−03	8.19E−03	1.56E−02
2010	1.41E−05	3.63E−03	1.39E−02	4.23E−03	8.63E−03	1.76E−02
2011	4.19E−03	1.85E−02	4.12E−02	4.13E−03	9.09E−03	2.00E−02
2012	1.31E−03	1.13E−02	2.96E−02	4.02E−03	9.58E−03	2.29E−02
2013	1.30E−03	1.12E−02	2.93E−02	3.88E−03	1.01E−02	2.62E−02

Table A-4. Plot data for weather-related trend plot (Figure 4)

	Plot Trend Error Bar Points			Regression Curve Data Points		
FY	**Lower (5%)**	**MLE**	**Upper (95%)**	**Lower (5%)**	**MLE**	**Upper (95%)**
1986	0.00E+00	0.00E+00	4.79E−02	5.71E−09	1.95E−05	6.63E−02
1987	0.00E+00	0.00E+00	4.27E−02	2.72E−08	3.83E−05	5.41E−02
1988	0.00E+00	0.00E+00	3.95E−02	1.29E−07	7.54E−05	4.42E−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	2.92E−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	2.98E−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	3.46E−04	2.14E−03	1.32E−02
1998	6.08E−04	1.18E−02	5.62E−02	4.45E−04	2.38E−03	1.27E−02
1999	0.00E+00	0.00E+00	3.30E−02	5.72E−04	2.64E−03	1.22E−02
2000	0.00E+00	0.00E+00	3.22E−02	7.31E−04	2.94E−03	1.18E−02
2001	5.46E−04	1.06E−02	5.05E−02	9.30E−04	3.27E−03	1.15E−02
2002	0.00E+00	0.00E+00	3.16E−02	1.18E−03	3.64E−03	1.12E−02
2003	0.00E+00	0.00E+00	3.23E−02	1.47E−03	4.04E−03	1.11E−02
2004	5.40E−04	1.05E−02	5.00E−02	1.82E−03	4.49E−03	1.11E−02
2005	0.00E+00	0.00E+00	3.19E−02	2.21E−03	5.00E−03	1.13E−02
2006	0.00E+00	0.00E+00	3.18E−02	2.62E−03	5.56E−03	1.18E−02
2007	0.00E+00	0.00E+00	3.12E−02	3.01E−03	6.18E−03	1.27E−02
2008	0.00E+00	0.00E+00	3.14E−02	3.34E−03	6.87E−03	1.41E−02
2009	5.44E−04	1.06E−02	5.03E−02	3.58E−03	7.64E−03	1.63E−02
2010	0.00E+00	0.00E+00	3.14E−02	3.73E−03	8.50E−03	1.94E−02
2011	2.13E−02	5.40E−02	1.14E−01	3.79E−03	9.45E−03	2.36E−02
2012	0.00E+00	0.00E+00	3.33E−02	3.78E−03	1.05E−02	2.92E−02
2013	0.00E+00	0.00E+00	3.28E−02	3.73E−03	1.17E−02	3.66E−02

Table A-5. Plot data for all LOOPs combined trend plot (Figure 5)

	Plot Trend Error Bar Points			Regression Curve Data Points		
FY	**Lower (5%)**	**MLE**	**Upper (95%)**	**Lower (5%)**	**MLE**	**Upper (95%)**
1986	1.31E−02	4.80E−02	1.24E−01	3.89E−02	7.08E−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	4.23E−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	5.37E−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	6.03E−03	2.64E−02	5.84E−02	4.49E−03	1.49E−02	4.96E−02
1998	1.77E−03	1.51E−02	3.93E−02	5.22E−03	1.56E−02	4.68E−02
1999	1.66E−03	1.42E−02	3.70E−02	6.04E−03	1.64E−02	4.44E−02
2000	1.63E−03	1.39E−02	3.62E−02	6.96E−03	1.72E−02	4.23E−02
2001	5.25E−03	2.30E−02	5.08E−02	7.96E−03	1.80E−02	4.06E−02
2002	1.60E−03	1.37E−02	3.56E−02	9.02E−03	1.88E−02	3.93E−02
2003	6.78E−02	1.16E−01	1.75E−01	1.01E−02	1.97E−02	3.85E−02
2004	2.08E−02	5.01E−02	8.96E−02	1.11E−02	2.06E−02	3.83E−02
2005	1.80E−05	4.59E−03	1.76E−02	1.20E−02	2.16E−02	3.90E−02
2006	9.91E−03	3.20E−02	6.44E−02	1.26E−02	2.26E−02	4.07E−02
2007	1.77E−05	4.50E−03	1.73E−02	1.30E−02	2.37E−02	4.34E−02
2008	1.59E−03	1.36E−02	3.54E−02	1.30E−02	2.48E−02	4.74E−02
2009	9.91E−03	3.20E−02	6.44E−02	1.28E−02	2.60E−02	5.27E−02
2010	1.78E−05	4.53E−03	1.74E−02	1.25E−02	2.72E−02	5.95E−02
2011	3.37E−02	6.97E−02	1.16E−01	1.20E−02	2.85E−02	6.78E−02
2012	2.80E−02	6.19E−02	1.07E−01	1.15E−02	2.99E−02	7.79E−02
2013	3.42E−02	7.06E−02	1.18E−01	1.09E−02	3.13E−02	9.00E−02