NUREG/CR-
INEEL/EXT-04-02326

October 2004

Evaluation of Loss of Offsite Power Events at Nuclear Power Plants: 1986 – 2003 (Draft)

S.A. Eide, INEEL
C.D. Gentillon, INEEL
T.E. Wierman, INEEL
D.M. Rasmuson, NRC

NUREG/CR-
INEEL/EXT-04-02326

Evaluation of Loss of Offsite Power Events at Nuclear Power Plants: 1986 – 2003 (Draft)

S.A. Eide, INEEL
C.D. Gentillon, INEEL
T.E. Wierman, INEEL
D.M. Rasmuson, NRC

Manuscript Completed: October 2004

Idaho National Engineering and Environmental Laboratory
Risk, Reliability, & Regulatory Support Department
Idaho Falls, Idaho 83415

Prepared for the
Division of Risk Analysis & Applications
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555
Job Code Y6546

ABSTRACT

This report is an update of two previous reports analyzing loss of offsite power (LOOP) events at U.S. commercial nuclear power plants. LOOP data over the period 1986 – 2003 were collected and analyzed. Frequency and duration estimates for critical and shutdown operations were generated for five categories of LOOPs: plant centered, switchyard centered, grid related, severe weather related, and extreme weather related. Overall, LOOP frequencies during critical operation have decreased significantly in recent years, while LOOP durations have increased. Various additional topics of interest were also addressed. These topics include comparisons with results from other studies; seasonal impacts on LOOP frequencies, consequential LOOPs, and others. Finally, additional engineering analyses of the LOOP data were presented. This information is needed in probabilistic risk assessment models of U.S. commercial nuclear power plants to accurately model current risk from LOOP and associated station blackout scenarios.

Contents

Appendices

FIGURES

TABLES

EXECUTIVE SUMMARY

The availability of alternating current (AC) power to commercial nuclear power plants is essential for safe operations and accident recovery. Unavailability of AC power can have a major negative impact on a power plant's ability to achieve and maintain safe shutdown conditions. This AC power normally is supplied by offsite power sources (from the electrical grid to which the plant is connected). Therefore, loss of offsite power (LOOP, but also referred to as LOSP) and subsequent restoration of offsite power are important inputs to plant probabilistic risk assessments (PRAs). These inputs need to reflect current industry performance in order for PRAs to accurately estimate the risk from LOOP initiated scenarios.

Selected previous reports analyzing data on LOOP and/or offsite power restoration include NUREG-1032, NUREG/CR-5496, NUREG/CR-5750, and various annual or biennial Electric Power Research Institute (EPRI) technical reports. NUREG-1032, *Evaluation of Station Blackout Accidents at Nuclear Power Plants*, evaluated LOOP data from U.S. commercial nuclear reactors over the period 1968 – 1985. NUREG/CR-5496, *Evaluation of Loss of Offsite Power Events at Nuclear Power Plants: 1980 – 1996*, looked at data from 1980 –1996. A more general report, NUREG/CR-5750, *Rates of Initiating Events at U.S. Nuclear Power Plants: 1987 – 1995* covered a wide variety of initiating events including LOOP for the period 1987 – 1995. Finally, EPRI reports covering LOOP events have been issued periodically. The latest EPRI report covers LOOP events from 1994 – 2003.

The present report is patterned after NUREG/CR-5496 but covers the data period 1986 – 2003. The year 1986 was chosen as the initial year in order to start where NUREG-1032 stopped. The extension of coverage from 1997 – 2003 (compared with NUREG/CR-5496) is especially noteworthy because of deregulation of the electrical industry, considered to start around 1997, and resultant changes to electrical grid operation. Therefore, special attention is given in this report to the analysis of LOOP before deregulation (up through 1996) and after the start of deregulation (1997 and on). A separate report, NUREG-1784, *Operating Experience Assessment – Effects of Grid Events on Nuclear Power Plant Performance*, focuses on a subset of LOOP events and the effects of deregulation of the electrical industry on such events. That report contains more detailed engineering information concerning deregulation and its effects on the electrical grid and related LOOP events.

The scope of this study is the statistical and engineering analysis of LOOP frequencies and durations. Data coverage includes performance of U.S. commercial nuclear reactors over the period 1986 – 2003. The data cover both critical (at power) and shutdown operations at these plants. Partial LOOP events, in which not all offsite power lines to the plant are lost or not all offsite power to safety buses is lost, are not covered in this report.

LOOP industry frequencies were determined for each of five LOOP event categories: plant centered, switchyard centered, grid related, severe weather related, and extreme weather related. Also, these frequencies were subdivided into results for critical and shutdown operation. Results are summarized in Figure ES-1. (Plant specific LOOP frequencies are presented in Appendix D.) For critical operation, grid-related LOOPs contribute 50% to the total frequency of 3.3E-2/rcry, while switchyard-centered LOOPs contribute 26%. The remaining three categories of LOOPs have frequency contributions ranging from 7 to 9%. For shutdown operation, switchyard-centered LOOPs contribute 54% to the total frequency of 1.9E-1/rsy, while plant-centered LOOPs contribute 27%.

A comparison of the current results with those from the previous studies is presented in Figure ES-2. For critical operation, the overall LOOP frequency has decreased from 1.1E-1/rcry (NUREG-1032) to 5.8E-2/rcry (NUREG/CR-5496) to the current estimate of 3.3E-2/rcry. In addition, the relative contributions of the five categories of LOOPs have changed significantly. However, the shutdown operation overall LOOP frequency has remained essentially constant at 1.9E-1/rsy.

				LOOP Frequency		
Mode	**LOOP Category**	**Data Group**	**Events**	**Reactor Critical or Shutdown Years**	**Mean Frequency**	**Frequency Units (note a)**
Critical operation	Plant centered	1997 - 2003	1	629.5	2.4E-03	/rcry
	Switchyard centered	1997 - 2003	5	629.5	8.7E-03	/rcry
	Grid related	1997 - 2003	10	629.5	1.7E-02	/rcry
	Severe weather related	1986 - 2003	4	1508.8	3.0E-03	/rcry
	Extreme weather related	1986 - 2003	3	1508.8	2.3E-03	/rcry
	All	Several			3.3E-02	/rcry
Shutdown operation	Plant centered	1986 - 2003	19	378.1	5.2E-02	/rsy
	Switchyard centered	1986 - 2003	38	378.1	1.0E-01	/rsy
	Grid related	1986 - 2003	3	378.1	9.3E-03	/rsy
	Severe weather related	1986 - 2003	9	378.1	2.5E-02	/rsy
	Extreme weather related	1986 - 2003	0	378.1	1.3E-03	/rsy
	All	1986 - 2003			1.9E-01	/rsy

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

Figure ES-1. LOOP frequencies.

		This Report (1986 - 2003)		NUREG/CR-5496 (1980 - 1996)	NUREG-1032 (1968 - 1985)
Mode	**LOOP Category**	**Mean Frequency**	**Frequency Units (note a)**	**Mean Frequency**	**Mean Frequency**
Critical operation	Plant centered	2.4E-03	/rcry	4.4E-02	8.7E-02
	Switchyard centered	8.7E-03	/rcry	Included in plant-centered category	Included in plant-centered category
	Grid related	1.7E-02	/rcry	2.9E-03	1.8E-02
	Severe weather related	3.0E-03	/rcry	1.2E-02	9.0E-03
	Extreme weather related	2.3E-03	/rcry	Included in severe-weather-related category	2.0E-03
	All	3.3E-02	/rcry	5.8E-02	1.1E-01
Shutdown operation	Plant centered	5.2E-02	/rsy	1.8E-01	Shutdown not covered
	Switchyard centered	1.0E-01	/rsy	Included in plant-centered category	Shutdown not covered
	Grid related	9.3E-03	/rsy	3.3E-03	Shutdown not covered
	Severe weather related	2.5E-02	/rsy	1.2E-02	Shutdown not covered
	Extreme weather related	1.3E-03	/rsy	Included in severe-weather-related category	Shutdown not covered
	All	1.9E-01	/rsy	1.9E-01	Shutdown not covered

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

Figure ES-2. LOOP frequency comparison with previous reports.

The August 14, 2003 grid blackout event that resulted in LOOPs at nine plants was included in the frequency estimates in this report. No other event of this magnitude has occurred over the entire period 1968 – 2003. We cannot predict how often this type of event might occur in the future. If the August 14, 2003 event is an outlier and will not be repeated, then the grid-related frequency presented in this report is an overestimation. (If that event had not occurred, the overall LOOP frequency for critical operation would have been 2.0E-2/rcry rather than 3.3E-2/rcry.) However, if such events continue to occur in the future, then the frequency presented in this report may be an underestimation. Grid-related LOOP events need to be monitored for the next few years to determine if the industry performance characterized in this report remains representative.

LOOP duration data were also analyzed. Probabilities of exceedance versus duration are summarized in Figure ES-3 for each of the five LOOP categories. As an example from Figure ES-3, there is a 0.14 probability, given a plant-centered LOOP, that the duration will be longer than one hour. In contrast, given a grid-related LOOP, the corresponding probability is 0.62. Also presented in Figure ES-3 are the summary statistics such as the mean and median durations. The mean duration of a plant-centered LOOP is 0.5 hours, and the mean duration for grid-related LOOPs is 2.7 hours. The corresponding curves are presented in Figure ES-4. Statistical analyses indicated that the critical operation and shutdown operation LOOP data were similar for each LOOP category, so the duration information in Figure ES-3 and Figure ES-4 is applicable to both types of operation.

	Probability of Exceedance				
	LOOP Category (Critical or Shutdown Operation)				
Duration (h)	**Plant Centered**	**Switchyard Centered**	**Grid Related**	**Severe Weather Related**	**Extreme Weather Related**
0.0	1.00	1.00	1.00	1.00	1.00
0.1	0.73	0.88	0.96	0.81	1.00
0.2	0.52	0.74	0.89	0.70	1.00
0.5	0.28	0.53	0.76	0.56	1.00
1.0	0.14	0.36	0.62	0.46	1.00
1.5	0.08	0.26	0.51	0.40	1.00
2.0	0.05	0.20	0.43	0.36	0.99
3.0	0.02	0.12	0.30	0.30	0.99
4.0	0.01	0.07	0.22	0.25	0.99
6.0	0.00	0.03	0.12	0.19	0.98
8.0	0.00	0.02	0.07	0.16	0.96
10.0	0.00	0.01	0.04	0.13	0.95
12.0	0.00	0.00	0.02	0.11	0.94
16.0	0.00	0.00	0.01	0.08	0.91
20.0	0.00	0.00	0.00	0.07	0.88
24.0	0.00	0.00	0.00	0.05	0.85
Curve Fit 95% (h)	2.0	5.0	9.3	25.1	187.4
Curve Fit Mean (h)	0.5	1.3	2.7	5.4	78.0
Actual Data Mean (h)	0.5	1.3	2.7	4.7	77.9
Curve Fit Median (h)	0.2	0.6	1.6	0.8	65.9
Curve Fit 5% (h)	0.0	0.0	0.1	0.0	10.3

Figure ES-3. LOOP probability of exceedance versus duration curve fits and summary statistics.

LOOP duration results were also compared with previous reports. Results are summarized in Figure ES-5. LOOP durations have increased compared with results from NUREG-1032 (1968 – 1985), but are similar to those from NUREG/CR-5486 (1980 – 1996). For plant-centered and switchyard-centered LOOPs, the average duration for 1986 – 2003 is 1.05 hours, compared with the NUREG-1032 result of 0.45 hour for 1968 – 1985. For grid-related LOOPs, the mean durations are 2.72 and 1.24 hours,

respectively. Finally, for severe- and extreme-weather related LOOPs, the mean duration for 1986 – 2003 is 16.0 hours, compared with 4.64 hours for 1968 – 1985.

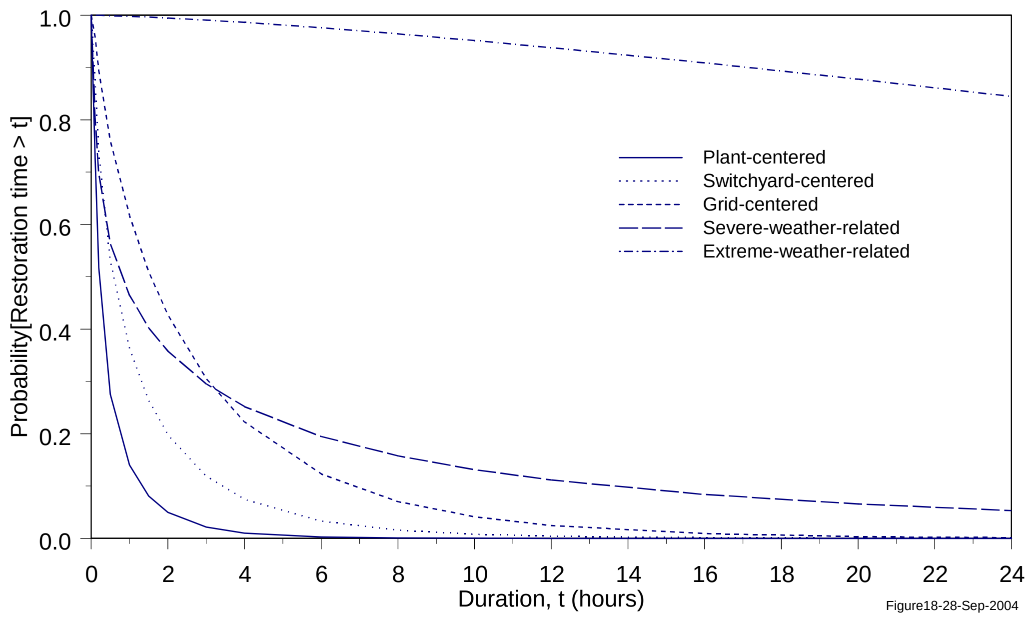


Figure ES-4. Probability of exceedance versus duration curves.

LOOP Category	Summary Statistic	Present Study	NUREG/CR-5496	NUREG-1032	Comments
Plant Centered (including switchyard centered)	Data Period	1986 - 2003	1980 - 1996	1968 - 1985	
	Median Duration (h) (Actual Data)	0.38	0.33	0.26	Present study excluded Diablo Canyon event as an outlier.
	Mean Duration (h) (Actual Data)	1.05	1.22	0.45	Present study excluded Diablo Canyon event as an outlier.
	Type of Fit	Weibull	Lognormal	Weibull	NUREG/CR-5496 excluded momentary events in the curve fit.
Grid Related	Data Period	1986 - 2003	1980 - 1996	1968 - 1985	
	Median Duration (h) (Actual Data)	1.53	2.38	0.55	
	Mean Duration (h) (Actual Data)	2.72	2.64	1.24	
	Type of Fit	Weibull	Lognormal	Weibull	NUREG/CR-5496 excluded momentary events in the curve fit.
Severe Weather Related (including extreme weather related)	Data Period	1986 - 2003	1980 - 1996	1968 - 1985	
	Median Duration (h) (Actual Data)	1.22	1.18	4.50	NUREG-1032 had no extreme-weather-related events.
	Mean Duration (h) (Actual Data)	16.0	11.8	4.64	NUREG-1032 had no extreme-weather-related events.
	Type of Fit	Weibull	Lognormal	Weibull	NUREG/CR-5496 excluded momentary events in the curve fit.

Figure ES-5. LOOP duration comparison with previous studies.

Frequency and duration data can be combined in frequency of exceedance versus duration curves. These curves are simply the probability of exceedance versus duration curves (such as those in Figure

ES-4) multiplied by their respective frequencies. Results for all five LOOP categories can be added to obtain a single composite curve. These single composite curves from the present study, NUREG/CR-5486, and NUREG-1032 are presented in Figure ES-6 for critical operation. Given a plant risk model with constant parameters except for the LOOP frequencies and durations, these composite curves indicate the relative risk from LOOP initiated scenarios. From Figure ES-6, the composite curve based on the current study data (representative of the period 1997 – 2003) lies below the NUREG/CR-5496 curve (1980 – 1996) and significantly below the NUREG-1032 curve (1968 – 1985) up to approximately two hours. Beyond two hours, the current study results lie between those of the other two reports and all converge after approximately 10 hours. Therefore, the increased LOOP durations (compared with the NUREG-1032 data collection period of 1968 – 1985) are compensated for by the reduction in LOOP frequency.

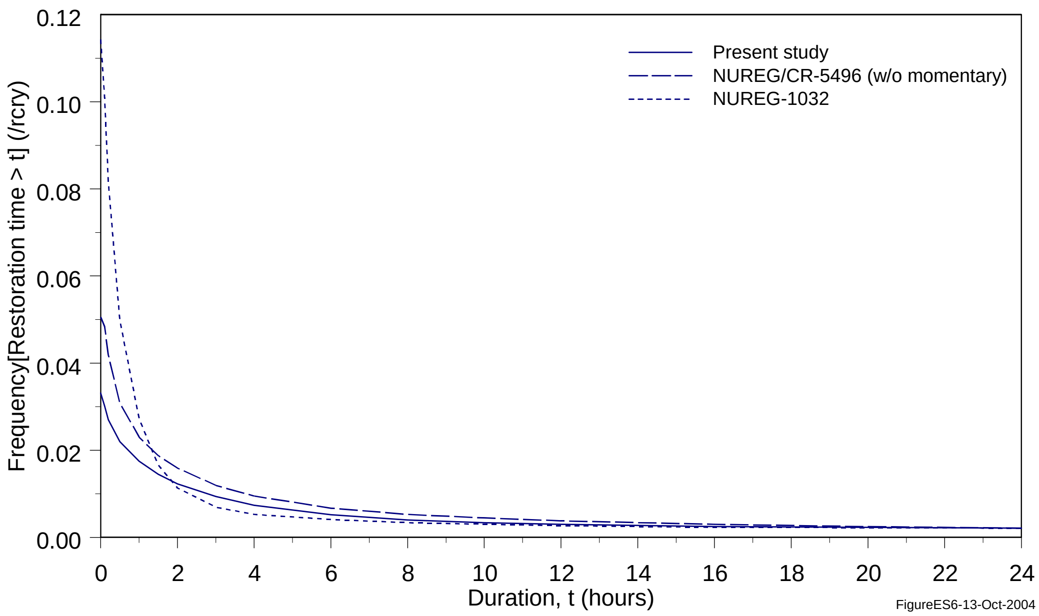


Figure ES-6. Frequency of exceedance versus duration curve comparison for critical operation.

In addition, to LOOP frequency and duration analyses, this report addresses special topics of interest such as seasonal effects, consequential LOOPs (events in which a reactor trip results in a subsequent LOOP), and modeling of sites with more than one plant. For critical operation, significant seasonal effects on the overall LOOP frequency were identified. During the five summer months (May through September), the overall LOOP frequency is almost twice as high as the annual average. However, no significant seasonal effects were identified for shutdown operation.

Consequential LOOPs were also reviewed to determine conditional probabilities of consequential LOOPs occurring, given a reactor trip. This review identified that this conditional probability has increased in recent years, from 2.6E-3 (1986 – 1996) to 7.4E-3 (1997 – 2003). In addition, this conditional probability is greater (1.8E-2) during the five summer months. Results were compared with those listed in NUREG-1784.

To provide information for risk models covering LOOPs at multiple plants at a single site, conditional probabilities were generated for other plants at a site experiencing a LOOP given a LOOP at one of the plants at the site. These conditional probabilities are highly dependent upon the LOOP category, ranging from a low of 3.2E-2 (plant-centered LOOPs) to a high of 6.4E-1 (grid-related LOOPs).

Overall, this report successfully updates estimates for LOOP frequencies for both critical and shutdown operation. In addition, LOOP duration information was successfully transformed into probability of exceedance versus duration curves. Both types of information are needed in PRA models of U.S. commercial nuclear power plants to accurately model current risk from LOOP and associated SBO scenarios. Additionally, this report provides information to modify LOOP frequencies for event analyses specific to the time of the year (summer or non-summer months).

FOREWORD

The availability of alternating current (AC) power is essential for safe operation and accident recovery of commercial nuclear power plants (NPPs). This essential power is normally supplied by offsite power sources from the electrical grid to which the plant is connected.

Unavailability of power can have a significant adverse impact on a plant's ability to achieve and maintain safe-shutdown conditions. In fact, risk analyses performed for NPPs indicate that the loss of all AC power can be a significant contributor to the risk from plant operation, contributing more than 70 percent of the overall risk at some plants. Therefore, a loss of offsite power (LOOP) and its subsequent restoration are important inputs to plant risk models. As a result, these inputs must reflect current industry performance in order for plant risk models to accurately estimate the risk associated with LOOP-initiated scenarios.

This report constitutes an update of two reports that the U.S. Nuclear Regulatory Commission (NRC) previously published to document analyses of LOOP events at U.S. commercial NPPs. Specifically, NUREG-1032, "Evaluation of Station Blackout Accidents at Nuclear Power Plants," covered events that occurred in 1968 – 1985, while NUREG/CR-5496, "Evaluation of Loss of Offsite Power Events at Nuclear Power Plants: 1980 – 1996," covered those that occurred in 1980 – 1996. This update was necessary, in part, because of a change in electrical power grid regulations beginning around 1997 and the associated concern about what impact deregulation might have on LOOP frequencies and/or durations and, therefore, on nuclear plant safety. The NRC's Office of Nuclear Reactor Research performed this work in conjunction with its contractor, the Idaho National Engineering and Environmental Laboratory.

This report is patterned after NUREG/CR-5496, but covers data for 1986 – 2003. The researchers selected 1986 as the starting point in order to begin where NUREG-1032 ended. Although historical records identify LOOP events in a straightforward manner, corresponding information concerning the durations of such events has not always been clear. Moreover, for some LOOP events, the durations were estimated based on other information and/or engineering judgments based on plant operating experience.

The analyses documented in this report resulted in different frequency estimates for critical and shutdown operations under five categories of LOOPs (plant-centered, switchyard-centered, grid-related, severe weather-related, and extreme-weather related). For power operation, grid-related LOOPs contribute 50 percent to the total frequency of 0.033 per reactor critical year, while switchyard-centered LOOPs contribute 26 percent. The remaining three categories of LOOPs have frequency contributions ranging from 7 to 9 percent.

while switchyard-centered LOOPs contribute 26 percent. The remaining three categories of LOOPs have frequency contributions ranging from 7 to 9 percent. By contrast, for shutdown operation, switchyard-centered LOOPs contribute 54 percent to the total frequency of 0.19 per reactor shutdown year, while plant-centered LOOPs contribute 27 percent.

Overall, LOOP frequencies during power operation have decreased significantly over the 36-year period from 1968 through 2003. However, during shutdown operation, the LOOP frequency has remained essentially constant over the 24-year period from 1980 through 2003, although the severe-weather-related LOOP frequency varied significantly depending upon coastal or non-coastal location. By contrast, during power operation, only the grid-related LOOP frequency varied significantly by geographical location. This difference is almost solely the result of one highly unusual LOOP event on the August 14, 2003, during which a grid blackout affected nine NPPs. Moving forward, it will be important to monitor industry performance to determine whether a similar event occurs in the future.

The analyses documented in this report also indicated that, on average, LOOP events lasted longer in 1996 – 2003 than in 1986 – 1996. In particular, the LOOP duration data for 1986 – 1996 exhibited a statistically significant increasing trend over time. By contrast, no statistically significant trend exists for 1997 – 2003.

The updated frequency and duration information from this study will support future assessments of the current risk (core damage frequency) associated with LOOP and SBO accident scenarios, as well as the evaluation of existing regulations regarding electrical power for the safe operation of NPPs.

.

ACKNOWLEDGMENTS

The authors would like to acknowledge the support of J. Einerson for preparing many of the figures. In addition, C.Atwood reviewed several drafts of this report and provided many helpful comments. Finally, D. Dube provided valuable comments on the final draft report.

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
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
NERC	North American Electric Reliability Council
NPCC	Northeastern Power Coordinating Council
PLOOP	partial loss of offsite power
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 Electric Coordinating Council

GLOSSARY

Actual bus restoration time – the duration, in minutes, from the event initiation until the first offsite electrical power was restored to a safety bus. This is the actual time taken to restore offsite power from the first available source to a safety bus.

Consequential loss of offsite power initiating event (LOOP-IE-C) – a LOOP-IE in which the LOOP is the direct or indirect result of a plant trip. For example, the event is consequential if the LOOP occurred during a switching transient (i.e., main generator tripping) after a unit trip from an unrelated cause. In this case the LOOP would not have occurred if the unit remained operating. LOOP-IE-C is a subset of LOOP-IE events.

Extreme-weather-related loss of offsite power event – a LOOP event caused by extreme weather. Examples of extreme weather are hurricanes, strong winds greater than 125 miles per hour, and tornadoes. Extreme-weather-related LOOP events are also distinguished from severe-weather-related LOOP events by their potential to cause significant damage to the electrical transmission system and long offsite power restoration times.

Functional loss of offsite power initiating event – a LOOP occurring while a plant is at power and also involving a reactor trip. The LOOP can cause the reactor to trip or both the LOOP event and the reactor trip can be part of the same transient.

Grid-related loss of offsite power event – a LOOP event in which the initial failure occurs in the interconnected transmission grid that is outside the direct control of plant personnel. Failures that involve transmission lines from the site switchyard are usually classified as switchyard-centered events if plant personnel can take actions to restore power when the fault is cleared. However, the event should be classified as grid related if the transmission lines fail from voltage or frequency instabilities, overload, or other causes that require restoration efforts or corrective action by the transmission operator.

Initial plant fault loss of offsite power initiating event (LOOP-IE-I) – a LOOP-IE in which the LOOP event causes the reactor to trip. LOOP-IE-I is a subset of LOOP-IE events. See Figure 2-1 for the LOOP classification scheme. NUREG/CR-5496 uses the term “initial plant fault” to distinguish these events from other “functional impact” events (LOOP-IE-C and LOOP-IE-NC).

Loss of offsite power (LOOP) event – the simultaneous loss of electrical power to all unit safety buses (also referred to as emergency buses, Class 1E buses, and vital buses) requiring all emergency power generators to start and supply power to the safety buses. The non-essential buses may also be de-energized as a result of this.

Loss of offsite power initiating event (LOOP-IE) – a LOOP occurring while a plant is at power and also involving a reactor trip. See Figure 2-1 for the LOOP classification scheme. The LOOP can cause the reactor to trip or both the LOOP event and the reactor trip can be part of the same transient. Note that this is the NUREG/CR-5750 definition of a functional impact LOOP initiating event (as opposed to an initial plant fault LOOP initiating event).

Loss of offsite power no trip event (LOOP-NT) – a LOOP occurring while a plant is at power but not involving a reactor trip. (Depending upon plant design, the plant status at the time of the LOOP, and the specific characteristics of the LOOP event, some plants have been able to remain at power given a LOOP.) See Figure 2-1 for the LOOP classification scheme.

Loss of offsite power shutdown event (LOOP-SD) – a LOOP occurring while a plant is shutdown. See Figure 2-1 for the LOOP classification scheme.

Momentary loss of offsite power event – a LOOP event in which the potential bus restoration time is less than two minutes.

Non-consequential loss of offsite power initiating event (LOOP-IE-NC) – a LOOP-IE in which the LOOP occurs following but is not related to the reactor trip. LOOP-IE-NC is a subset of LOOP-IE events. See Figure 2-1 for the LOOP classification scheme.

Partial loss of offsite power (PLOOP) event – the loss of electrical power to at least one (but not all) unit safety bus, requiring at least one emergency power generator to start and supply power to the safety bus(es).

Plant-centered loss of offsite power event – a LOOP event in which the design and operational characteristics of the nuclear power plant unit itself play the major role in the cause and duration of the loss of offsite power. Plant-centered failures typically involve hardware failures, design deficiencies, human errors, and localized weather-induced faults such as lightning. The line of demarcation between plant-centered and switchyard-centered events is the nuclear power plant main and station power transformers high-voltage terminals.

Potential bus restoration time – the duration, in minutes, from the event initiation until the first offsite electrical power could have been restored to a safety bus. This time estimate is less than or equal to the actual bus restoration time.

Severe-weather-related loss of offsite power event – a LOOP event caused by severe weather, in which the weather was widespread, not just centered on the site, and capable of major disruption. Severe weather is defined to be weather with forceful and non-localized effects. A LOOP is classified as a severe-weather event if it was judged that the weather was widespread, not just centered at the power plant site, and capable of major disruption. An example is storm damage to transmission lines instead of just debris blown into a transformer. This does not mean that the event had to actually result in widespread damage, as long as the potential is there. Examples of severe weather include thunderstorms, snow, and ice storms. Lightning strikes, though forceful, are normally localized to one unit, and so are coded as plant centered or switchyard centered. LOOP events involving hurricanes, strong winds greater than 125 miles per hour, and tornadoes are included in a separate category – extreme-weather-related LOOPs.

Station blackout (SBO) – the complete loss of alternating current (ac) electrical power to safety buses in a nuclear power plant unit. Station blackout involves the loss of offsite power concurrent with the failure of the onsite emergency alternating current power system. It does not include the loss of available ac power to safety buses fed by station batteries through inverters or successful HPCS operation.

Sustained loss of offsite power event – a LOOP event in which the potential bus restoration time is equal to or greater than two minutes.

Switchyard-centered loss of offsite power event – a LOOP event in which the equipment or human-induced failures of equipment in the switchyard play the major role in the loss of offsite power. The line of demarcation between switchyard-related events and grid-related events is the output bus bar in the switchyard.

Switchyard restoration time – the duration, in minutes, from the event initiation until the first offsite electrical power was actually restored (or could have been restored, whichever time is shorter) to the switchyard. Such items as no further interruptions to the switchyard, adequacy of the frequency and voltage levels to the switchyard, and no transients that could be disruptive to plant electrical equipment should be considered in determining the time.

Glossary

Evaluation of Loss of Offsite Power Events At Nuclear Power Plants: 1986 - 2003

1. INTRODUCTION

The availability of alternating current (AC) power to commercial nuclear power plants is essential for safe operations and accident recovery. Unavailability of AC power can have a major negative impact on a power plant's ability to achieve and maintain safe shutdown conditions. This AC power normally is supplied by offsite power sources (from the electrical grid to which the plant is connected). Therefore, loss of offsite power (LOOP, but also referred to as LOSP) and subsequent restoration of offsite power are important inputs to plant probabilistic risk assessments (PRAs). These inputs need to reflect current industry performance in order for PRAs to accurately estimate the risk from LOOP initiated scenarios.

Selected previous reports analyzing data on LOOP and/or offsite power restoration include NUREG-1032, NUREG/CR-5496, NUREG/CR-5750, and various annual or biennial Electric Power Research Institute (EPRI) technical reports. NUREG-1032, *Evaluation of Station Blackout Accidents at Nuclear Power Plants* [1], evaluated LOOP data from U.S. commercial nuclear reactors over the period 1968 – 1985. NUREG/CR-5496, *Evaluation of Loss of Offsite Power Events at Nuclear Power Plants: 1980 – 1996* [2], looked at data from 1980 –1996. A more general report, NUREG/CR-5750, *Rates of Initiating Events at U.S. Nuclear Power Plants: 1987 – 1995* [3] covered a wide variety of initiating events including LOOP for the period 1987 – 1995. Finally, EPRI reports covering LOOP events have been issued periodically. The latest EPRI report covers LOOP events from 1994 – 2003 [4].

The present report is patterned after NUREG/CR-5496 but covers the data period 1986 – 2003. The year 1986 was chosen as the initial year in order to start where NUREG-1032 stopped. The extension of coverage from 1997 – 2003 (compared with NUREG/CR-5496) is especially noteworthy because of deregulation of the electrical industry, considered to start around 1997, and resultant changes to electrical grid operation. Therefore, special attention is given in this report to the analysis of LOOP before deregulation (up through 1996) and after the start of deregulation (1997 and on). A separate report, NUREG-1784, *Operating Experience Assessment – Effects of Grid Events on Nuclear Power Plant Performance* [5], focuses on a subset of LOOP events and the effects of deregulation on such events. That report contains more detailed engineering information concerning deregulation and its effects on the electrical grid and related LOOP events.

The scope of this study is the statistical and engineering analysis of LOOP frequencies and durations. Data coverage includes performance of U.S. commercial nuclear reactors over the period 1986 – 2003. The data cover both critical (at power) and shutdown operations at these plants. Partial LOOP events, in which not all offsite power lines to the plant are lost or not all offsite power to safety buses is lost, are not covered in this report.

The present study is part of a larger NRC effort to characterize the risk from LOOP initiated scenarios, including station blackout (SBO). That larger effort was initiated following the widespread grid blackout on August 14, 2003, which caused LOOPs at nine commercial nuclear power plants in the U.S. Results of the present study – frequencies and durations for five different categories and associated insights – will be used as inputs to the actual risk evaluations. Those LOOP and SBO risk evaluations will be documented in a separate report.

Section 2 of this report addresses definitions, the categorization of types of LOOP events, and the data collection process. Then Section 3 presents LOOP frequency results and comparisons with previous

studies. LOOP durations are analyzed in Section 4. Results combining LOOP frequencies and durations are presented in Section 5. Special issues such as time period differences, seasonal effects, consequential LOOP, and others are discussed in Section 6. Engineering analyses of the results are covered in Section 7. Finally, Section 8 includes the summary and conclusions, while Section 9 lists the references. In addition, appendices cover details of the LOOP event database, statistical methods and analysis results, and plant-specific LOOP frequency information.

2. DEFINITIONS, LOOP CATEGORIZATION, AND DATA COLLECTION

Definitions used in this study are presented in the Glossary. LOOP is defined as the simultaneous loss of electrical power to all plant safety buses (also referred to as emergency buses, Class 1E buses, and vital buses) requiring all emergency power generators to start and supply power to the safety buses. The non-essential buses may also be de-energized as a result of this. The impacts from such an event depend upon whether the plant is critical or shut down. If the plant is critical when a LOOP occurs, then a reactor trip generally occurs. This reactor trip then challenges various safety systems designed to bring the plant to a safe shutdown. Most of the safety systems require AC power, so emergency diesel generators (or other types of emergency AC power sources) must start and run to supply this power until offsite power is restored to the safety buses. If the emergency AC power sources fail, the plant is still designed to shut down safely, by relying on portions of safety systems that can function for a limited period of time given no AC power (e.g., turbine-driven pumps for coolant injection). Even if the plant is shut down when a LOOP occurs, emergency AC power must be supplied to the residual heat removal systems.

One categorization of LOOP events used in this report is the classification scheme presented in Figure 2-1. The first subdivision breaks down LOOP events into those that occur while a plant is shut down (LOOP-SD) and those occurring during critical operation. For LOOPS occurring during critical operation, two classes of events are distinguished: events involving a plant trip (LOOP-IE) and events in which the plant is able to continue critical operation without a plant trip (LOOP-NT). The second level of decomposition further subdivides the LOOP-IE events. Following the initiating event nomenclature in NUREG/CR-5750, LOOP-IE events are subdivided into those in which the LOOP event causes the reactor trip (initial plant fault event or LOOP-IE-I) and those in which the LOOP occurs after the reactor trip. These latter events are included in the functional impact initiating event classification in NUREG/CR-5750, and include those in which the reactor trip causes a LOOP to occur (consequential LOOP or LOOP-IE-C) and those in which the reactor trip and LOOP are unrelated but occur during the same transient (LOOP-IE-NC). Each LOOP event fits into only one of the resulting LOOP categories: LOOP-SD, LOOP-NT, LOOP-IE-I, LOOP-IE-C, or LOOP-IE-NC. This classification scheme is used to help determine which LOOP events should be included when determining LOOP frequency estimates, as explained in Section 3 of this report.

A second categorization scheme used in this report is focused on the event or cause of the LOOP and is illustrated in Figure 2-2. LOOP events can be subdivided into five types by cause: plant centered, switchyard centered, grid related, severe weather related, and extreme weather related. Plant-centered LOOP events occur within the plant, up to but not including the auxiliary or station transformers. For such events, plant personnel perform the actions to restore offsite power to the safety buses. Switchyard-centered events occur within the switchyard, up to and including the output bus bar. Plant and switchyard personnel coordinate to perform the restoration actions. Severe-weather-related events have the potential to affect areas larger than one site. In such events, restoration of offsite power often requires a longer time because of either the damage caused or the continuing effects of the storm hampering restoration efforts. A similar but more severe category, extreme-weather-related LOOPs, is used for those weather-related LOOPs involving hurricanes, strong winds greater than 125 miles per hour, and tornadoes. Finally, grid-related LOOP events include those in which the initial failure occurs in the interconnected transmission grid that is outside the direct control of plant personnel. In such cases, restoration of offsite power is performed mainly by transmission grid personnel (with plant personnel restoring power from the switchyard to the safety buses). This event categorization scheme is used because offsite power restoration times vary by type of LOOP. Therefore, LOOP frequencies are determined for each event category.

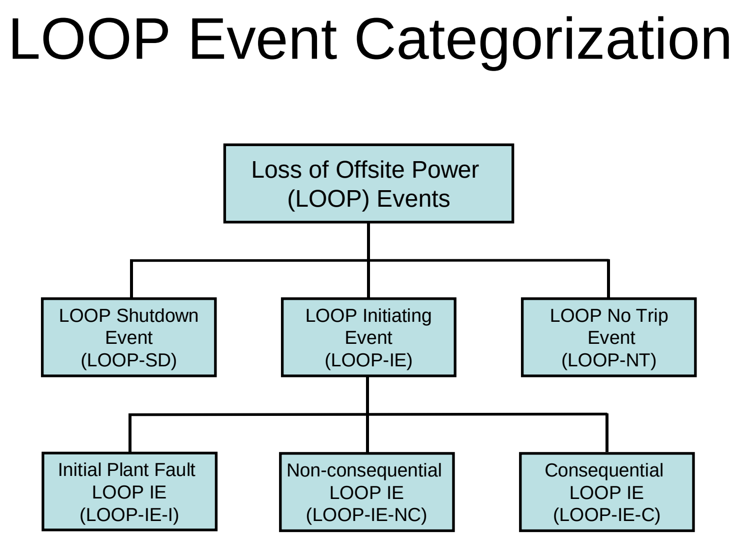


Figure 2-1. LOOP classes.

Figure 2-2. LOOP categories.

In the previous report NUREG/CR-5496, LOOPs were subdivided into only three event types, with the switchyard-centered events grouped into the plant-centered category and the extreme-weather-related LOOPs grouped in with the severe-weather-related LOOPs. The present report includes switchyard-centered events as a separate category for two reasons: deregulation potentially has an impact on some switchyard-related activities (as discussed in NUREG-1784) and offsite power restoration curves are different if switchyard-centered LOOPs are separated from other plant-centered LOOPs. In addition, the present report distinguishes extreme-weather-related LOOPs in order to better model offsite power restoration differences.

In the previous report NUREG-1032, four event categories were used: plant centered, severe weather related, extreme weather related, and grid related. Similar to NUREG/CR-5496, the plant-centered LOOPs included the switchyard-centered LOOPs.

The final categorization scheme discussed in this report subdivides LOOP events into momentary and sustained categories. Momentary LOOP events are defined as those in which offsite power is restored (or is potentially recoverable) to at least one safety bus within less than two minutes. Sustained LOOP events require two minutes or more to restore offsite power to at least one safety bus. The use of two minutes as the demarcation between momentary and sustained LOOPs is arbitrary but agrees with NUREG/CR-5496. This duration categorization scheme was used in NUREG/CR-5496 to help determine which LOOPs to include in the offsite power restoration analysis. However, the present report does not make this distinction; both types were included in both the frequency estimates and the offsite power restoration analysis.

Collection and interpretation of LOOP data involved a three-step process: review of the data from NUREG/CR-5496 (1986 – 1996), addition of data for 1997 – 2003, and review of data by licensees and NRC site inspectors. As a first step, the LOOP data from NUREG/CR-5496 were reviewed based on the refined definitions presented in the Glossary. This effort included the separation of switchyard-centered events from the plant-centered category used in NUREG/CR-5496. In addition, the extreme-weather-related LOOPS were separated from the severe-weather-related LOOPs. Finally, offsite power restoration times were expanded to include three values (given sufficient information related to the event): switchyard restoration time, potential bus restoration time, and actual bus restoration time. Details of this effort are provided in Section 6.7 as a special topic of interest. Significant effort was expended on this task. Also, the effort was aided by additional information obtained from the recent draft EPRI report [4] and recent Accident Sequence Precursor (ASP) Program results. LOOP events in NUREG/CR-5496 were originally identified from a review of licensee event reports (LERs). That effort also included supplemental information from a variety of NRC and EPRI reports. The supplemental information was needed for completeness because a LOOP event by itself does not necessarily require that an LER be submitted. However, if a plant trip occurs, then an LER is submitted.

The second step expanded the data coverage to include 1997 – 2003. Again, LERs were searched to identify and categorize LOOP events. Restoration times were identified. In addition, the recent EPRI report covering LOOP events from 1994 – 2003 was reviewed to identify any additional events not covered by the LERs.

As a final quality check of the resulting LOOP database and as part of the Temporary Instruction 2515/156, “Offsite Power System Operational Readiness” [6], NRC site resident inspectors were asked to confirm the LOOP events, their categorization, and their offsite restoration times. The results of this effort were incorporated into the final LOOP database, which is presented in Appendix A of this report.

3. LOOP FREQUENCIES

Results of the statistical analyses of the LOOP occurrence data – LOOP frequencies – are presented in this section. Section 3.1 addresses LOOP industry frequency results, Section 3.2 looks at regional differences in frequencies, Section 3.3 discusses plant-specific LOOP frequency estimates, and Section 3.4 compares current results with those from previous studies. LOOP events included in each frequency calculation are listed in Appendix A. Details of the statistical analyses of the LOOP data are presented in Appendices B and C in this report. Plant-specific frequency estimates are presented in Appendix D.

3.1 LOOP Industry Frequencies

LOOP industry frequencies were determined for each of the five LOOP event categories: plant centered, switchyard centered, grid related, severe weather related, and extreme weather related. In addition, these frequencies are subdivided into results for critical and shutdown operation. Results are summarized in Table 3-1. For critical operation, the LOOP events included in the frequency calculations for Table 3-1 include LOOP-IE-I, LOOP-IE-C, and LOOP-IE-NC from Figure 2-1. Therefore, the frequencies in Table 3-1 represent functional LOOPs (as defined in NUREG/CR-5750), as opposed to initial plant fault LOOPs (which would use only LOOP-IE-I events). For shutdown operation, only the LOOP-SD events were used. (The statistical analyses described in Appendices B and C looked to see if there were differences between the shutdown operation LOOPs and the critical operation LOOPs. In almost all cases, there were differences so the data groups were analyzed separately.) The LOOP-NT events were not included in the frequency analyses.

Table 3-1. LOOP frequencies.

Mode	LOOP Category	LOOP Frequency				
		Data Group	Events	Reactor Critical or Shutdown Years	Mean Frequency (note a)	Frequency Units (note b)
Critical operation	Plant centered	1997 - 2003	1	629.5	2.38E-03	/rcry
	Switchyard centered	1997 - 2003	5	629.5	8.74E-03	/rcry
	Grid related	1997 - 2003	10	629.5	1.67E-02	/rcry
	Severe weather related	1986 - 2003	4	1508.8	2.98E-03	/rcry
	Extreme weather related	1986 - 2003	3	1508.8	2.32E-03	/rcry
	All	Several			3.31E-02	/rcry
Shutdown operation	Plant centered	1986 - 2003	19	378.1	5.16E-02	/rsy
	Switchyard centered	1986 - 2003	38	378.1	1.02E-01	/rsy
	Grid related	1986 - 2003	3	378.1	9.26E-03	/rsy
	Severe weather related	1986 - 2003	9	378.1	2.51E-02	/rsy
	Extreme weather related	1986 - 2003	0	378.1	1.32E-03	/rsy
	All	1986 - 2003			1.89E-01	/rsy

a. The mean is a Bayesian update using a Jeffreys prior. Mean = (0.5 + events)/(critical or shutdown years).

b. Frequency units are per reactor critical year (/rcry) or per reactor shutdown year (/rsy).

Trend plots for all five LOOP event categories and all LOOPs combined are presented in Figure 3-1 through Figure 3-6. As discussed previously, trends exist in several of the five LOOP categories. For plant-centered and switchyard-centered LOOPs, industry performance has improved considerably. Therefore, the baseline period for determining industry frequencies representative of current (centered around the year 2000) performance is 1997 – 2003. As indicated in Figure 3-1 and Figure 3-2, the industry performance over this recent period is constant. In contrast, for grid-related LOOPs, performance has worsened recently because of 2003, as indicated in Figure 3-3. In Figure 3-3, a trend analysis over 1986 – 2002 indicated no trend. The 2003 data are considered to be a potential outlier. (Future industry performance will indicate whether 2003 is actually an outlier or is the start of an increasing trend.) Again, the baseline period for grid-related LOOPs is 1997 – 2003, to capture this more recent industry performance. For severe-weather-related and extreme-weather-related LOOPs, Figure 3-4 and Figure 3-5 indicate no significant trend over the entire period covered, 1986 – 2003. Therefore, the baseline period used is 1986 – 2003. However, the results are also applicable to the period 1997 – 2003. The trend plot for all LOOPs combined is presented in Figure 3-6. There is a slight downward trend in the combined LOOPs during critical operation over the period 1986 – 2002. However, 2003 resulted in a large jump in the number of LOOPs because of the single August 14, 2003 grid blackout that resulted in LOOPs at nine plants (eight of which were in critical operation). The 2003 result is similar to industry performance during 1987, 1992, and 1993, but those other years included several different types of events, rather than a single event impacting many plants.

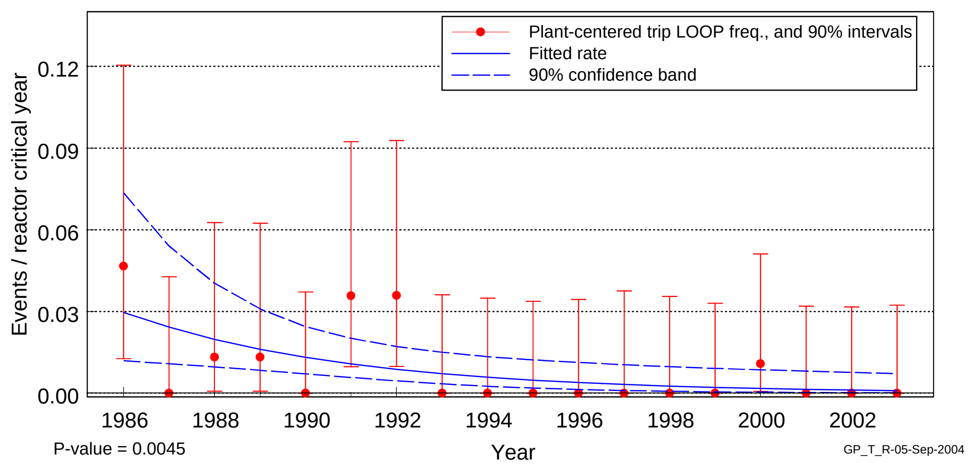


Figure 3-1. Trend plot of industry performance for plant-centered LOOPs during critical operation.

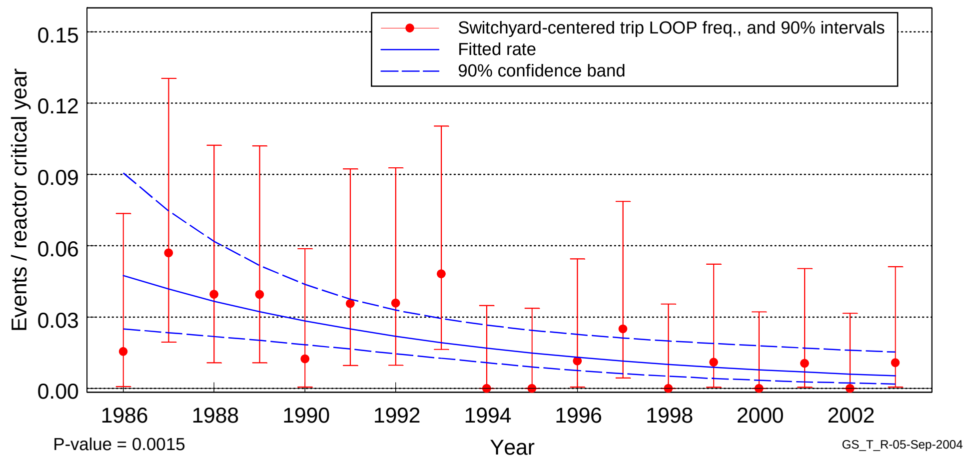
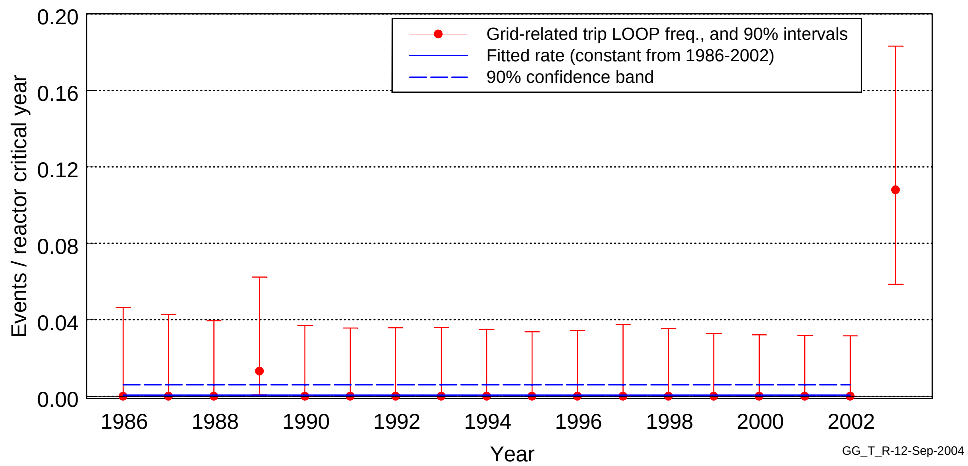


Figure 3-2. Trend plot of industry performance for switchyard-centered LOOPs during critical operation.



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

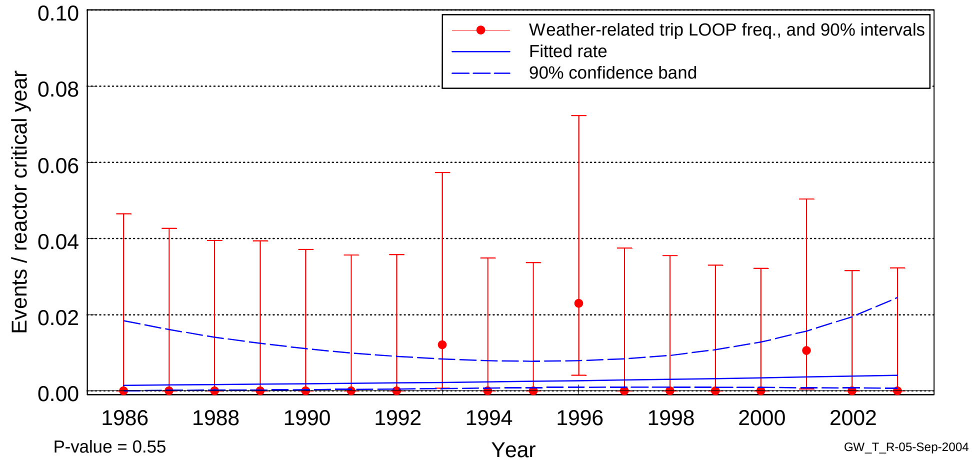


Figure 3-4. Trend plot of industry performance for severe-weather-related LOOPs during critical operation.

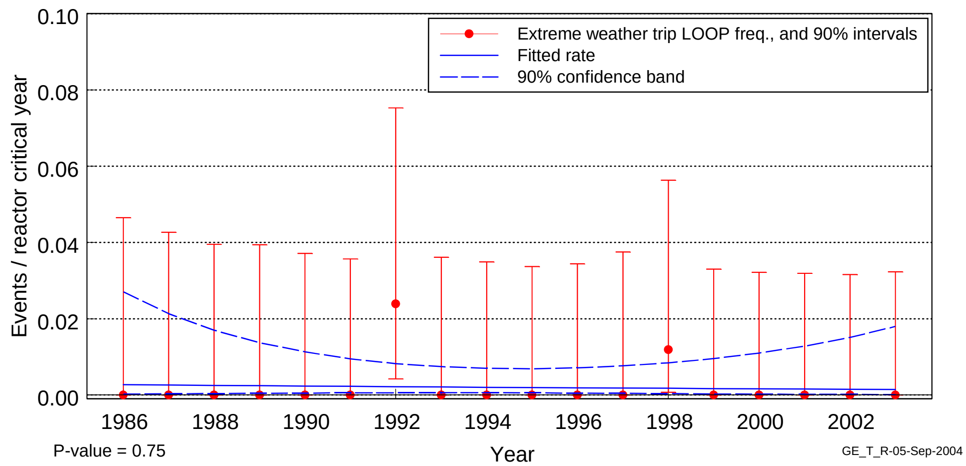
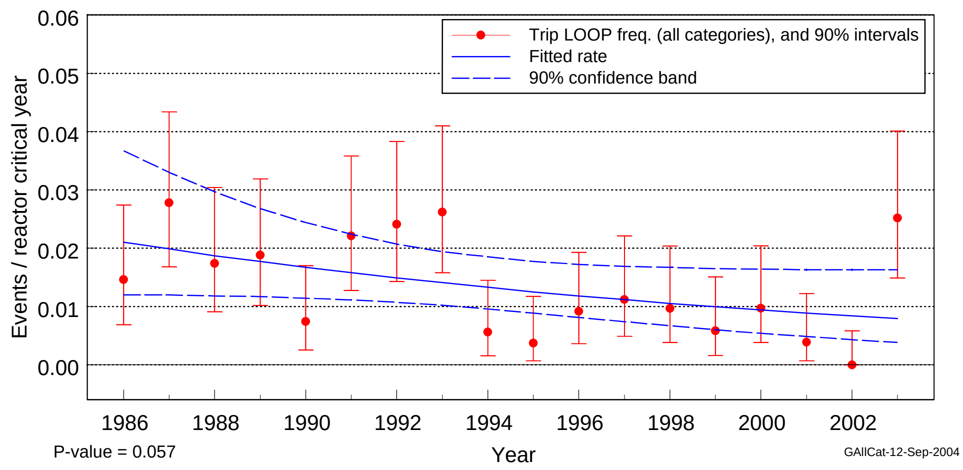


Figure 3-5. Trend plot of industry performance for extreme-weather-related LOOPs during critical operation.



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 3-6. Trend plot of industry performance for all LOOPs combined during critical operation.

Similar results for shutdown operation are also presented in Table 3-1. The industry mean frequency of LOOP events during shutdown (including momentary LOOPs) is 1.9E-1/reactor shutdown year, or 1.9E-1/rsy. This frequency is the sum of five contributions: 5.2E-2/rsy for plant-centered LOOPs (27.3 %), 1.0E-1/rsy for switchyard-centered LOOPs (53.8 %), 9.3E-3/rsy for grid-related LOOPs (4.9 %), 2.5E-2/rsy for severe-weather-related LOOPs (13.3 %), and 1.3E-3/rsy for extreme-weather-related LOOPs (0.7 %). All of these LOOP frequencies for shutdown operation were obtained using the entire data period, 1986 – 2003. No significant trends in industry performance exist over this period.

As a check of the resulting LOOP mean frequencies listed in Table 3-1, Poisson distribution predictions of the number of LOOPs expected over the seven-year period 1997 – 2003 were compared with the actual industry performance. These results are presented in Table 3-2. The overall mean frequency for a plant is the critical operation LOOP frequency weighted by its fraction of time in critical operation plus the shutdown operation LOOP frequency weighted by its fraction of time in shutdown operation. Over the period 1997 – 2003, the U.S. commercial nuclear power plants were in critical operation 87.3% of the calendar time. Therefore, this overall weighted LOOP frequency is

$$(0.0331/\text{rcry})(0.873\text{rcry}/\text{rcy}) + (0.189/\text{rsy})(0.127\text{rsy}/\text{rcy}) = 0.0529/\text{rcy},$$

where reactor calendar year is denoted by “rcy”. For a seven-year period, the mean expected number of events at a plant is

$$(0.0529/\text{rcy})(7\text{rcy}) = 0.370.$$

Given a Poisson process and 103 plants, 71 plants are expected to experience no LOOPs over a seven-year period. The actual industry experience is 79 plants with no LOOPs over 1997 – 2003. Also, 26 plants are expected to experience one LOOP. Actual industry experience is 22 plants with one LOOP. Five plants are predicted to experience two LOOPs, while the actual industry experience indicates three plants experienced two LOOPs. Finally, about one plant is predicted to experience three LOOPs, and the actual industry experience is two plants. Overall, the 103 plants are predicted to experience 38 LOOPs over a seven-year period, while the actual industry experience was 33 LOOPs.

Uncertainty distributions for the industry LOOP frequencies in Table 3-1 are presented in Table 3-3. Presented are the 5 %, median, mean, 95 %, error factor (95 %/median), and shape (a) and scale (b) parameters for the gamma distributions. For categories with limited data (five or fewer events), the distribution was assumed to follow the constrained noninformative distribution (CNID) defined in the article "Constrained Noninformative Priors in Risk Assessment" [7]. The CNID has an error factor of 8.4 for gamma distributions. For categories with greater than five events, empirical Bayes analysis was used to search for variability in the data using several grouping schemes: plant, site, various geographical areas, various electrical grid areas, year, and others. In cases where the empirical Bayes analyses identified more than one grouping with significant variability, a judgment call was made concerning which set of results to use. (See Appendices B and C for more information.) Also, the 10 grid events during critical operation (Table 3-1) include eight resulting from a single grid disturbance on August 14, 2003. This extreme dependence between events violates assumptions inherent in the empirical Bayes analysis, so the CNID was used as a default for this category. The uncertainty in the grid related frequency might be larger than indicated by the CNID. Finally, the nine severe weather events during shutdown (Table 3-1) include several dependencies, so the CNID was also used as a default for that category.

To determine the distributions for the overall LOOP frequencies for critical and shutdown operation, simulation was used. Results were then fit to a gamma distribution using a maximum likelihood estimate. For critical operation, the overall mean frequency of 3.3E-2/rcry has a lower bound (5%) of 4.8E-3/rcry and an upper bound (95%) of 8.2E-2/rcry. The error factor for this gamma distribution is 3.0. For shutdown operation, the overall mean frequency of 1.9E-1/rsy has a lower bound of 3.9E-2/rsy, an upper bound of 4.3E-1/rsy, and an error factor of 2.7.

Table 3-2. Comparison of Poisson distribution predictions with actual LOOPs for 1997 – 2003.

Plant Name	Date	Mode	LOOP Category
BRAIDWOOD 1	6-Sep-98	Shutdown	Severe weather related
BROWNS FERRY 3	5-Mar-97	Shutdown	Switchyard centered
BRUNSWICK 1	3-Mar-00	Shutdown	Switchyard centered
CLINTON 1	6-Jan-99	Shutdown	Switchyard centered
DAVIS-BESSE	24-Jun-98	Critical	Extreme weather related
DAVIS-BESSE	22-Apr-00	Shutdown	Plant centered
DAVIS-BESSE	14-Aug-03	Shutdown	Grid related
DIABLO CANYON 1	15-May-00	Critical	Plant centered
FARLEY 1	9-Apr-00	Shutdown	Switchyard centered
FERMI 2	14-Aug-03	Critical	Grid related
FITZPATRICK	14-Aug-03	Critical	Grid related
FORT CALHOUN	20-May-98	Shutdown	Switchyard centered
FORT CALHOUN	26-Oct-99	Shutdown	Plant centered
GINNA	14-Aug-03	Critical	Grid related
INDIAN POINT 2	1-Sep-98	Shutdown	Plant centered
INDIAN POINT 2	31-Aug-99	Critical	Switchyard centered
INDIAN POINT 2	14-Aug-03	Critical	Grid related
INDIAN POINT 3	16-Jun-97	Shutdown	Grid related
INDIAN POINT 3	14-Aug-03	Critical	Grid related
NINE MILE PT. 1	14-Aug-03	Critical	Grid related
NINE MILE PT. 2	14-Aug-03	Critical	Grid related
OYSTER CREEK	1-Aug-97	Critical	Switchyard centered
PALISADES	22-Dec-98	Shutdown	Plant centered
PALISADES	25-Mar-03	Shutdown	Plant centered
PEACH BOTTOM 2	15-Sep-03	Critical	Grid related
PEACH BOTTOM 3	15-Sep-03	Critical	Grid related
PERRY	14-Aug-03	Critical	Grid related
PILGRIM	1-Apr-97	Shutdown	Severe weather related
QUAD CITIES 2	2-Aug-01	Critical	Switchyard centered

Poisson Model Comparison with Actual Experience

Mean = (0.0331*0.873+0.189*0.127)(7years) = 0.370

Number of Events	Probability	Prediction for 103 plants	Actual (1997 - 2003)	Chi-Square Statistic
0	0.6905	71.1	79	0.872
1	0.2557	26.3	21	1.082
2	0.0473	4.9	3	0.722
3	0.0058	0.6	2	3.247
4	0.0005	0.1	0	0.056
Totals	0.370	38.1	33.0	5.979
		Value of Chi-Square Test		0.201

The 0.201 chi-square test value indicates that the hypothesis of the Poisson model fitting actual LOOP data for 1997 - 2003 should not be rejected.

The Zion 1 LOOP was not included in the above analysis because it was permanently shut down early in the 1997 - 2003 period and is not included in the 103 plants.

Table 3-2. Comparison of Poisson distribution predictions with actual LOOPs for 1997 – 2003. (continued)

Plant Name	Date	Mode	LOOP Category	Poisson Model Comparison with Actual Experience
SALEM 1	29-Jul-03	Critical	Switchyard centered	
SEABROOK	5-Mar-01	Critical	Severe weather related	
THREE MILE ISL 1	21-Jun-97	Critical	Switchyard centered	
TURKEY POINT 4	21-Oct-00	Shutdown	Switchyard centered	
ZION 1	11-Mar-97	Shutdown	Switchyard centered	

Table 3-3. LOOP frequency distributions.

Mode	LOOP Category	LOOP Frequency Distribution (note a)							
		5%	Median (50%)	Mean	95%	Error Factor	Gamma Shape Parameter (a)	Gamma Scale Parameter (b, years)	Source (note b)
Critical operation	Plant centered	9.37E-06	1.08E-03	2.38E-03	9.15E-03	8.44	0.500	209.83	CNID
	Switchyard centered	3.44E-05	3.97E-03	8.74E-03	3.36E-02	8.44	0.500	57.23	CNID
	Grid related	6.56E-05	7.59E-03	1.67E-02	6.41E-02	8.44	0.500	29.98	CNID
	Severe weather related	1.17E-05	1.36E-03	2.98E-03	1.15E-02	8.44	0.500	167.64	CNID
	Extreme weather related	9.12E-06	1.06E-03	2.32E-03	8.91E-03	8.44	0.500	215.54	CNID
	All	4.87E-03	2.70E-02	3.31E-02	8.22E-02	3.04	1.737	52.47	Simulation
Shutdown operation	Plant centered	1.41E-04	2.21E-02	5.16E-02	2.03E-01	9.19	0.468	9.07	EB
	Switchyard centered	7.02E-03	7.40E-02	1.02E-01	2.92E-01	3.95	1.135	11.15	EB
	Grid related	3.64E-05	4.21E-03	9.26E-03	3.56E-02	8.44	0.500	54.01	CNID
	Severe weather related	9.88E-05	1.14E-02	2.51E-02	9.65E-02	8.44	0.500	19.90	CNID
	Extreme weather related	5.20E-06	6.02E-04	1.32E-03	5.08E-03	8.44	0.500	378.10	CNID
	All	3.86E-02	1.62E-01	1.89E-01	4.33E-01	2.67	2.246	11.88	Simulation

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

b. CNID - constrained noninformative distribution, EB - empirical Bayes distribution, simulation - sum of 5 categories simulated and fit to gamma

3.2 LOOP Frequency Comparison (1986 – 1996 versus 1997 – 2003)

For comparison purposes, LOOP frequencies were calculated by subdividing the entire data collection period into two periods: 1986 – 1996 and 1997 – 2003. The results are presented in Table 3-4. For critical operation, the plant-centered and switchyard-centered LOOP frequencies dropped considerably from the older period to the more current period. The plant-centered LOOP frequency dropped from 1.3E-2/rcry to 2.4E-3/rcry, and the switchyard-centered frequency dropped from 2.7E-2/rcry to 8.7E-3/rcry. However, the grid-related LOOP frequency increased from 1.7E-3/rcry to 1.7E-2/rcry mainly because of the August 14, 2003 grid disturbance. Severe-weather-related LOOPs dropped from 5.1E-3/rcry to 2.4E-3/rcry, while extreme-weather-related LOOPs dropped slightly. These results support the decisions discussed in Section 3.1, where the recommended LOOP frequencies for critical operation were based on either the 1997 – 2003 period (if a significant trend existed) or the entire 1986 – 2003 period (if no significant trend existed). Finally, the overall LOOP frequency for critical operation dropped from 4.9E-2/rcry to 3.3E-2/rcry. See Appendix C for statistical analyses of the two data periods.

Table 3-4 also lists the shutdown operation LOOP frequency comparison. The overall LOOP frequency for both periods is approximately 1.9E-1/rsy. There are some differences in LOOP category frequencies, but none of them were considered to be statistically significant. For the recommended LOOP frequencies in Section 3.1, the entire data period 1986 – 2003 was used for each of the LOOP categories for shutdown operation. Again, refer to Appendix C for statistical analysis results.

3.3 LOOP Regional Frequencies

The LOOP data were also analyzed to identify significant subgroups of the entire industry (103 plants) in terms of initiating event frequencies. The subgroups considered include states, groups of states, coastal versus non-coastal, and various grid-related geographical breakdowns. Plant assignments with respect to each of the subgroups are presented in Appendix A. Details of the statistical analysis effort are provided in Appendices B and C. No significant differences in frequencies for the various subgroups analyzed were observed for the plant-centered and switchyard-centered LOOPs. Also, there were too few extreme-weather-related LOOPs to identify any significant differences between subgroups. However, differences were identified for the severe-weather-related and grid-related LOOPs.

For severe-weather-related LOOPs, a significant subgroup in terms of distinguishing frequencies is coastal versus non-coastal (Figure 3-7). However, this significance is evident only in the shutdown operation data. (There are too few events during critical operation to distinguish coastal versus non-coastal.) Table 3-5 presents the subgroup frequencies for severe-weather-related LOOPs during shutdown operation. For the coastal plants (including plants near the coast), the frequency for severe-weather-related LOOPs during shutdown operation is 4.4E-2/rsy, compared with 1.0E-2/rsy for non-coastal plants. Coastal plants have higher frequencies because many of the severe-weather-related LOOPs are the result of salt spray or high winds. The salt spray events occur only at coastal plants, and the frequencies for high winds (mainly due to hurricanes) are generally higher for coastal plants.

Table 3-4. LOOP frequency comparison (1986 – 1996 versus 1997 – 2003).

		LOOP Data and Results (1986 - 1996)				LOOP Data and Results (1997 - 2003)			
Mode	LOOP Category	Events	Reactor Critical or Shutdown Years	Mean Frequency (note a)	Frequency Units (note b)	Events	Reactor Critical or Shutdown Years	Mean Frequency (note a)	Frequency Units (note b)
Critical operation	Plant centered	11	879.3	1.31E-02	/rcry	1	629.5	2.38E-03	/rcry
	Switchyard centered	23	879.3	2.67E-02	/rcry	5	629.5	8.74E-03	/rcry
	Grid related	1	879.3	1.71E-03	/rcry	10	629.5	1.67E-02	/rcry
	Severe weather related	3	879.3	3.98E-03	/rcry	1	629.5	2.38E-03	/rcry
	Extreme weather related	2	879.3	2.84E-03	/rcry	1	629.5	2.38E-03	/rcry
	All			4.83E-02	/rcry			3.26E-02	/rcry
Shutdown operation	Plant centered	14	281.7	5.15E-02	/rsy	5	96.4	5.71E-02	/rsy
	Switchyard centered	31	281.7	1.12E-01	/rsy	7	96.4	7.78E-02	/rsy
	Grid related	1	281.7	5.32E-03	/rsy	2	96.4	2.59E-02	/rsy
	Severe weather related	7	281.7	2.66E-02	/rsy	2	96.4	2.59E-02	/rsy
	Extreme weather related	0	281.7	1.77E-03	/rsy	0	96.4	5.19E-03	/rsy
	All			1.97E-01	/rsy			1.92E-01	/rsy

a. The mean is a Bayesian update using a Jeffreys prior. Mean = (0.5 + events)/(critical or shutdown years).

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

Table 3-5. LOOP frequency regional differences.

Mode	LOOP Category	Subgroup (Region)	LOOP Frequency				
			Data Group	Events	Reactor Critical or shutdown years	Mean Frequency (note a)	Frequency Units (note b)
Critical operation	Plant centered	N/A	1997 - 2003	1	629.5	2.38E-03	/rcry
	Switchyard centered	N/A	1997 - 2003	5	629.5	8.74E-03	/rcry
	Grid related	ECAR	1997 - 2003	2	41.1	3.52E-02	/rcry
		FRCC	1997 - 2003	0	31.6	8.13E-03	/rcry
		MAAC	1997 - 2003	2	82.2	2.23E-02	/rcry
		MAIN	1997 - 2003	0	88.3	4.23E-03	/rcry
		MAPP	1997 - 2003	0	37.1	7.46E-03	/rcry
		NPCC	1997 - 2003	6	64.0	6.92E-02	/rcry
		SERC	1997 - 2003	0	190.6	2.27E-03	/rcry
		SPP	1997 - 2003	0	19.0	1.02E-02	/rcry
		ERCOT	1997 - 2003	0	25.4	9.04E-03	/rcry
		WECC	1997 - 2003	0	50.2	6.24E-03	/rcry
	Severe weather related	N/A	1986 - 2003	4	1508.8	2.98E-03	/rcry
	Extreme weather related	N/A	1986 - 2003	3	1508.8	2.32E-03	/rcry
Shutdown operation	Plant centered	N/A	1986 - 2003	19	378.1	5.16E-02	/rsy
	Switchyard centered	N/A	1986 - 2003	38	378.1	1.02E-01	/rsy
	Grid related	N/A	1986 - 2003	3	378.1	9.26E-03	/rsy
	Severe weather related	Coastal	1986 - 2003	7	151.9	4.37E-02	/rsy
		Non-coastal	1986 - 2003	2	226.3	1.02E-02	/rsy
	Extreme weather related	N/A	1986 - 2003	0	378.1	1.32E-03	/rsy

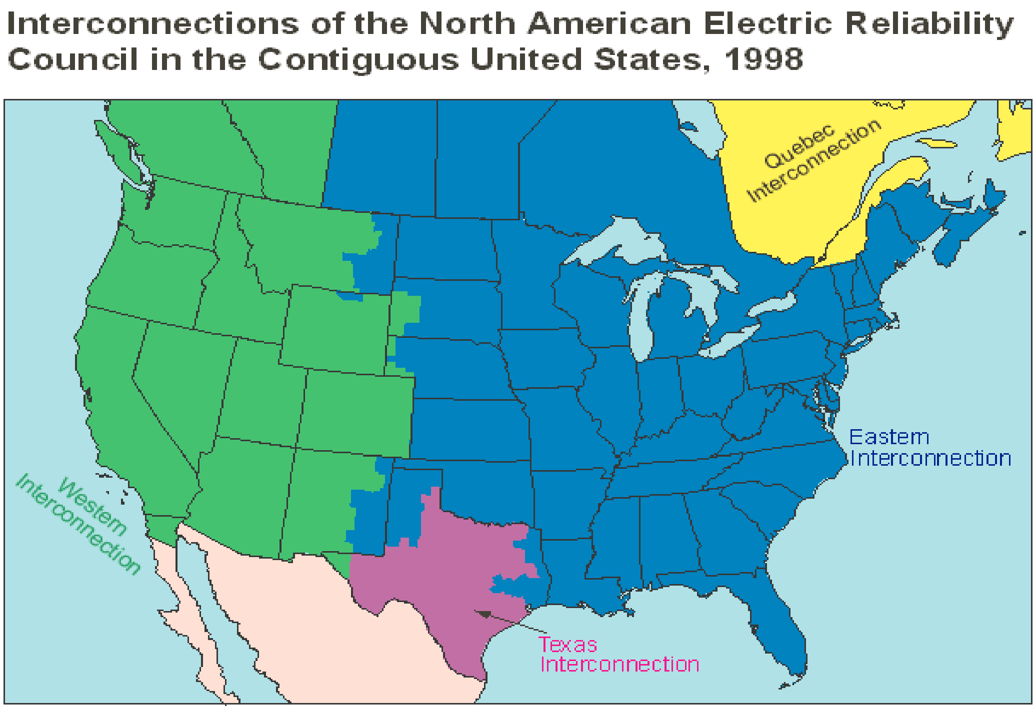
a. For LOOP categories without a subgroup breakdown, the mean is a Bayesian update using a Jeffreys prior. In that case, mean = (0.5 + events)/(critical or shutdown years). For subgroup breakdowns, the mean is a Bayesian update using a constrained noninformative prior (with mean obtained from the industry result in Table 3-1). For example, for grid-related, the subgroup result for critical operation is mean = (0.5 + events)/(29.9 + critical years). (For the constrained noninformative gamma prior, "a" = 0.5 and "b" = "a"/industry mean = 29.9.)

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

Note – See Table A-3 in Appendix A for a listing of the coastal and non-coastal plants.
Note – U.S. Nuclear Plants Country-Wide Map. Copyright © 2004 Nuclear Energy Institute.

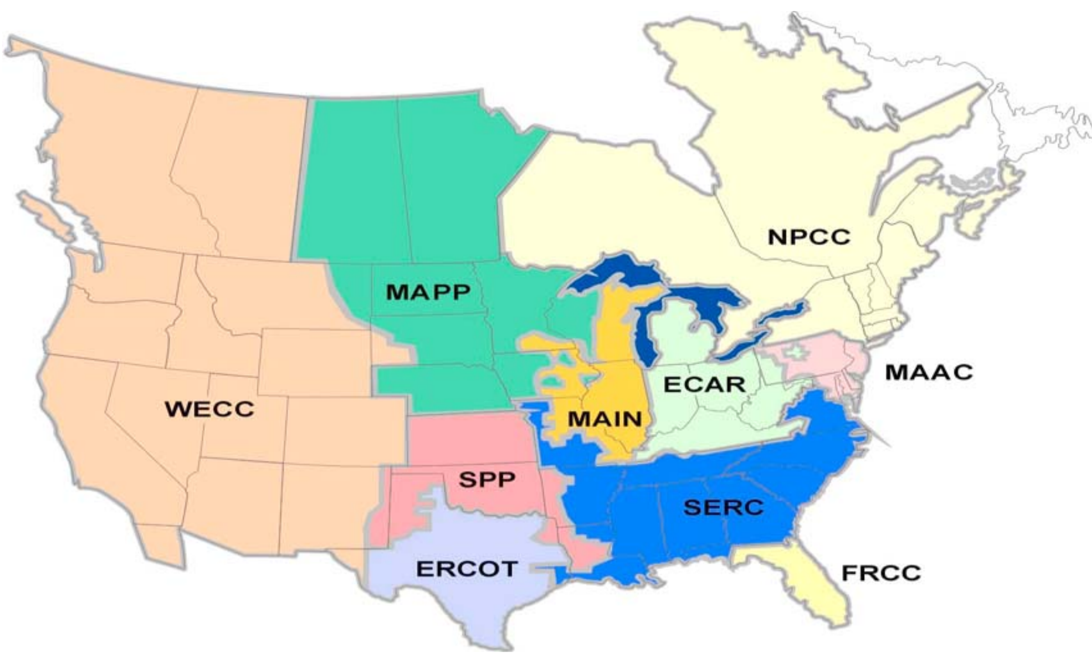
Figure 3-7. Coastal versus non-coastal regions.

Grid-related LOOP analysis by region included three different subdivisions (Figure 3-8 through Figure 3-10): North American Electric Reliability Council (NERC) interconnections (three regions), NERC reliability councils (10 regions), and NERC sub-regions (18 sub-regions with one not containing any commercial nuclear power plants). Empirical Bayes analyses identified the NREC reliability council and NERC sub-regions as significant geographical groups during critical operation. (At the interconnection level, there were too few commercial nuclear power plants in the western and Texas interconnection regions to distinguish their performance from the eastern interconnection region. Also, for shutdown operation there were too few events to distinguish regions.) However, this analysis is complicated by the dominance of one grid disturbance event, the August 14, 2003 event causing a LOOP at nine plants (eight of which were in critical operation). The total number of grid-related events during 1997 – 2003 for critical operation is only 10, so this event clearly dominates. Regional results are presented in Table 3-5 for the NERC reliability councils. Grid-related frequencies for these councils range from a low of 2.3E-3/rcry for the Southeastern Electric Reliability Council (SERC) to a high of 6.9E-2/rcry for the Northeastern Power Coordinating Council (NPCC). However, all six of the NPCC events and both of the East Central Area Reliability Coordination Agreement (ECAR) Council events are the result of the August 14, 2003 grid disturbance event. Although these reliability council frequency estimates for grid-related LOOPs are indicative of recent past performance, the dominance of one event indicates that the frequency estimates may not be representative of future performance.



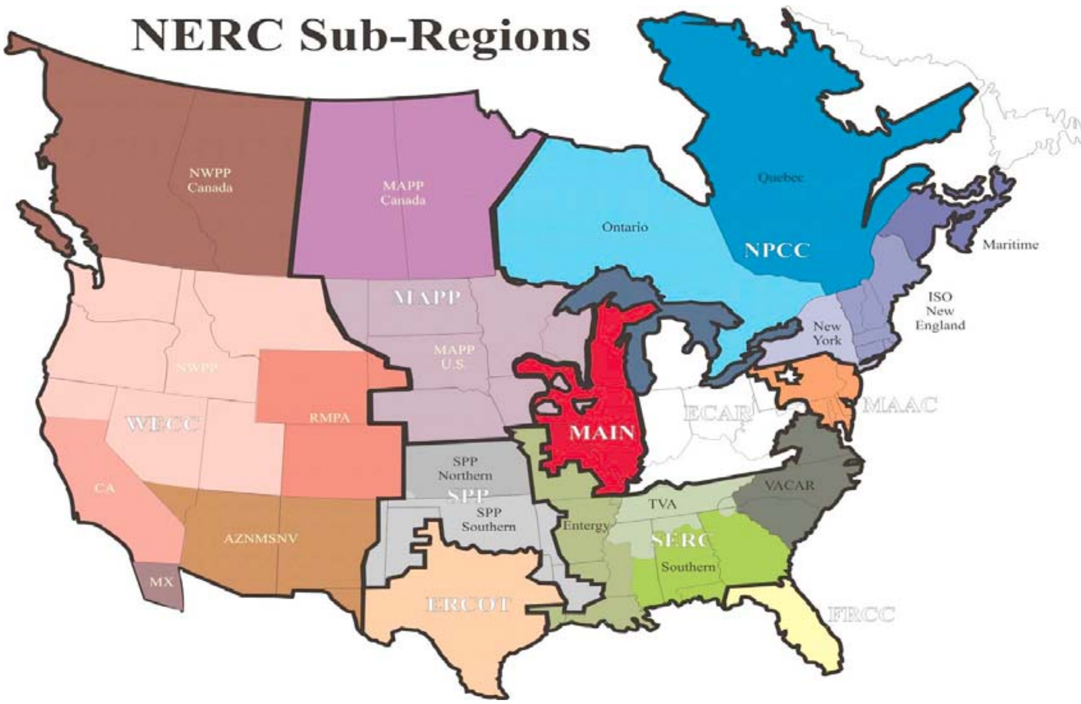
Note – [NERC Interconnections](#).

Figure 3-8. NERC reliability council interconnection regions.



Note – [NERC Regions Map](#).

Figure 3-9. NERC reliability council regions.



Note – NERC subregions.

Figure 3-10. NERC sub-regions.

Grid-related frequencies are not presented for the NERC sub-regions, which are a finer breakdown than the NERC reliability councils. At this finer breakdown, the impact of the August 14, 2003 grid disturbance is even greater, and frequency estimates may be even less indicative of future performance.

3.4 LOOP Plant-Specific Frequencies

LOOP frequencies for a specific plant can be estimated in several ways. One approach is to use the industry frequencies presented in Table 3-1 (and distribution information in Table 3-3) for all of the 103 operating plants. Using this approach, the overall LOOP frequency for each of the 103 plants during critical operation is 3.3E-2/rcry, and 1.9E-1/rsy for shutdown operation.

Another approach is to use the regional information in Table 3-5. (This approach is similar to what was done in NUREG-1032, except that design characteristic or environmental groupings were used rather than regions in that study.) For example, consider the Indian Point 2 plant, which lies within the NPCC reliability council for grid-related LOOPs. (For critical operation, only the grid-related LOOPs exhibited a significant regional dependence.) The industry frequencies for plant-centered, switchyard-centered, severe-weather-related, and extreme-weather-related LOOPs are applicable to Indian Point 2. For grid-related LOOPs, the NPCC reliability council regional frequency is 6.9E-2/rcry. Therefore, the overall LOOP frequency for critical operation at Indian Point 2 is

2.4E-3/rcry + 8.7E-3/rcry + 6.9E-2/rcry + 3.0E-3/rcry + 2.3E-3/rcry = 8.5E-2/rcry.

This compares with the industry value of 3.3E-2/rcry. Similarly, because Indian Point 2 is in the coastal region for severe-weather-related LOOPs, the overall LOOP frequency for shutdown operation at Indian Point 2 is

5.2E-2/rsy + 1.0E-1/rsy + 9.3E-3/rsy + 4.4E-2/rsy + 1.3E-3/rsy = 2.1E-1/rsy.

This compares with the industry value of 1.9E-1/rsy.

A third approach is to perform Bayesian updates with plant-specific data. The priors used in this Bayesian update process are the industry distributions listed in Table 3-3. Plant-specific data from 1997 - 2003 are used in the Bayesian update in order to reflect recent plant performance. This approach is similar to what was done in NUREG/CR-5496, except that plant-specific (or site-specific) estimates were generated only for those LOOP categories in which the empirical Bayes analyses indicated a significant difference between plants (or sites). For Indian Point 2, the 1997 – 2003 period for critical operation (4.64 rcry) included one switchyard-centered and one grid-related LOOP. There were no plant-centered or weather-related LOOPs. (See Appendix D for a listing of the plant-specific data for 1997 – 2003.) The Bayesian update for plant-centered LOOPs results in a posterior mean frequency of

(0.5 + 0)/(209.83 rcry + 4.64 rcry) = 2.3E-3/rcry.

Similar Bayesian updates for the other categories result in 2.4E-2/rcry for switchyard-related LOOPs, 4.3E-2/rcry for grid-related LOOPs, 2.9E-3/rcry for severe-weather-related LOOPs, and 2.3E-3/rcry for extreme-weather-related LOOPs. The overall LOOP frequency for critical operation at Indian Point 2 is then 7.5E-2/rcry. This compares with the industry value of 3.3E-2/rcry and the regional approach value of 8.5E-2/rcry.

For shutdown operation, Indian Point 2 experienced one plant-centered LOOP during 1997 – 2003 (2.36 rsy) and no LOOPs for the other four categories. Similar Bayesian updates for each of the five LOOP categories results in an overall LOOP frequency for shutdown operation of 2.5E-1/rsy. This compares with the industry value of 1.9E-1/rsy and regional approach value of 2.1E-1/rsy.

The results for all three approaches are summarized in Table 3-6. For plant-specific analyses based on current plant performance, the third approach discussed above is suggested. Plant-specific frequencies using this approach are presented in Appendix D. However, future plant performance may not match current plant performance given the infrequent nature of LOOPs and plant efforts to improve performance, so these Bayesian updates should be recalculated periodically to include the most recent plant-specific performance.

Table 3-6. Summary of plant-specific LOOP estimates for Indian Point 2.

Mode	LOOP Category	Indian Point 2 LOOPs during 1997 - 2003	LOOP Mean Frequency for Indian Point 2			
			Industry Frequency Approach	Regional Frequency Approach	Bayesian Update with Plant-Specific Experience	Frequency Units (note a)
Critical operation	Plant centered	0	2.38E-03	2.38E-03	2.33E-03	/rcry
	Switchyard centered	1	8.74E-03	8.74E-03	2.43E-02	/rcry
	Grid related	1	1.67E-02	6.92E-02	4.34E-02	/rcry
	Severe weather related	0	2.98E-03	2.98E-03	2.90E-03	/rcry
	Extreme weather related	0	2.32E-03	2.32E-03	2.32E-03	/rcry
	All	2	3.31E-02	8.56E-02	7.53E-02	/rcry

Table 3-6. Summary of plant-specific LOOP estimates for Indian Point 2. (continued)

Mode	LOOP Category	Indian Point 2 LOOPs during 1997 - 2003	LOOP Mean Frequency for Indian Point 2			
			Industry Frequency Approach	Regional Frequency Approach	Bayesian Update with Plant-Specific Experience	Frequency Units (note a)
Shutdown operation	Plant centered	1	5.16E-02	5.16E-02	1.24E-01	/rsy
	Switchyard centered	0	1.02E-01	1.02E-01	6.88E-02	/rsy
	Grid related	0	9.26E-03	9.26E-03	8.87E-03	/rsy
	Severe weather related	0	2.51E-02	4.37E-02	2.24E-02	/rsy
	Extreme weather related	0	1.32E-03	1.32E-03	1.31E-03	/rsy
	All	1	1.89E-01	2.08E-01	2.25E-01	/rsy

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

3.5 Comparison with Previous Studies

LOOP industry frequencies presented in Table 3-1 were compared with results from three previous reports: NUREG-1032, NUREG/CR-5496, and NUREG/CR-5750. NUREG-1032 covered the period 1968 – 1985. NUREG/CR-5496 covered 1980 – 1996, and NUREG/CR-5750 covered 1987 – 1995. The frequency comparison is summarized in Table 3-1. This frequency comparison is not exact because of differences in several areas: events included (functional LOOP events versus the more restrictive initial plant fault LOOP events) and frequency units (reactor critical year versus site calendar or critical year).

For critical operation, the combined plant-centered and switchyard-centered category frequency estimate has dropped significantly, from a high of 8.7E-2/rcry (NUREG-1032) to a low of 1.1E-2/rcry (this report). This trend is also shown in Figure 3-1 and Figure 3-2. Performance in terms of reducing LOOPs from causes within the control of the plant staff has improved considerably over the years. However, the grid-related LOOP frequency estimates show an initial improvement and then a recent decline. The NUREG-1032 frequency estimate is 1.8E-2/rcry. NUREG/CR-5496 indicated a significant improvement in grid performance in terms of LOOPs with a frequency estimate of 2.4E-3/rcry. However, the present report estimate for 1997 – 2003 is 1.7E-2/rcry, indicating a worsening of grid performance, mainly because of 2003. This is also shown in Figure 3-3. Plant staff generally does not have much influence on grid performance. Finally, the frequency estimates of severe-weather-related and extreme-weather-related LOOPs indicate a recent drop in the frequency estimate, from 1.1E-2/rcry to 5.3E-3/rcry.

For shutdown operation, the present results can be compared with NUREG/CR-5496. (NUREG/CR-5750 and NUREG-1032 did not cover shutdown operation.) The overall LOOP frequency is the same for both reports, 1.9E-1/rsy. However, the recent data analysis indicates improvement in the combined plant-centered and switchyard-centered category but worsening in the grid-related and severe-weather-related categories.

Table 3-7. LOOP frequency comparison with previous studies.

Mode	LOOP Category	This Report Mean Frequency	This Report Frequency Units (note a)	NUREG/CR-5750 (note b) Mean Frequency	NUREG/CR-5496 (note c) Mean Frequency	NUREG-1032 (note d) Mean Frequency
Critical operation	Plant centered	2.38E-03	/rcry	Categories not distinguished	4.4E-02	8.7E-02
	Switchyard centered	8.74E-03	/rcry	Categories not distinguished	Included in plant-centered category	Included in plant-centered category
	Grid related	1.67E-02	/rcry	Categories not distinguished	2.9E-03	1.8E-02
	Severe weather related	2.98E-03	/rcry	Categories not distinguished	1.2E-02	9.0E-03
	Extreme weather related	2.32E-03	/rcry	Categories not distinguished	Included in severe-weather-related category	2.0E-03
	All	3.31E-02	/rcry	4.6E-02	5.8E-02	1.1E-01
Shutdown operation	Plant centered	5.16E-02	/rsy	Shutdown not covered	1.8E-01	Shutdown not covered
	Switchyard centered	1.02E-01	/rsy	Shutdown not covered	Included in plant-centered category	Shutdown not covered
	Grid related	9.26E-03	/rsy	Shutdown not covered	3.3E-03	Shutdown not covered
	Severe weather related	2.51E-02	/rsy	Shutdown not covered	1.2E-02	Shutdown not covered
	Extreme weather related	1.32E-03	/rsy	Shutdown not covered	Included in severe-weather-related category	Shutdown not covered
	All	1.89E-01	/rsy	Shutdown not covered	1.9E-01	Shutdown not covered

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

b. The functional LOOP frequency estimate is presented. The initial plant fault frequency estimate is 2.4E-2/rcy.

c. Frequency estimates from Section 3.4 of NUREG/CR-5496. Grid-related and severe-weather-related LOOP frequencies are presented in terms of per site calendar year. Note that NUREG/CR-5496 excluded events in which the reactor trip preceded the LOOP, so its frequencies are representative of initial plant fault frequencies (using the NUREG/CR-5750 terminology) rather than functional LOOP frequencies.

d. Frequency estimates from Table 3.1 in NUREG-1032. Grid-related and severe-weather-related LOOP frequencies are presented in terms of per site calendar year. Note that NUREG-1032 excluded events in which the reactor trip preceded the LOOP, so its frequencies are representative of initial plant fault frequencies (using the NUREG/CR-5750 terminology) rather than functional LOOP frequencies. The extreme-weather-related LOOP frequency is for the SS3 group as indicated in ORNL/NRC/LTR-89/11.

4. LOOP DURATIONS

4.1 Probability of Exceedance versus Duration Analysis

Each LOOP has three durations associated with the event, indicating actual or potential times to restore offsite power to the switchyard or a safety bus. These three durations are listed in the Glossary. Switchyard restoration time is the duration from the start of the LOOP to when offsite power was restored (or could have been restored) to the switchyard. Actual bus restoration time is the duration from the start of the LOOP to when offsite power was actually restored to a safety bus. Finally, plants may delay the restoration of offsite power to safety buses when the emergency electrical power sources are running (and appear to be stable) because of other higher priorities related to the LOOP event. Therefore, the potential bus restoration time is the duration from the start of the LOOP to when offsite power could have been restored to a safety bus. Potential bus restoration times were estimated based on operator actions required to restore power from the switchyard to a safety bus given station blackout conditions (no emergency power sources powering safety buses). More details concerning the estimation of the potential bus restoration time are presented in Section 6.7, and a listing of LOOP events and their associated durations is presented in Appendix A.

The probability of exceedance versus LOOP duration analysis involves the examination of LOOP duration data within each LOOP category. The objective is to determine the probabilities of LOOPs exceeding various durations, given that a LOOP occurs. For example, what is the probability that a LOOP will require more than two hours to restore offsite power, given that the LOOP was plant centered? Similar to the approach used in NUREG-1032 and NUREG/CR-5496, the probability of exceedance versus duration analysis was performed on LOOP duration data aggregated at the site event level, rather than at the individual plant level. For example, if a single severe-weather occurrence resulted in a LOOP at both plants at a two-plant site, then this was considered to be a single piece of information for severe-weather-related LOOP durations. In this example, the restoration times (switchyard, potential bus, and actual bus) for the aggregated single piece of data are averages of the two individual plant entries. Two LOOP-causing occurrences resulted in simultaneous LOOPs at more than one site. One is the widespread winter storm that occurred during March 16 and 17, 1993 in the southeastern United States. That storm caused LOOPs at both Brunswick plants (late on March 16 for Brunswick 2 and early on March 17 for Brunswick 1) and at Crystal River 3 (March 17). Aggregating LOOP data at the site level for this event results in one Brunswick LOOP duration data entry and one Crystal River data entry. The other widespread event is the grid blackout on August 14, 2003, in which nine plants at six sites experienced LOOPs. At the Indian Point site, the potential bus restoration times were 99 minutes for Indian Point Units 2 and 3. At the Nine Mile Point and Fitzpatrick sites (considered one site in this report), the potential bus restoration times were 57, 385, and 168 minutes for Nine Mile Point Units 1 and 2 and Fitzpatrick, respectively. Other sites (with only one plant) had potential bus restoration times ranging from 50 to 849 minutes. Therefore, the differences in restoration times between sites for this event are greater than the differences between plants at a given site. Aggregating this widespread grid disturbance at the site level preserves the site-to-site variation observed. LOOP duration data aggregated at the site level are presented in Appendix A.

For risk analyses, the probability of not restoring offsite power to a safety bus at various times following initiation of the LOOP is needed. This information can be presented in the form of curves of probability of exceedance versus duration. These curves are generated by first fitting the potential bus restoration times for a given LOOP cause category to a density function (e.g., lognormal or Weibull). Then the probability of exceedance is determined by one minus the cumulative distribution function evaluated for a given duration. These probabilities are conditional upon experiencing the LOOP. Similar curves can be generated using the switchyard restoration or actual bus restoration times.

LOOP Durations

Probability of exceedance versus duration curves were generated for each of the five LOOP cause categories: plant centered, switchyard centered, grid related, severe weather related, and extreme weather related. No significant differences were identified 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 were identified within each LOOP category between the 1986 – 1996 and 1997 – 2003 data periods, so the entire 1986 – 2003 period was used. (See Section 4.2 for a discussion of trends in LOOP durations over the period 1986 – 2003. If the individual LOOP category data are combined, a statistically significant increasing trend in durations is observed over the period 1986 – 1996.) Both lognormal and Weibull curve fits were generated. In general, the Weibull curves fit the data better, so Weibull curve fits were used for all five LOOP cause categories. Details of the statistical analyses are presented in Appendices B and C.

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

$$f(t) = \frac{\alpha}{t}\left(\frac{t}{\beta}\right)^{\alpha} e^{-(t/\beta)^{\alpha}} \qquad (1)$$

$$F(t) = 1 - e^{-(t/\beta)^{\alpha}} \qquad (2)$$

where t = offsite power restoration time

α = Weibull shape parameter

β = Weibull scale parameter (h).

The definitions of the Weibull shape and parameters in Equations 1 and 2 are those found in Microsoft® Excel and the curve fitting software described in Appendix B. The definitions are not the same as those in NUREG-1032.

Results of the Weibull curve fits to the potential bus restoration times are summarized in Table 4-1. The corresponding probability of exceedance versus duration curves are presented in Figure 4-1 through Figure 4-7. For plant-centered LOOPs, the mean duration from the Weibull curve fit is 0.5 hour. Switchyard-centered LOOPs have a longer mean duration, 1.3 hours from the curve fit. Grid-related LOOPs have a mean duration of 2.7 hours. Finally, severe- and extreme-weather-related LOOPs have mean durations of 4.7 and 78 hours, respectively. Also shown in Table 4-1 are the mean durations from the actual LOOP data. Except for the severe-weather-related LOOP durations, the curve fit means lie within 4% of the actual means. For the severe-weather-related LOOPs, the curve fit mean is approximately 15% higher than the actual data mean.

The significant differences noted between plant-centered and switchyard-centered LOOP durations support the decision to distinguish between these two categories (compared with the single combined plant-centered LOOP category used in NUREG-1032 and NUREG/CR-5496). In addition, severe- and extreme-weather-related LOOPs exhibit very large differences, again supporting the decision to distinguish between these (compared with NUREG/CR-5496 using a single combined category).

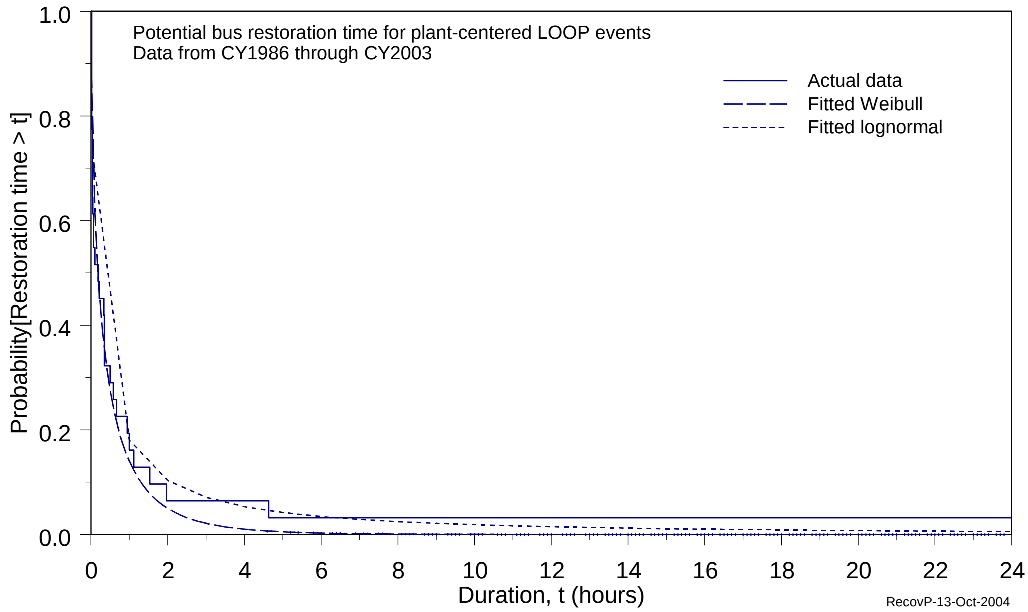


Figure 4-1. Probability of exceedance versus duration for plant-centered LOOPs.

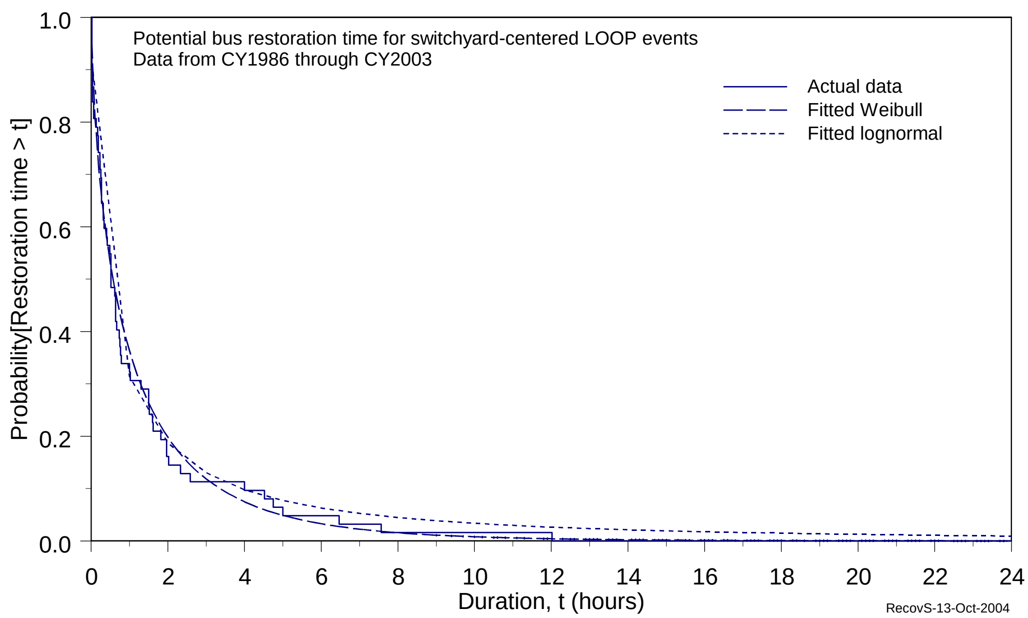


Figure 4-2. Probability of exceedance versus duration for switchyard-centered LOOPs.

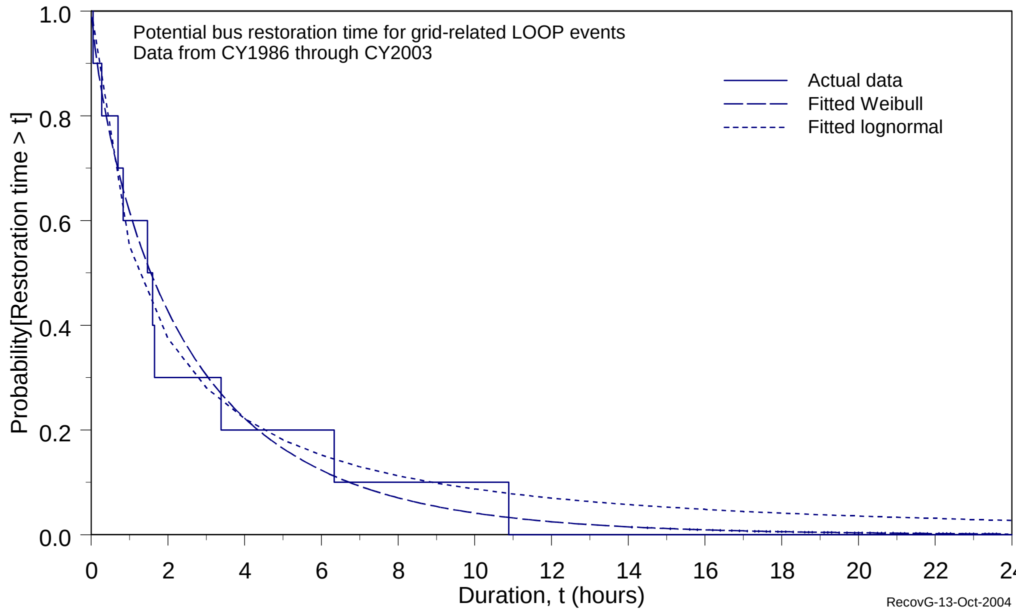


Figure 4-3. Probability of exceedance versus duration for grid-related LOOPs.

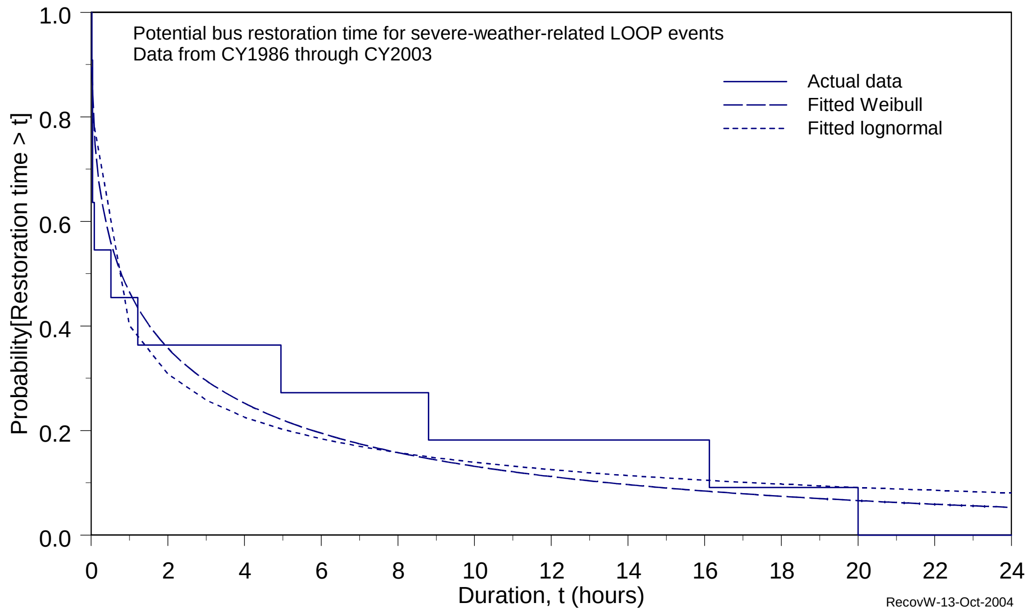


Figure 4-4. Probability of exceedance versus duration for severe-weather-related LOOPs.

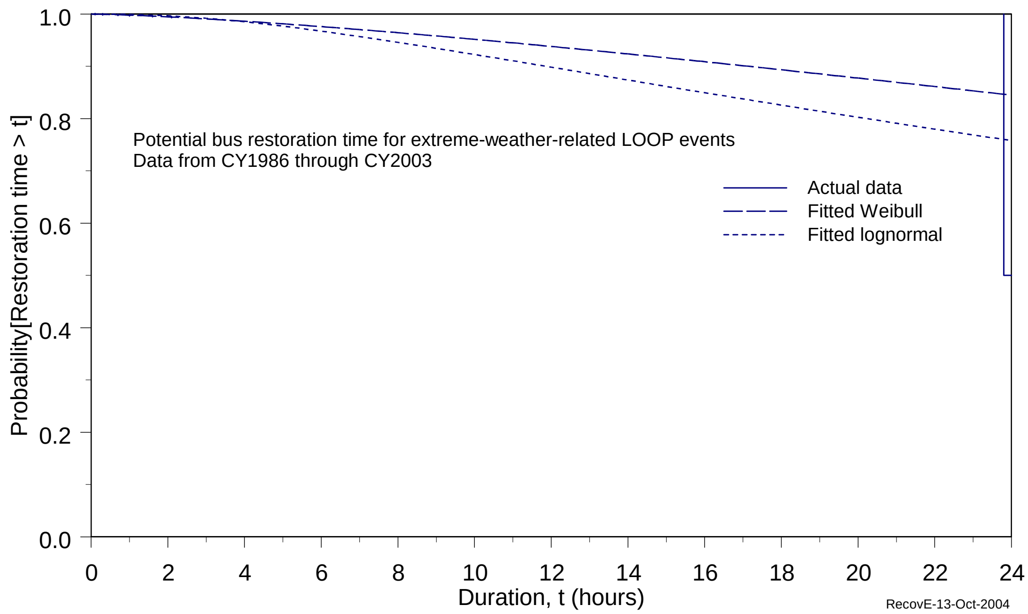


Figure 4-5. Probability of exceedance versus duration for extreme-weather-related LOOPs.

Table 4-1. Probability of exceedance versus duration curve fits and summary statistics.

Duration (h)	Probability of Exceedance (Potential bus Restoration)								
	LOOP Category (Critical or Shutdown Operation)					Critical Operation		Shutdown Operation	
	Plant Centered	Switchyard Centered	Grid Related	Severe Weather Related	Extreme Weather Related	Composite (note a)	Actual Data	Composite (note a)	Actual Data
0.0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
0.1	0.729	0.875	0.959	0.805	1.000	0.910	0.889	0.831	0.687
0.2	0.517	0.740	0.895	0.698	1.000	0.816	0.852	0.683	0.597
0.5	0.276	0.531	0.760	0.564	0.999	0.664	0.667	0.480	0.403
1.0	0.140	0.363	0.617	0.464	0.998	0.529	0.482	0.333	0.254
1.5	0.081	0.264	0.510	0.402	0.997	0.438	0.444	0.249	0.194
2.0	0.050	0.198	0.426	0.358	0.995	0.373	0.278	0.195	0.164
3.0	0.021	0.119	0.305	0.295	0.991	0.282	0.241	0.131	0.131
4.0	0.010	0.075	0.222	0.252	0.986	0.224	0.222	0.094	0.119
6.0	0.003	0.033	0.123	0.195	0.976	0.157	0.148	0.057	0.075
8.0	0.001	0.016	0.071	0.158	0.964	0.122	0.074	0.040	0.075
10.0	0.000	0.008	0.041	0.131	0.952	0.102	0.074	0.031	0.060
12.0	0.000	0.004	0.025	0.112	0.938	0.089	0.074	0.025	0.060
16.0	0.000	0.001	0.009	0.084	0.909	0.076	0.074	0.019	0.030
20.0	0.000	0.000	0.004	0.066	0.878	0.069	0.056	0.015	0.000
24.0	0.000	0.000	0.001	0.053	0.845	0.065	0.037	0.013	0.000
Weibull Fits									
p value (goodness of fit)	0.306	0.760	0.892	0.667	0.969				
Shape factor (a)	0.610	0.678	0.819	0.422	1.400				
Scale factor (b)	0.330	0.981	2.431	1.872	85.630				
Curve Fit 95% (h)	2.00	4.96	9.29	25.14	187.44				
Curve Fit Mean (h)	0.49	1.28	2.71	5.39	78.04				
Actual Data Mean (h)	0.51	1.31	2.72	4.71	77.91				
Curve Fit Median (h)	0.18	0.57	1.55	0.79	65.91				
Curve Fit 5% (h)	0.00	0.01	0.06	0.00	10.27				

a. The composite curve is a frequency-weighted average of the five individual category curves. Frequencies are presented in Table 3-1.

Figure 4-1 through Figure 4-5 present the probability of exceedance curves for the five LOOP event categories. Both Weibull and lognormal curve fits are shown, but as discussed previously, the Weibull curve fits were selected for use. Also shown in these figures are the actual data, to show how well the Weibull and lognormal curves fit the data. Figure 4-6 presents all five probability of exceedance curves in one graph for comparison purposes. As expected, the plant-centered LOOPs result in the lowest probabilities of exceedance versus duration, and switchyard-centered LOOPs have the next lowest probabilities. Severe-weather-related LOOPs and grid-related LOOPs have curves that intersect, with severe-weather-related LOOPs having lower probabilities of exceedance up to approximately three hours and higher probabilities after three hours. Finally, the extreme-weather-related LOOPs result in the highest probabilities of exceedance.

The composite probability of exceedance curves summarized in Table 4-1 and illustrated in Figure 4-7 for critical operation and shutdown operation are frequency-weighted averages of the five individual category curves. Although the individual category curves are applicable to both critical and shutdown operation (both types of data were used to generated the curves), the different frequencies for critical operation and shutdown operation result in differing composite curves. For risk assessment models that do not distinguish the different LOOP categories and use a single overall LOOP frequency, the corresponding composite probability of exceedance curve is used. However, if the risk model distinguishes between the different LOOP categories, then curves for each individual LOOP category are used.

Finally, Figure 4-8 through Figure 4-12 show for each LOOP category the probability of exceedance curves based on switchyard, potential bus, and actual bus restoration times. The potential bus curves lie between those for the switchyard and actual bus curves (except for a portion of the grid-related LOOP figure) and typically are close to the switchyard curves.

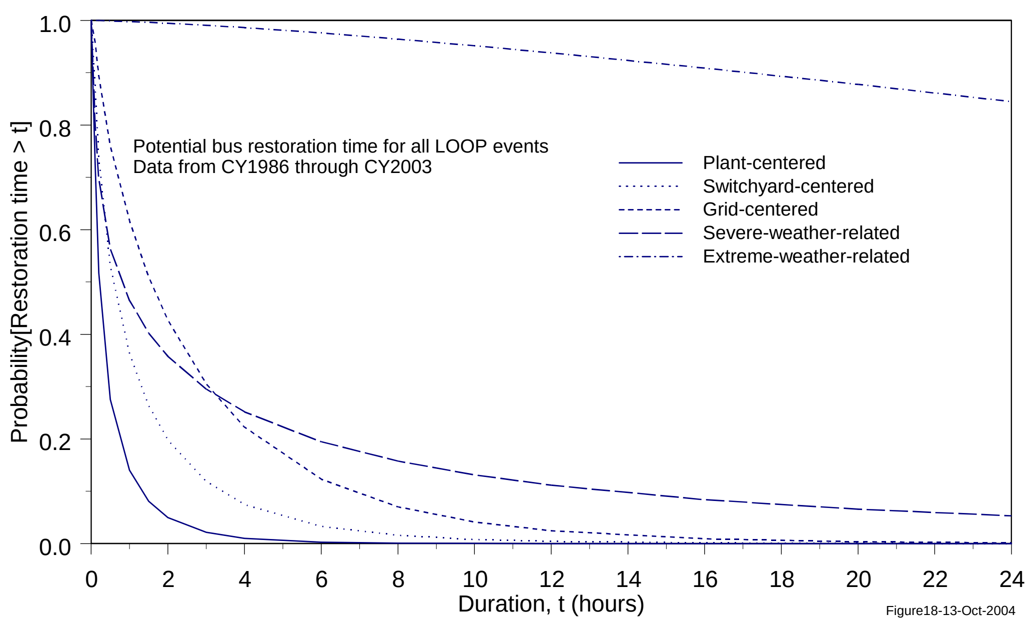


Figure 4-6. Summary of probability of exceedance versus duration curves.

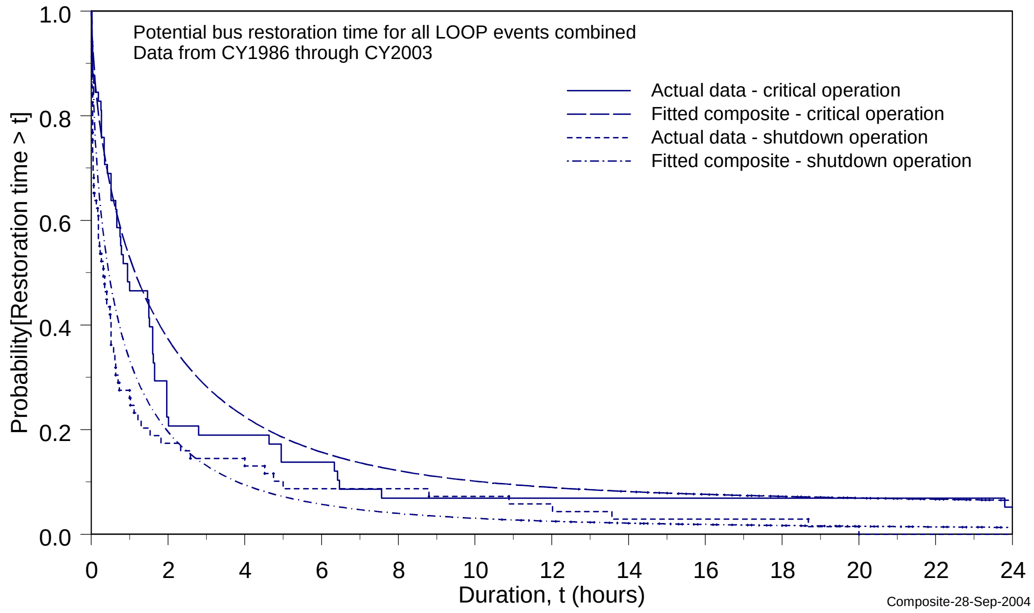


Figure 4-7. Probability of exceedance versus duration composite for all LOOPs.

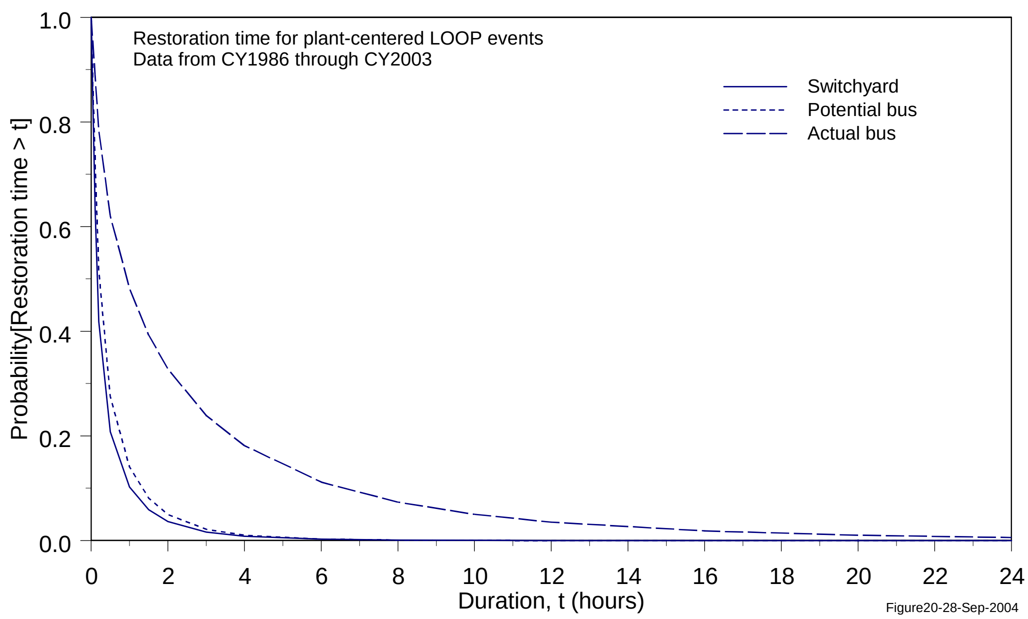


Figure 4-8. Probability of exceedance versus duration for switchyard, potential bus, and actual bus restoration for plant-centered LOOPs.

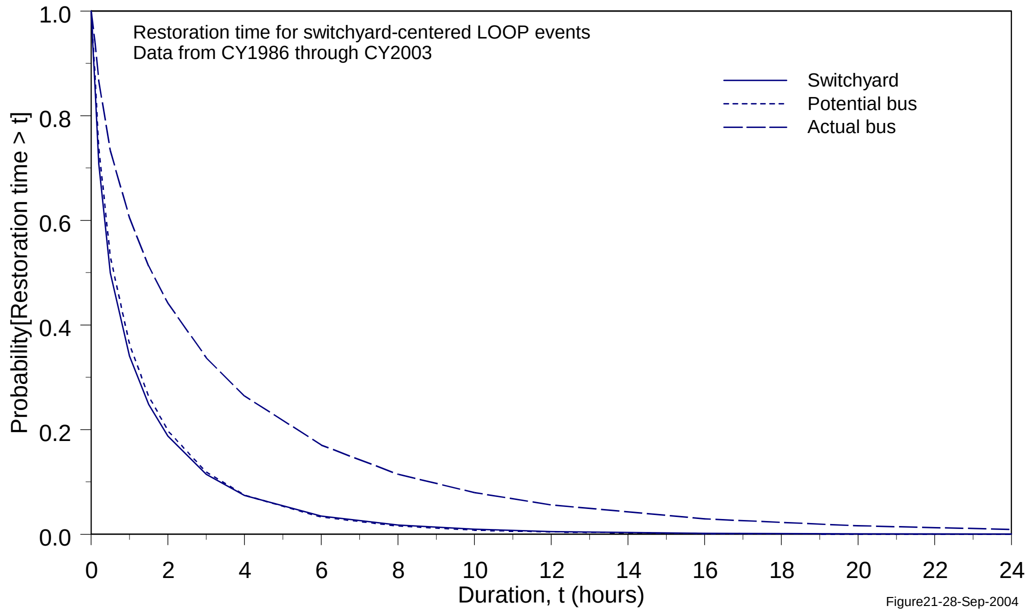


Figure 4-9. Probability of exceedance versus duration for switchyard, potential bus, and actual bus restoration for switchyard-centered LOOPs.

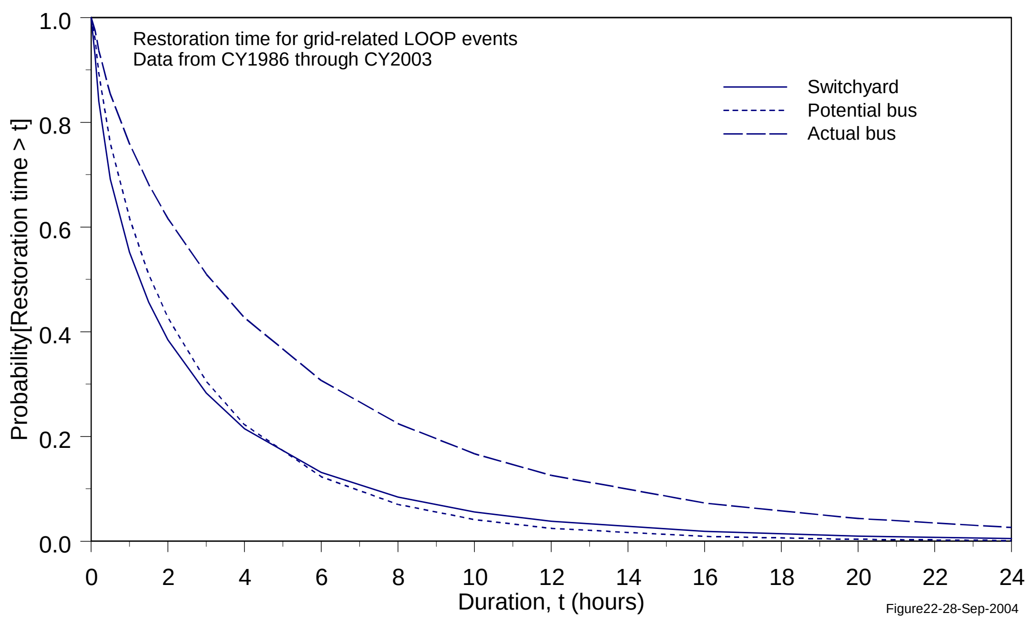


Figure 4-10. Probability of exceedance versus duration for switchyard, potential bus, and actual bus restoration for grid-related LOOPs.

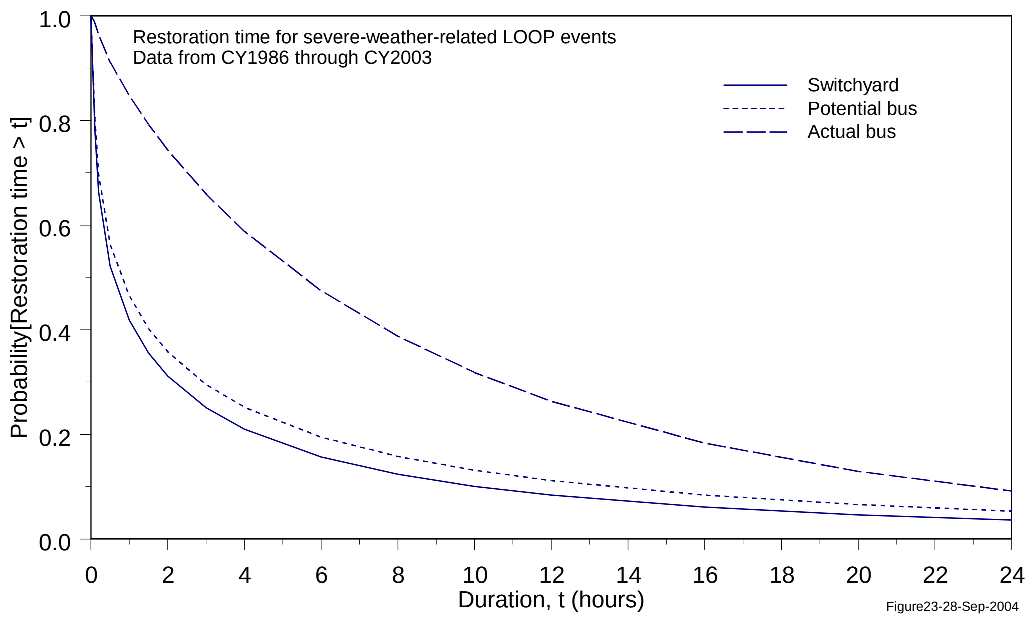


Figure 4-11. Probability of exceedance versus duration for switchyard, potential bus, and actual bus restoration for severe-weather-related LOOPs.

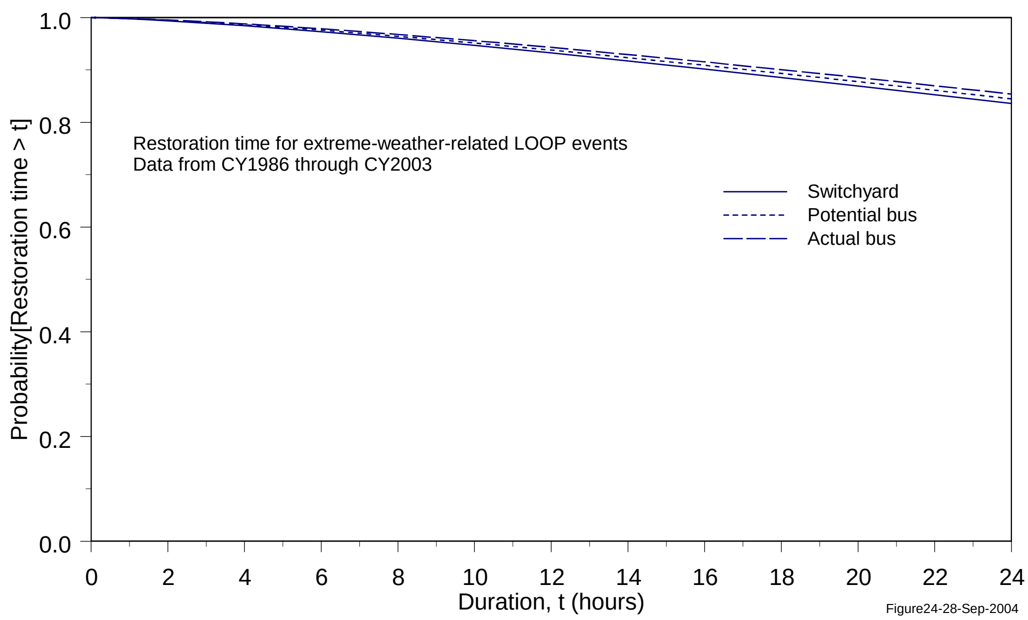
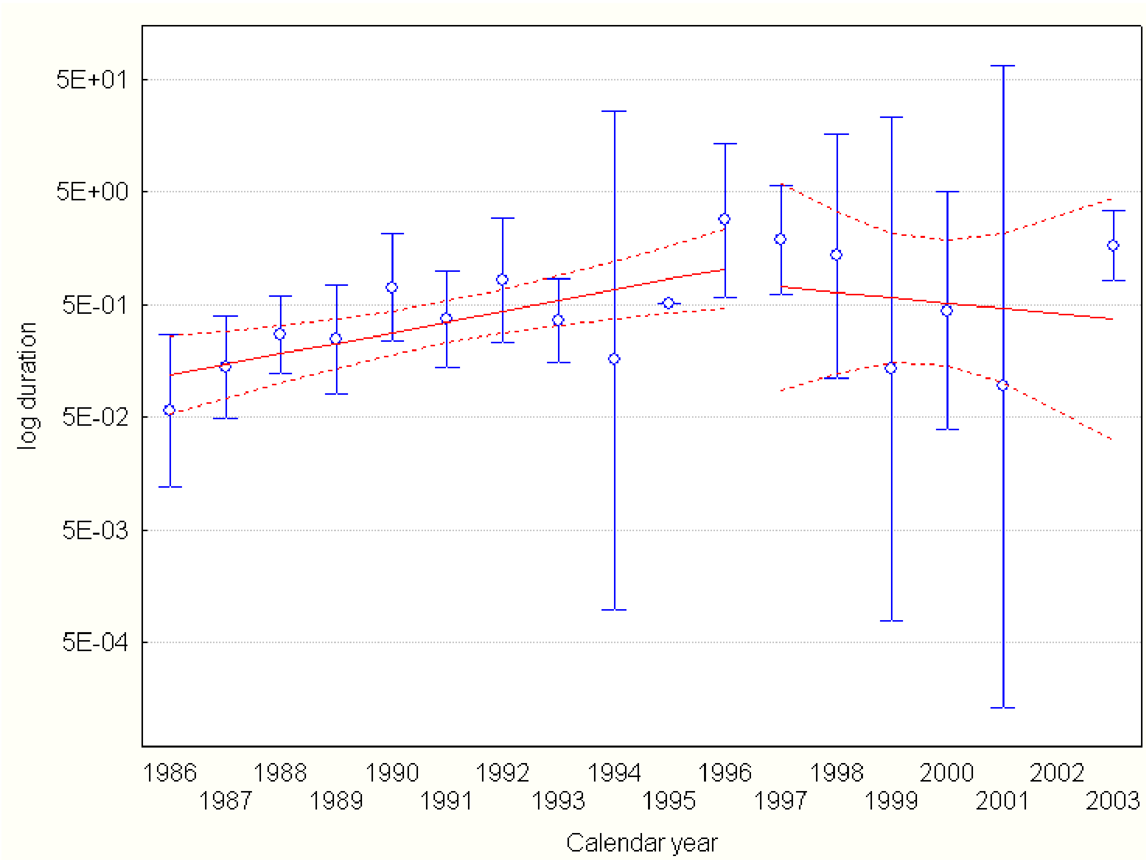


Figure 4-12. Probability of exceedance versus duration for switchyard, potential bus, and actual bus restoration for extreme-weather-related LOOPs.

4.2 Trending of LOOP Durations

As discussed in Section 4.1, LOOP duration data over the entire period 1986 – 2003 were used to generate probability of exceedance versus duration curves for each of the five LOOP categories. Statistical analyses indicated that within each category, there was not a statistically significant difference between the 1986 – 1996 data and the 1997 – 2003 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 – 2003 duration data do not exhibit a significant trend. The results of this trending analysis are presented in Figure 4-13. Finally, if the entire period 1986 – 2003 is considered, there is no statistically significant trend in LOOP durations.



Note – The increasing trend over for 1986 – 1996 is statistically significant (p-value for the slope is 0.016), while the apparently decreasing trend over 1997 – 2003 is not statistically significant (p-value for the slope is 0.736).

Figure 4-13. Trend plot of LOOP duration for 1986 – 1996 and 1997 – 2003.

4.3 Comparison with Previous Studies

The probability of exceedance versus duration curves developed in this study, based on LOOP data over the period 1986 – 2003, can be compared with similar curves from NUREG-1032 and NUREG/CR-5496. However, NUREG-1032 combined plant-centered and switchyard-centered LOOPs into a single plant-centered category. In addition, NUREG/CR-5496 combined severe-weather-related and extreme-weather-related LOOPs. Therefore, in order to compare the present study results with those from these

other reports, three LOOP categories were used: plant centered (including switchyard centered), grid related, and severe weather related (including extreme weather related). In addition, the actual Weibull curve parameters for NUREG-1032 were not listed in that report. Instead, the report ORNL/NRC/LTR-89/11 [8] was used. The Weibull parameters in the ORNL report are defined differently compared with the present report, so conversions were performed to make the parameters consistent. Finally, NUREG/CR-5496 did not include the momentary events (those with offsite power restoration times less than two minutes) in its curve fits.

Results are presented in Figure 4-14 through Figure 4-16 for these three categories. In addition, overall composite curves are compared in Figure 4-17. Finally, mean and median LOOP durations from the current study, NUREG/CR-5496, and NUREG-1032 are summarized in Table 4-2. All of the values in Table 4-2 were calculated from the actual data rather than from the curve fits.

For plant-centered (including switchyard-centered) LOOPs (Figure 4-14), the current study curve agrees well with the NUREG/CR-5496 curve, indicating that LOOP durations for these types of events have not changed significantly since 1996 (the last year covered by NUREG/CR-5496). However, both of these curves lie well above the NUREG-1032 curve, indicating that durations for these LOOPs since 1985 (the last year covered by NUREG-1032) have increased. Table 4-2 also supports these conclusions.

Grid-related LOOP durations in Figure 4-15 also show the current study and NUREG/CR-5496 curves lying above the NUREG-1032 results. However, the current study curve lies below the NUREG/CR-5496 curve up to approximately five hours and then above for beyond five hours. Table 4-2 supports these observations. Both the median and mean durations from NUREG-1032 lie significantly below those from the other two studies. In addition, the current study median is lower than the NUREG/CR-5496 value, while the mean is higher. This explains the crossover in curves.

Severe-weather-related (including extreme-weather-related) LOOP duration curves are presented in Figure 4-16. Unlike the other two cases, the NUREG-1032 and NUREG/CR-5496 curves are similar, while the current study curve lies below them up to approximately four hours and then above them beyond four hours. This behavior is not obvious from the summary statistics presented in Table 4-2. However, the summary statistics are based on all of the LOOP data, while NUREG/CR-5496 excluded the momentary events when determining its curve fits. The fraction of events that were momentary in the NUREG/CR-5496 data set is much higher than for the other two data sets.

Finally, the LOOP duration composite curve comparison for critical operation is presented in Figure 4-17. With respect to composite curves, the current study results lie above the NUREG/CR-5496 results and significantly above the NUREG-1032 results.

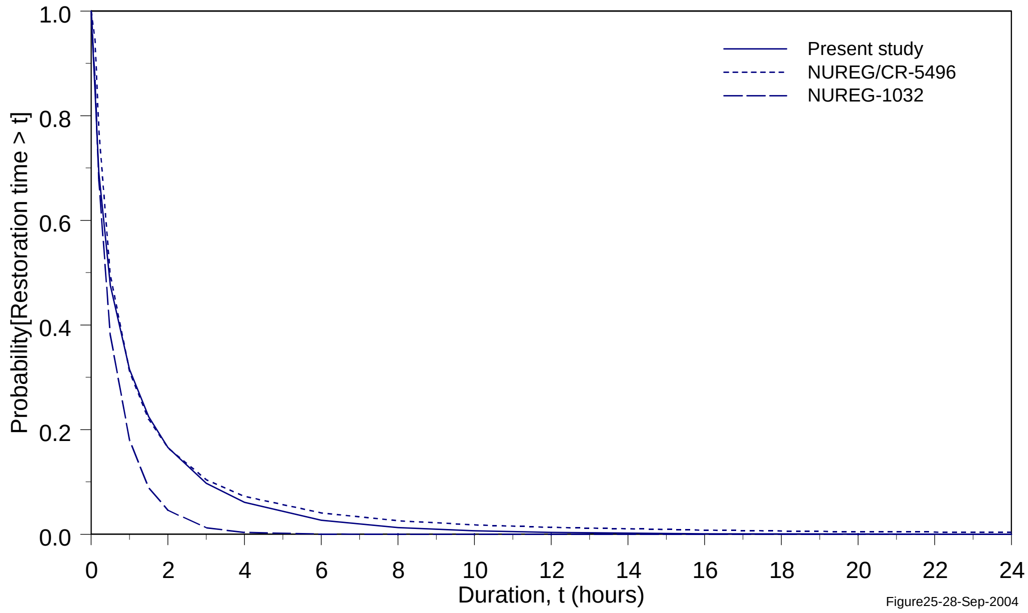


Figure 4-14. Probability of exceedance versus duration comparison for plant-centered LOOPs.

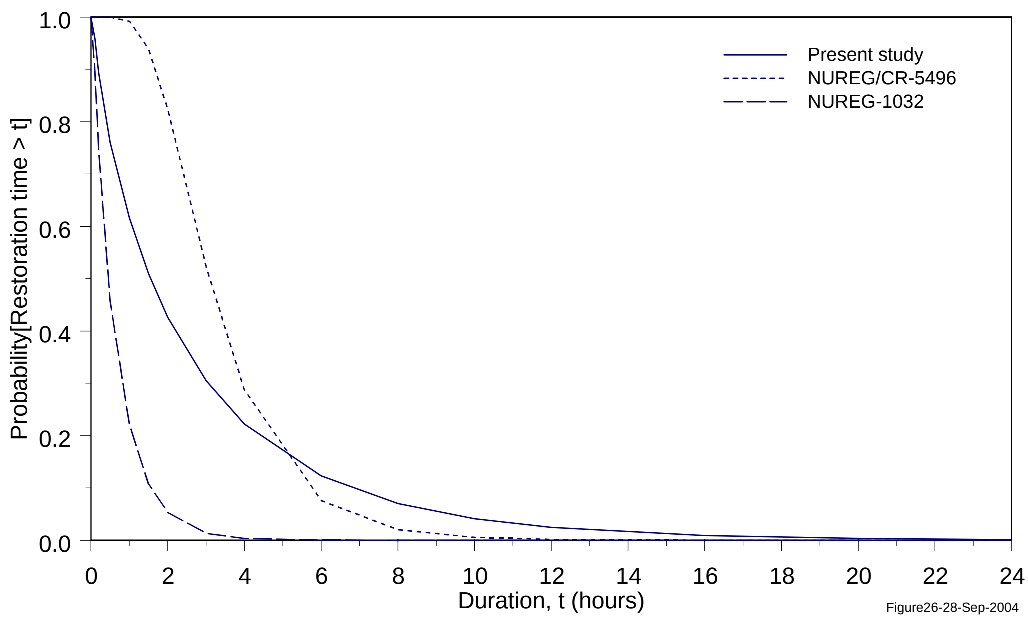


Figure 4-15. Probability of exceedance versus duration comparison for grid-related LOOPs.

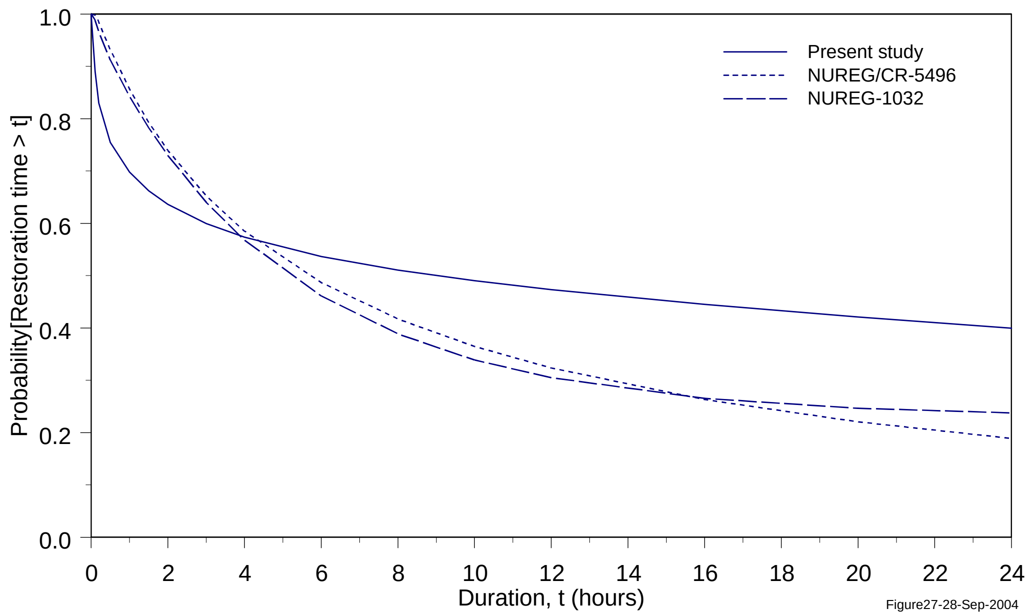


Figure 4-16. Probability of exceedance versus duration comparison for severe-weather-related LOOPs.

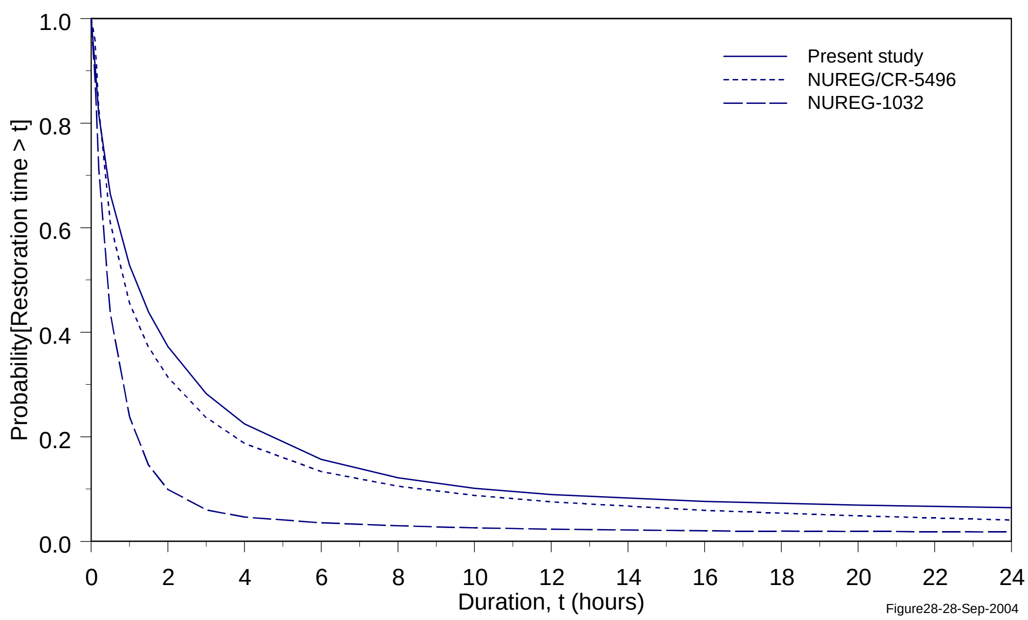


Figure 4-17. Probability of exceedance versus duration composite comparison.

Table 4-2. LOOP duration comparison with previous studies.

LOOP Category	Summary Statistic	Present Study	NUREG/CR-5496	NUREG-1032	Comments
Plant Centered (including switchyard centered)	Data Period	1986 - 2003	1980 - 1996	1968 - 1985	
	Median Duration (h) (Actual Data)	0.38	0.33	0.26	Present study excluded Diablo Canyon event as an outlier.
	Mean Duration (h) (Actual Data)	1.05	1.22	0.45	Present study excluded Diablo Canyon event as an outlier.
	Type of Fit	Weibull	Lognormal	Weibull	NUREG/CR-5496 excluded momentary events in the curve fit.
Grid Related	Data Period	1986 - 2003	1980 - 1996	1968 - 1985	
	Median Duration (h) (Actual Data)	1.53	2.38	0.55	
	Mean Duration (h) (Actual Data)	2.72	2.64	1.24	
	Type of Fit	Weibull	Lognormal	Weibull	NUREG/CR-5496 excluded momentary events in the curve fit.
Severe Weather Related (including extreme weather related)	Data Period	1986 - 2003	1980 - 1996	1968 - 1985	
	Median Duration (h) (Actual Data)	1.22	1.18	4.50	NUREG-1032 had no extreme-weather-related events.
	Mean Duration (h) (Actual Data)	15.97	11.80	4.64	NUREG-1032 had no extreme-weather-related events.
	Type of Fit	Weibull	Lognormal	Weibull	NUREG/CR-5496 excluded momentary events in the curve fit.

LOOP Durations

5. COMBINING LOOP FREQUENCY AND DURATION

Section 3 discussed the current study LOOP frequencies and compared them with results from previous studies. In addition, Section 4 addressed the LOOP durations on a conditional basis (given the occurrence of a LOOP). The combined impact of LOOP frequency and LOOP duration on plant risk can be examined by generating frequency of exceedance versus duration curves. These curves are similar to the conditional probability of exceedance curves, but multiplied by the LOOP frequency. Current study results for the five LOOP categories are presented in Figure 5-1 and Figure 5-2 for critical operation and shutdown operation, respectively. Given a plant risk model with constant input parameters except for the LOOP category frequencies and durations, the curves in Figure 5-1 and Figure 5-2 are indications of the relative risk from LOOP initiated core damage scenarios from each LOOP category. The composite frequency of exceedance curves shown in the figures are the summation of the individual curves.

As indicated in Figure 5-1 for critical operation, grid-centered LOOPs dominate the frequency of exceedance versus duration curves up to approximately six hours. This reflects the relatively high frequency for grid-related LOOPs during critical operation and the moderate durations. Beyond six hours, the extreme-weather-related LOOPs dominate. In addition, up to approximately one and one-half hours, the switchyard-centered LOOPs are important contributors, again mainly because of the relatively high frequency.

For shutdown operation (Figure 5-2), the switchyard-centered LOOPs dominate the frequency of exceedance curves up to approximately five hours. This reflects the high relative frequency of such events during shutdown operation and the moderate durations. Beyond five hours, the severe-weather-related LOOPs dominate. Unlike the critical operation results, the extreme-weather-related LOOPs are only a minor contributor.

Finally, the composite frequency of exceedance versus duration curve for critical operation from this study is compared with similar results from NUREG-1032 and NUREG/CR-5496 in Figure 5-3. Two separate curves are presented for NUREG/CR-5496, one using the frequencies from that study including momentary LOOPs and the other using frequencies not including momentary LOOPs. Because NUREG/CR-5496 did not use the momentary LOOPs in its duration analysis, the most appropriate curve is probably the one using frequencies evaluated without momentary LOOPs. In addition, the current Standardized Plant Analysis Risk (SPAR) modeling for LOOPs is presented in Figure 5-3. The SPAR models use the NUREG-1032 composite curve for probability of exceedance versus duration, but use the functional LOOP frequency of 4.6E-2/rcry from NUREG/CR-5750. Given a plant risk model with constant input parameters except for the LOOP frequencies and durations, the curves in Figure 5-3 are indications of the relative risk from LOOP initiated core damage scenarios from each data set. From Figure 5-3, the composite curve based on the current study data (representative of the period 1997 – 2003) lies below the NUREG/CR-5496 curve (1980 – 1996) and significantly below the NUREG-1032 curve (1968 – 1985) up to approximately two hours. Therefore, the increased LOOP durations (compared with the NUREG-1032 data collection period of 1968 – 1985) are compensated for by the reduction in LOOP frequency. Finally, current study results are lower than the SPAR model only up to approximately one-half hour and are higher beyond that time.

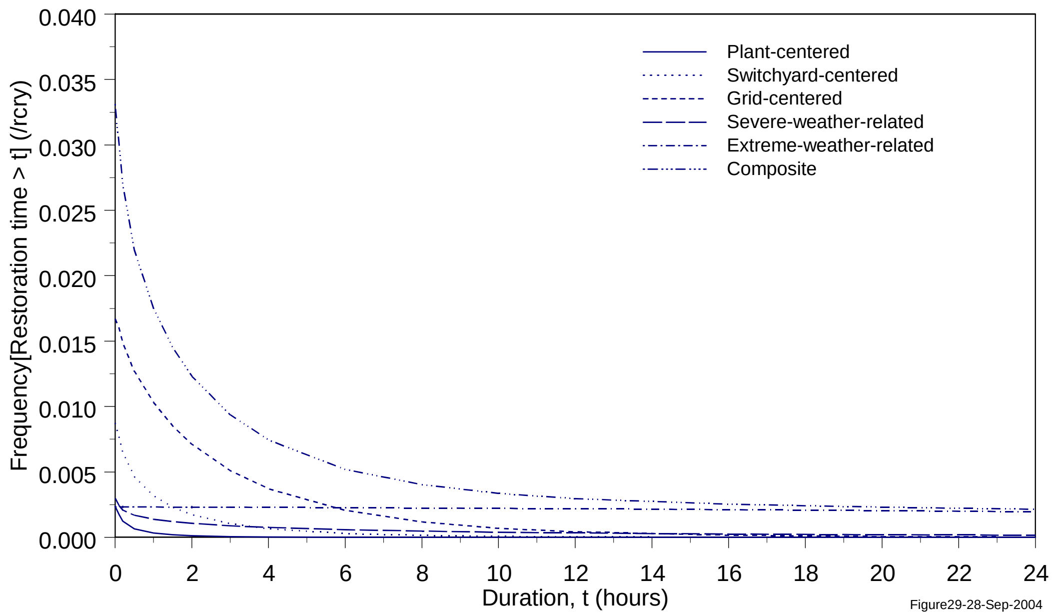


Figure 5-1. Frequency of exceedance versus duration for critical operation.

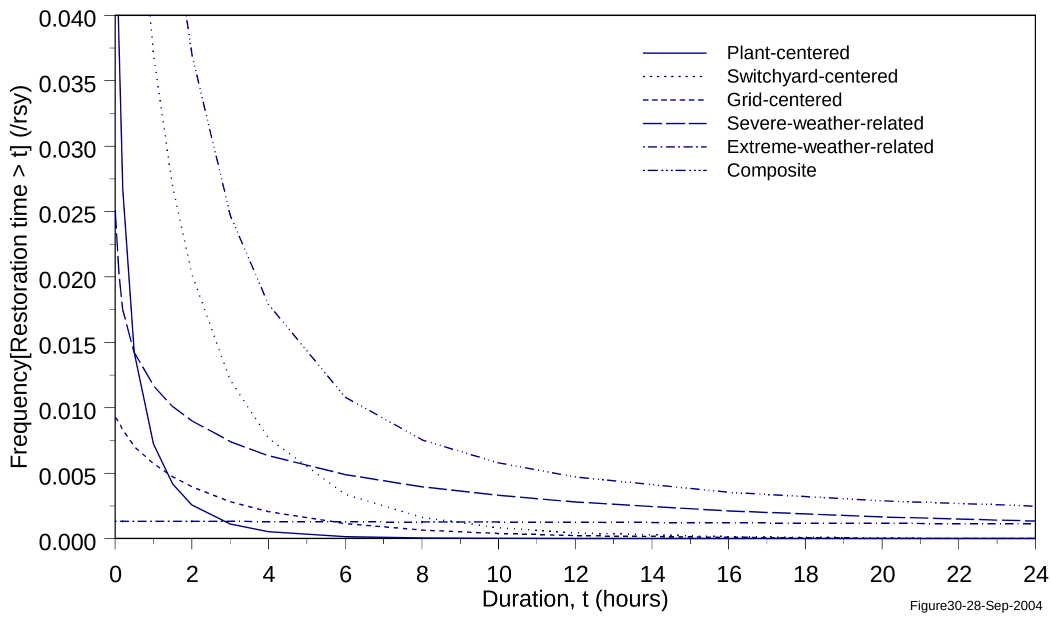


Figure 5-2. Frequency of exceedance versus duration for shutdown operation.

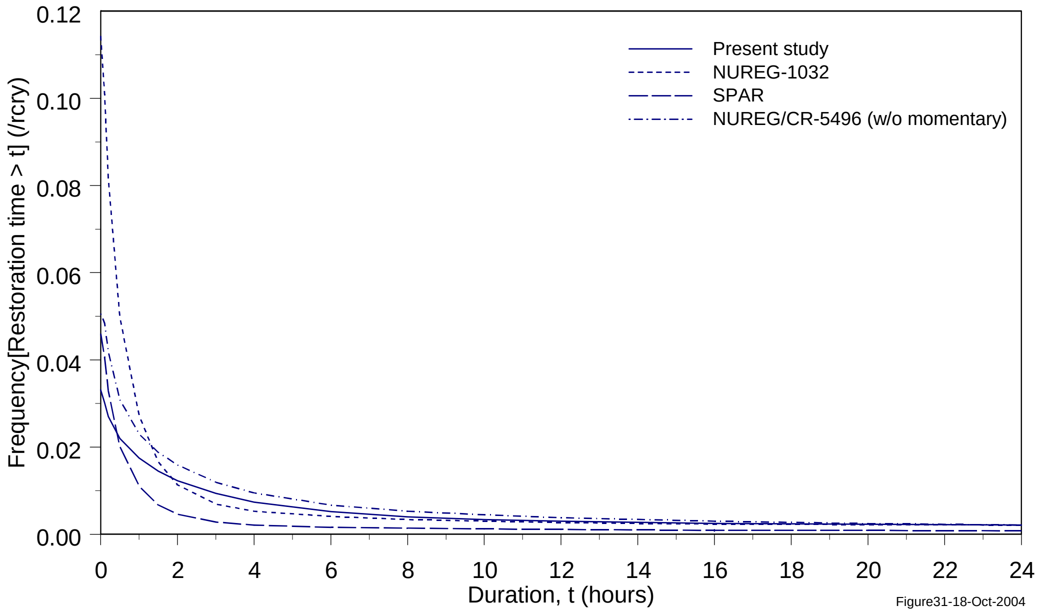


Figure 5-3. Frequency of exceedance versus duration comparison for critical operation.

Combining LOOP Frequency and Duration

6. SPECIAL TOPICS OF INTEREST

6.1 Comparison with NUREG-1784

The scope of the present study differs from that of NUREG-1784, which was to evaluate the potential effects of deregulation of the electrical industry and its effects on electrical grid operation. In contrast, the major focus of the present study is the estimation of current frequencies for categories of LOOPs and probability of exceedance versus duration curves for use in PRAs, along with general engineering insights. The present study addressed all LOOP events and covers the period 1986 – 2003. NUREG-1784 addressed LOOP events during power operation from 1985 – 2001. In NUREG-1784, the period up through 1996 was considered to be "before deregulation" and the period 1997 to the present was considered to be "after deregulation." The primary differences between the present report and NUREG-1784 are presented in Table 6-1.

Differences in results between the present study and NUREG-1784 are primarily due to differences in the definition of the grid and treatment of restoration times. The data classification scheme (five LOOP categories) used in the present study differs from those used in previous LOOP studies so that events can be easily grouped to address the needs of follow-on risk studies for LOOP and SBO. NUREG-1784 identified the subset of LOOPs during critical operation that is grid initiated or related (switchyard, transmission line, grid, and consequential) and compared LOOP performance over the periods 1985 – 1996 and 1997 – 2001. In contrast, the present study used a more limited definition of grid events, similar to what was done in NUREG-1032 and NUREG/CR-5496. NUREG-1784 based restoration of offsite power on the actual time power was restored to one safety bus. The present report used three different restoration times – restoration to the switchyard, actual restoration time to a safety bus, and potential restoration time to a safety bus. Potential recovery time is most appropriate for use in PRAs. The present study includes switchyard and actual bus restoration times for comparison purposes and to assist in the estimation of potential bus restoration times. As part of this effort, the data in NUREG/CR-5496 were reevaluated to obtain these three restoration times.

NUREG-1784 concluded the following for the more recent, deregulated period:

1. The frequency of LOOPs addressed in that study has decreased.

2. The average duration of LOOPs has increased (the percentage of LOOPs longer than four hours has increased substantially).

3. Unlike the earlier period during which LOOPs occurred more or less randomly throughout the year, most LOOP events now occur during the summer months (May through September).

4. The probability of a LOOP as a consequence of a reactor trip has increased during the summer months.

Items 1 and 2 above are addressed in this section. Item 3 is addressed in Section 6.2, while Item 4 is covered in Section 6.3.

With respect to Item 1 above, the analysis of LOOP frequencies in Section 3 of this report found that plant-centered and switchyard-centered LOOP frequencies for critical operation have decreased, comparing the period 1986 – 1996 with 1997 – 2003 (Table 3-4). Trends for these two LOOP category frequencies are shown in Figure 3-1 and Figure 3-2. To obtain current frequency estimates for these two categories of LOOPs, only the period 1997 – 2003 was used. However, grid-related LOOP occurrences

Table 6-1. Comparison of NUREG-1784 with current study.

Item	NUREG-1784 Result	Current Study Result
Purpose	Assess change based on LOOP event data before and after 1997	Using LOOP event data estimate the frequency and nonrecovery probabilities for use in PRA
Time	1985 – 2001	1986 – 2003
Definitions	Grid events = consequential LOOPs, switchyard LOOPs, transmission system LOOPs, and wide spread grid problems	Grid events = Transmission system LOOPs and wide spread grid problems
LOOP Frequency	LOOP estimates for critical operation only	LOOP estimates for critical and shutdown operation
Recovery Times	Used actual time to restore power to one safety bus for power operational events	Three restoration times–switchyard, potential, and actual to a bus. Potential restoration time is used in PRAs.
LOOP frequency has decreased	5.7E-2/rcry for 1985–1996 1.8E-2/rcry for 1997–2001	4.8E-2/rcry for 1986–1996 3.3E-2/rcry for 1997–2003 including Aug. 14, 2003
LOOPs occurred mostly in the 5 summer months	24 summer and 23 nonsummer events for 1986–1996 5 summer and 1 nonsummer events for 1997–2001	21 summer and 19 nonsummer events for 1986–1996 17 summer and 1 nonsummer events for 1997–2003
Probability of a consequential LOOP given a reactor trip	2.0E-3 for 1985–1996 4.5E-3 for 1997–2001 1.0E-2 for 1997–2001 summer months	2.6E-3 for 1986–1996 7.4E-3 for 1997–2003 1.8E-2 for 1997-2003 summer months
Average LOOP duration has increased	<u>Median Duration</u> 60 min. for 1985–1996 688 min. for 1997–2001	<u>Median Duration</u> ~125 min. for actual bus restoration for 1986–1996 ~690 min. for actual bus restoration for 1997–2001 ~355 min. for actual bus restoration for 1997–2003
LOOP events exceeding 4 hours	Longer LOOP durations are getting longer	Not specifically addressed in report
Trends in duration	No trends in report	Presents trends in frequency and duration

have increased, as indicated in Figure 3-4. Again, to obtain a current frequency estimate for this category, only the period 1997 – 2003 was used. Finally, the frequencies of severe-weather-related and extreme-weather-related LOOPs appear to have remained constant over the period 1986 – 2003, so the entire period was used to determine their frequencies. The comparison of present study results with previous studies (Table 3-7) indicates that the overall LOOP frequency for critical operation has dropped steadily with time, from a high of 1.1E-1/rcry over the period 1968 – 1985 to the present study result of 3.3E-2/rcry for 1997 – 2003. Therefore, the present study supports the observation in NUREG-1784 that overall LOOP frequencies during critical operation have dropped. However, the present study did not evaluate the change in grid LOOP frequency using the grid definition from NUREG-1784.

With respect to LOOP durations, Table 4-2 summarizes the LOOP duration data over three periods, 1968 – 1985 (NUREG-1032), 1980 – 1996 (NUREG/CR-5496), and 1986 – 2003 (present study). All three studies used their entire data periods to determine probability of exceedance versus duration curves and duration summary statistics (median and mean durations). (All three looked at potential trends with time over their respective data periods but did not identify significant trends with time.) The median and mean duration information in Table 4-2 indicates that in general the durations of LOOPs have increased over time. However, that table does not specifically address the period 1997 – 2003. Also, the present study did not specifically evaluate the increase in the longer LOOPs as was done in NUREG-1784.

In summary, the present study systematically reviewed LOOP data (for frequency and duration) over the period 1986 – 2003. That effort included a comparison of data over the periods 1986 – 1996 and 1997 – 2003. In cases where differences were identified, results were generated using only the newer data, 1997 – 2003. However, the current study has not tried to identify why such differences exist. Even though 1997 – 2003 represents the period "after deregulation," other factors may also be affecting the results.

6.2 Seasonal Effects

NUREG-1784 indicated that more recent LOOPs (switchyard centered and grid related) occur mostly during the five summer months (defined in that document to cover May through September). The LOOP data used for the present study were reviewed to determine if this seasonal effect exists within the five categories of LOOPs over the periods 1986 – 1996 and 1997 – 2003. Results for critical operation are presented in Table 6-2, and results for shutdown operation are in Table 6-3. The Table 6-3 results indicate no major seasonal effects on the shutdown overall LOOP frequency. However, the critical operation LOOPs over the more recent period, 1997 – 2003, indicate a large seasonal difference in the overall LOOP frequency. The summer frequency for this period is 6.5E-2/rcry compared with 4.2E-3/rcry for non-summer. Even if the August 14, 2003 grid blackout event (contributing eight grid-related LOOPs for critical operation) were excluded, there would still be a significant seasonal difference. The summer frequency of 6.5E-2/rcry is almost double the annual average result of 3.3E-2/rcry (Table 3-1).

6.3 Consequential LOOPs

NUREG-1784 identified events in which a reactor trip (unrelated to a LOOP) occurred and then a subsequent LOOP occurred because of the response to the reactor trip. These events were termed consequential LOOPs in that report. In such events, the LOOP would not have occurred if the reactor trip had not occurred. NUREG-1784 identified nine consequential LOOP events over the period 1985 – 2001. The present study identified nine consequential LOOP events over the period 1986 - 2003. The nine events are identified in Appendix A by the classification designation LOOP-IE-C. Four of these nine consequential LOOPs occurred during 1997 – 2003. The consequential LOOPs are included in the frequency calculations presented in Table 3-1.

Comparing the NUREG-1784 list of consequential LOOP events with the present study, the following is a list of differences:

1. The Three Mile Island 1 event on June 21, 1997 (listed as 6/19/97 in NUREG-1784) was reclassified as a consequential LOOP in the present study.

2. The Indian Point 2 consequential LOOP on December 12, 1985 in NUREG-1784 is not included in the present report because it occurred before 1986, the starting point for the present report.

3. The Byron 2 consequential LOOP on October 2, 1987 (listed incorrectly as 1/16/90 in NUREG-1784) was classified as a shutdown LOOP in the present report and is therefore not a consequential LOOP as defined in this report.

An additional consequential LOOP was identified outside the NUREG-1784 data collection period, the Salem 1 event on August 26, 2003.

The data analyzed in the present report indicate that five consequential LOOPs occurred during 1986 – 1996, while four occurred during 1997 – 2003. Therefore, the frequency of consequential LOOPs has increased only slightly in recent years, from (5 + 0.5)/(879.3rcry) = 6.3E-3/rcry (1986 – 1996) to (4 + 0.5)/(629.5rcry) = 7.1E-3/rcry (1997 – 2003). This latter frequency contributes approximately 20% to the overall total of 3.3E-2/rcry during critical operation.

Several conditional probabilities of a consequential LOOP, given a reactor trip, can also be estimated. These include annual average estimates for the periods 1986 – 1996 and 1997 – 2003 and seasonal estimates for both periods. All of these results can be compared with those from NUREG-1784.

NUREG-1784 concluded that the probability of consequential LOOPs occurring given a reactor trip has increased, from 2.0E-3 (1985 – 1996) to 4.5E-3 (1997 – 2001). For the present study, there were 2168 reactor trips over the period 1986 – 1996 (from NUREG-1784). Subtracting the 50 LOOP-IE-I events (from Appendix A), there were 2118 reactor trips not initiated by a LOOP. Of these, five resulted in consequential LOOPs. Therefore, the conditional probability of a consequential LOOP given a reactor trip during the period 1986 – 1996 is

(5 + 0.5)/(2118 + 1) = 2.6E-3.

Similarly, over the period 1997 – 2003, there were approximately 620 reactor trips. Subtracting the 14 LOOP-IE-I events, the total is 606 reactor trips not initiated by a LOOP. Of these 606 reactor trips, four resulted in consequential LOOPs. Therefore, the conditional probability of a consequential LOOP given a reactor trip is

(4 + 0.5)/(606 + 1) = 7.4E-3.

These two conditional probabilities are higher than those listed in NUREG-1784. However, they do indicate a recent increase in the conditional probability of a consequential LOOP given a reactor trip.

Table 6-2. LOOP events by season – critical operation.

	Number of LOOPs					
	1986 - 1996		1997 - 2003		1986 - 2003	
LOOP Category	Summer	Non-Summer	Summer	Non-Summer	Summer	Non-Summer
Plant Centered	5	6	1	0	6	6
Switchyard Centered	11	12	5	0	16	12
Grid Related	1	0	10	0	11	0
Severe Weather Related	2	1	0	1	2	2
Extreme Weather Related	2	0	1	0	3	0
All	21	19	17	1	38	20
Reactor Critical Years	380.7	498.6	271.0	358.5	651.7	857.1
LOOP Frequency (/rcry)	5.65E-02	3.91E-02	6.46E-02	4.18E-03	5.91E-02	2.39E-02

Note – Summer is defined as May through September.

Table 6-3. LOOP events by season – shutdown operation.

	Number of LOOPs					
	1986 – 1996		1997 - 2003		1986 - 2003	
LOOP Category	Summer	Non-Summer	Summer	Non-Summer	Summer	Non-Summer
Plant Centered	6	8	1	4	7	12
Switchyard Centered	11	20	1	6	12	26
Grid Related	1	0	2	0	3	0
Severe Weather Related	0	7	1	1	1	8
Extreme Weather Related	0	0	0	0	0	0
All	18	35	5	11	23	46
Reactor Shutdown Years	103.8	177.9	31.6	64.8	135.4	242.7
LOOP Frequency (/rsy)	1.78E-01	2.00E-01	1.74E-01	1.77E-01	1.74E-01	1.92E-01

Note – Summer is defined as May through September.

The existence of a seasonal variation in this conditional probability of a consequential LOOP was also investigated. For the period 1986 – 1996, the five consequential LOOPs include two during the five summer months and three during the seven non-summer months. Therefore, no significant seasonal variation exists for this period. However, the four consequential LOOP events during 1997 – 2003 all occurred during the five summer months. Reactor trip data presented in NUREG-1784 indicate that there is no significant seasonal variation in overall reactor trips. The approximately 606 reactor trips not initiated by a LOOP over 1997 – 2003 can then be split into approximately 253 (5/12 of the total) reactor trips during the five summer months and 353 (7/12 of the total) during the non-summer months. The conditional probability of a consequential LOOP given a reactor trip over the five summer months (when the grid is most likely to be degraded) is

$$(4 + 0.5)/(253 + 1) = 1.8E\text{-}2.$$

NUREG-1784 estimated this conditional probability to be 1.0E-2. The corresponding conditional probability for the non-summer months is

$$(0.5)/(353 + 1) = 1.4E\text{-}3.$$

6.4 August 2003 Grid Blackout

The August 14, 2003 grid blackout event resulted in nine plant LOOPs (eight during critical operation and one during shutdown operation) at six sites. This single blackout dominates the grid-related events during the period 1997 – 2003, contributing eight of the 10 LOOPs during critical operation used to determine the grid-related LOOP frequency for critical operation. If this blackout had not occurred, then the grid-related LOOP frequency would have been based on two LOOPs (rather than 10) over 629.5 rcry (from Table 3-1). The resulting frequency would have been 4.0E-3/rcry, rather than the study result of 1.7E-2/rcry. This would then have decreased the overall LOOP frequency for critical operation from 3.3E-2/rcry to 2.0E-2/rcry.

The August 14, 2003 event also influences the duration analyses discussed in Section 4. If that event had not occurred, the average grid-related LOOP duration over 1986 – 2003 would have been 0.6 hour rather than 2.7 hour (Table 4-1).

We cannot predict how often this type of event might occur in the future. If the August 14, 2003 event is an anomaly and will not be repeated, then the grid-related frequency and duration presented in this report are overestimations. However, if such events continue to occur in the future, then the frequency presented in this report may be an underestimation. Grid-related LOOP events need to be monitored for the next few years to determine if the industry performance characterized in this report remains representative.

6.5 Multi-Unit Site Considerations

Among the 127 LOOP plant level events considered in this study for frequency and duration analyses (140 total events, minus 10 LOOP-NTs, and with the LaCrosse and two Pilgrim salt spray LOOPs removed), there were ten occurrences 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 6-4. Nine involved two plants, while one (on August 14, 2003) involved all three plants at the site. The remaining 106 events were single plant events. Of the 103 presently operating plants, there are 27 single-plant sites, 32 dual-plant sites, and four three-plant sites. (The four three-plant sites are Oconee, Palo Verde, Hope Creek/Salem, and Fitzpatrick/Nine Mile Point.)

Table 6-4. LOOP events (1986-2003) that affected more than one plant at a site.

Site	Date	Number of Plants at Site	Number of Plants Affected	LOOP Category	Mode
Calvert Cliffs	7/23/1987	2	2	Switchyard Centered	Critical Operation
Peach Bottom	7/29/1988	2	2	Switchyard Centered	Shutdown Operation
Turkey Point	8/24/1992	2	2	Extreme Weather Related	Critical Operation
Sequoyah	12/31/1992	2	2	Switchyard Centered	Critical Operation
Brunswick	03/16-17/1993	2	2	Severe Weather Related	Shutdown Operation
Beaver Valley	10/12/1993	2	2	Switchyard Centered	Critical Operation/ Shutdown Operation
Prairie Island	6/29/1996	2	2	Severe Weather Related	Critical Operation
Nine Mile Point and Fitzpatrick	8/14/2003	3	3	Grid Related	Critical Operation
Indian Point	8/14/2003	2	2	Grid Related	Critical Operation
Peach Bottom	9/15/2003	2	2	Grid Related	Critical Operation

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 6-5. These conditional probabilities range from 2.9E-2 for plant-centered LOOPs to 7.5E-1 for extreme-weather-related LOOPs. Because all of the 10 events in listed in Table 6-4 affected all plants at a site, the probabilities listed in Table 6-5 apply to all other plants at the site. For example, if a site has three plants and one plant experiences a grid-related LOOP, then the probability that the other two plants also experience the same grid-related LOOP is 0.70 from Table 6-5.

Table 6-5. 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 Other Plants at Multi-Plant Site Experiencing the LOOP Given a LOOP at One of the Plants at the Site (note a)		
			5%	Mean	95%
Plant Centered	0	16	2.27E-04	2.94E-02	1.06E-01
Switchyard Centered	4	39	4.44E-02	1.13E-01	2.03E-01
Grid Related	3	4	3.53E-01	7.00E-01	9.53E-01
Severe Weather Related	2	4	1.69E-01	5.00E-01	8.31E-01
Extreme Weather Related	1	1	2.38E-01	7.50E-01	9.98E-01
All	10	64	1.53E-03	1.62E-01	5.31E-01

a. The mean is a Bayesian update using a Jeffreys prior. Mean = (0.5 + events)/(total events + 1). See Appendix C for the derivation of the uncertainties.

6.6 No Trip LOOPs

Of the 140 LOOP events during the period 1986 – 2003, there were 10 LOOPs that occurred while a plant was in critical operation, but the plant did not experience a reactor trip. These events are termed the "no trip" LOOPs, or LOOP-NTs. Some plants have unique designs that have enabled them to experience some LOOPs without incurring a reactor trip. The ten LOOP-NT events occurred at eight plants. (Nine Mile Point 2 experienced three LOOP-NTs.) However, three of these plants also experienced LOOPs during critical operation that did result in reactor trips. Also, one of the other five plants experienced a LOOP during critical operation that resulted in a reactor trip in 2004. Therefore, four of the eight plants that experienced a LOOP-NT also experienced a LOOP in which a reactor trip occurred. Whether these plants will experience a reactor trip given a LOOP during critical operation is uncertain. Similar to NUREG-1032 and NUREG/CR-5496, the LOOP-NTs were not included in the frequency calculations presented in this report. This approach introduces a potential maximum error (underprediction) of approximately 8% in the overall LOOP frequency during critical operation. The actual error is unknown but is probably smaller.

6.7 Offsite Power Restoration Times

For each of the 140 LOOP events that occurred during 1986 – 2003, three restoration times (durations) are presented (Appendix A): switchyard restoration, potential bus restoration, and actual bus restoration. Switchyard restoration time is the duration from the start of the LOOP to when offsite power was restored (or could have been restored) to the switchyard. Actual bus restoration time is the duration from the start of the LOOP to when offsite power was actually restored to a safety bus. Finally, plants may delay the restoration of offsite power to safety buses when the emergency electrical power sources are running (and appear to be stable) because of other higher priorities related to the LOOP event. Therefore, the potential bus restoration time is the duration from the start of the LOOP to when offsite power could have been restored to a safety bus.

Because of incomplete information in the LER (or EPRI report if not covered by an LER), one or more of these three restoration times often was not listed. In such cases, an estimate was made, based on available information. This effort was aided by additional information from the recent EPRI report [4] and ASP Program results. Appendix A presents a list of the LOOP events with their restoration times and associated uncertainties in the times. The associated uncertainty indicates one of three cases: the time is certain (clearly stated in the LER), the time is uncertain but some information was available in the LER to estimate the time, or no information is available (and no estimate is provided).

For purposes of risk analysis, the potential bus restoration time is generally most appropriate. Probability of exceedance versus duration curves presented in Section 4 are based on potential bus restoration times. Also, these curves were based on LOOP events aggregated at the site level, similar to what was done in NUREG-1032 and NUREG/CR-5496. Of the 116 site-level LOOP events listed in Appendix A, Table A.7, 34 of them have potential bus restoration times listed as certain. The remaining entries are listed as uncertain (except for one listed as unknown).

To assist in the estimation of these uncertain potential bus restoration times, a three-step process was used. The first step involved characterizing the appropriate conditions (plant status and level of urgency) for operators who would be restoring power to a safety bus once offsite power had been restored to the switchyard. These conditions are listed below:

- SBO conditions exist (emergency power sources have failed and there is no AC power to the safety buses).

- Offsite power has just been restored to the switchyard (and the offsite power is of usable quality).
- Because of the SBO conditions, there is a sense of urgency to restore power to at least one safety bus.
- No repair is required. (LOOPs where some repair appears to be required are treated separately and have substantially longer restoration times.)
- No extensive diagnostics are required and no synchronization is required (because the safety buses are dead).
- Operator actions to restore power from the switchyard to a safety bus involve relatively routine verification and switching.

As the second step, given these conditions, engineers with previous reactor operator experience were asked to estimate how long it would take to restore power to a safety bus. The consensus was that this process would most likely take less than a minute to complete. This consensus was based on very few actions required and the urgency of the situation. NUREG/CR-5496 addressed this same issue (with a different group of engineers with previous reactor operator experience) and came to a similar conclusion – one to two minutes was an appropriate estimate given the conditions listed above.

Finally, the third step was a validation of this estimate by a review of the actual restoration data. The LOOP data in Appendix A indicate eight cases in which the actual bus restoration time (indicated in Table A-7 as certain) was less than or equal to one minute greater than the switchyard restoration time (again indicated in Table A-7 as certain). Therefore, these eight cases (which did not involve station blackout and the associated urgency) indicate that the operators can (and did) restore offsite power to a safety bus within one minute after power was restored to the switchyard. In other cases, there was no urgency in restoring power to a safety bus (emergency power sources were powering the buses and these sources were operating in a stable manner), and operators decided to perform other activities before restoring offsite power to the safety buses and shutting down the emergency power sources.

Based on the results of this three-step process, one minute was chosen as the additional time required to potentially restore power to a safety bus once offsite power has been restored to the switchyard, unless the LOOP event introduced complications that required repair or unusual rerouting of power. A review of the restoration times associated with the LOOP events indicate that this one-minute assumption was used for almost all of the potential bus restoration times listed as uncertain in Appendix A.

As a sensitivity study on this one-minute assumption, the uncertain potential bus restoration times were changed from one minute longer than the switchyard restoration times to 10 minutes longer and to 30 minutes longer (as long as the potential bus restoration time remained shorter than the actual bus restoration time). Probability of exceedance versus duration curves were then generated for all five LOOP categories and the composite. The composite curve for critical operation from this sensitivity case is compared with the baseline composite curve in Figure 6-1. Assuming 10 minutes as the minimum additional time to potentially restore offsite power to a bus (given offsite power to the switchyard) rather than one minute results in approximately a 15% increase in the probability of exceedance up to six hours. For example, at two hours, the baseline composite curve indicates a 0.37 probability of not having recovered offsite power, while the 10 minute sensitivity curve indicates a 0.43 probability. After six hours, the two curves are similar. The composite curve assuming 30 minutes as the minimum additional time varies from the baseline curve by up to 30%. (The probability at two hours is 0.49 rather than 0.37.)

Therefore, these sensitivity study results indicate that the overall restoration results are not overly sensitive to the assumption of one minute.

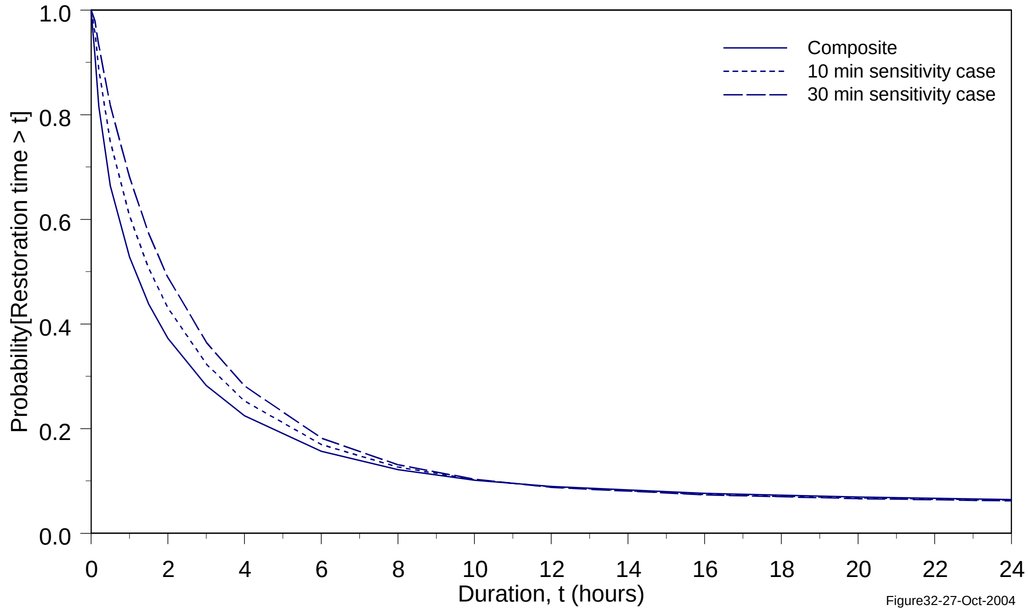


Figure 6-1. Probability of exceedance versus duration composite curves for critical operation for sensitivity analysis on potential bus restoration times.

6.8 Momentary versus Sustained LOOPs

NUREG/CR-5496 distinguished between momentary LOOPs (those with durations less than two minutes) and sustained LOOPs (those with duration equal to or greater than two minutes). In that study, LOOP frequencies were generated separately for the momentary LOOPs and the sustained LOOPs. Also, the probability of exceedance versus duration curves were generated using only the sustained LOOPs in that study. The present study uses both momentary and sustained LOOPs in both the frequency and duration analyses. This approach does not have to rely on a criterion for distinguishing between momentary and sustained LOOPs.

6.9 Plant Design Impacts on LOOPs

NUREG-1032 included an analysis of plant-centered (and switchyard-centered) LOOP data with respect to plant and switchyard design characteristics. Three different groups modeled these characteristics, I1 through I3. Group I1 includes plants with automatic transfers to two backup sources of offsite power if the normal source of offsite power becomes available (and the emergency power sources fail). This group was found to have the lowest frequency of exceedance versus duration curve of the three design groups, mainly because the mean duration of LOOPs for plants within this category was the shortest of the three (0.20 hour). Group I2 includes plants with one automatic transfer to offsite power (two or more pathways feed the safety buses) or an automatic transfer to one offsite power source and the capability to manually transfer to other sources of offsite power. Also, these plants do not include two or more switchyards that are electrically independent of each other. The I2 plants had a higher frequency of exceedance versus duration curve than the I1 plants, again mainly because their LOOP mean durations

were higher (0.39 hour). Finally, the I3 plants had either manual transfers to other sources of offsite power or less independence in these other sources. The I3 plants had the highest frequency of exceedance versus duration curve, with a LOOP mean duration of 0.78 hour. The frequencies for plant-centered (and switchyard-centered) LOOPs for these three groups of plants were not significantly different.

NUREG/CR-5496 performed a similar analysis with respect to LOOP durations. No significant differences were identified for either critical operation or shutdown operation. Also, NUREG/CR-5496 analyzed whether these three design groups had significantly different numbers of momentary LOOPs. Again, no significant difference was identified.

The present study investigated whether these three design groups had significantly different plant-centered and switchyard-centered LOOP frequencies and/or durations. With respect to frequencies, if the 1997 – 2003 data are used, there are too few events to distinguish the three design groups. Differences were identified if the entire data period 1986 – 2003 was used. However, because of the significant improvement in plant performance for these two LOOP categories in recent years, the entire data period should not be used. Therefore, the conclusion with respect to frequencies is that the data are too sparse over the relevant period (1997 – 2003) to distinguish differences in frequencies between the three design groups. A similar analysis for LOOP durations indicated no significant differences between design groups. This analysis looked at the entire data period 1986 – 2003 because the duration analysis in Section 4 used the entire data period. (No significant differences were noted between the current period 1997 – 2003 and the entire period in that analysis.)

6.10 Abnormal Electrical Configurations

The final topic in this section involves abnormal electrical system configurations. Each LOOP event was reviewed to identify abnormal electrical system configurations that may have increased the vulnerability to a loss of offsite power or may have increased the recovery time. Table 6-6 summarizes the results. For most of the LOOPs involving abnormal electrical configurations, subjective analysis suggests that the LOOP might not have occurred had the plant electrical system been aligned in a normal configuration. In addition, for some events, recovery was delayed by complications resulting from the abnormal configuration.

For critical operation, results in Table 6-6 indicate that only three of the 58 LOOPs involved an abnormal electrical configuration. However, 42 of the 69 LOOPs occurring during shutdown involved such configurations. This is consistent with expectations because Technical Specifications limit plant electrical configurations at power, and maintenance involving abnormal electrical system configurations is normally performed while shutdown. We do not have information concerning the percentage of time during shutdown operation that plants are in an abnormal electrical configuration. Therefore, we cannot estimate the frequency of LOOPs during shutdown given an abnormal electrical configuration.

Table 6-6. LOOP event counts for abnormal electrical system configuration.

		Data and Time Period (note a)		
Mode	LOOP Category	1986 - 1996	1997 - 2003	1986 - 2003
Critical Operation	Plant Centered	1(11)	0(1)	1(12)
	Switchyard Centered	2(23)	0(5)	2(28)
	Grid Related	0(1)	0(10)	0(11)
	Severe Weather Related	0(3)	0(1)	0(4)
	Extreme Weather Related	0(2)	0(1)	0(3)

Table 6-6. LOOP event counts for abnormal electrical system configuration. (continued)

Mode	LOOP Category	Data and Time Peri 1986 - 1996	1997 - 2003	1986 - 2003
	All	3(40)	0(18)	3(58)
Shutdown Operation	Plant Centered	10(14)	4(5)	14(19)
	Switchyard Centered	19(31)	4(7)	23(38)
	Grid Related	1(1)	0(2)	1(3)
	Severe Weather Related	4(7)	0(2)	4(9)
	Extreme Weather Related	0(0)	0(0)	0(0)
	All	34(53)	8(16)	42(69)

a. Data are presented as: number of abnormal electrical configuration LOOPs (total number of LOOPs). LOOP-NT events are excluded, as well as the LaCrosse and two Pilgrim salt spray LOOPs.

7. ADDITIONAL ENGINEERING ANALYSIS OF LOOP DATA

This section reviews the LOOP events from an engineering perspective. Many of the special topics of interest covered in Section 6 could also be considered engineering analyses. The objective of this part of the study is to provide additional qualitative insights with respect to the LOOP events.

Figure 7-1 shows the distribution of 1986 – 2003 LOOP events by category and operational mode. Of the 140 LOOP events, 44% occurred while critical and 56% occurred while shutdown. During the period 1986 – 2003, plants were in critical operation 80% of the time. Therefore, LOOPs occur much more frequently per unit time during shutdown operation. This observation is also obvious from the frequency results presented in Table 3-1. The overall LOOP frequency during critical operation is 3.3E-2/rcry, while the corresponding frequency during shutdown operation is 1.9E-1/rsy.

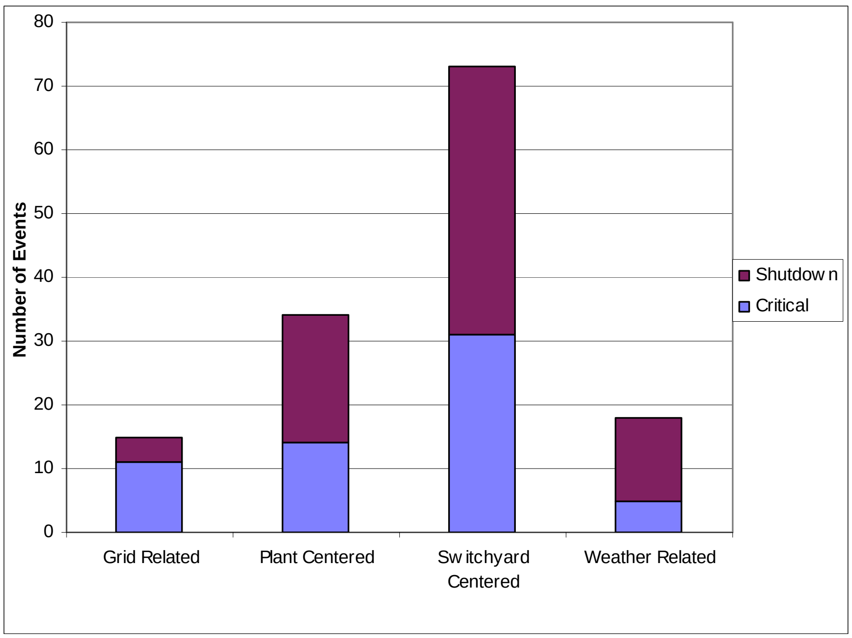


Figure 7-1. LOOP event counts by category and operational mode.

Switchyard-centered LOOPs are the largest category, accounting for approximately 52% of all events. Plant-centered LOOPs are the second largest, accounting for approximately 24%. Severe- and extreme-weather related LOOPs contribute 13%. In addition, 14 of these 18 plant events occurred at only five sites – Pilgrim, Crystal River, Brunswick, Prairie Island, and Turkey Point. The plants at these sites have diverse designs with little similarity in electrical power supply design or redundancy. Finally, the nature and small number of grid-related events indicate that losses of offsite power to a nuclear power plant due to grid disturbances are rare. However, in August 2003, a large grid power loss affected nine plants. That grid blackout is discussed in Section 6.4. Grid-related LOOPs contribute 11% to the total.

Similar to what was done in NUREG/CR-5496, events were segregated according to specific causes. Figure 7-2 shows the LOOP data illustrating the causes and cause breakdowns. The results are also summarized in Table 7-1. The cause breakdown can appear confusing, because severe weather is both a LOOP category and a LOOP cause in the figure and table. However, the definition of severe-weather-related LOOPs in the Glossary indicates that localized severe weather events such as lightning strikes at a single plant or switchyard are coded as plant-centered or switchyard-centered LOOPs, even though the cause is severe weather. Approximately 39% of the events are caused by equipment failures,

and approximately 33% of the events are caused by human errors. A finer breakdown of the equipment failures is presented in Figure 7-3. Transformers dominate the results. Figure 7-4 presents a finer breakdown of human error events. Maintenance activities contribute the largest fraction. Finally, Figure 7-5 shows the breakdown of weather-related LOOP events. The hurricane and tornado events are also classified as extreme-weather-related events in Sections 3 through 5.

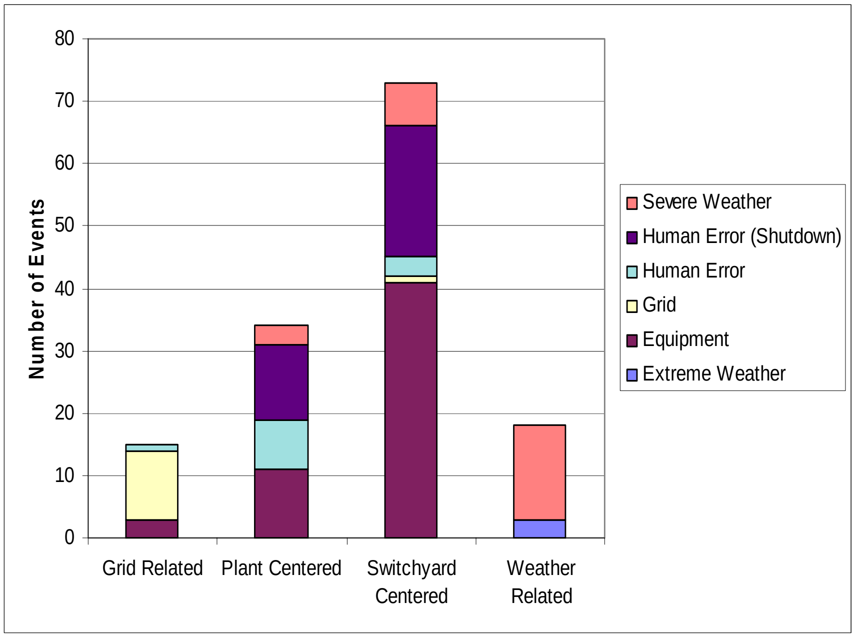


Figure 7-2. LOOP event counts by cause breakdown.

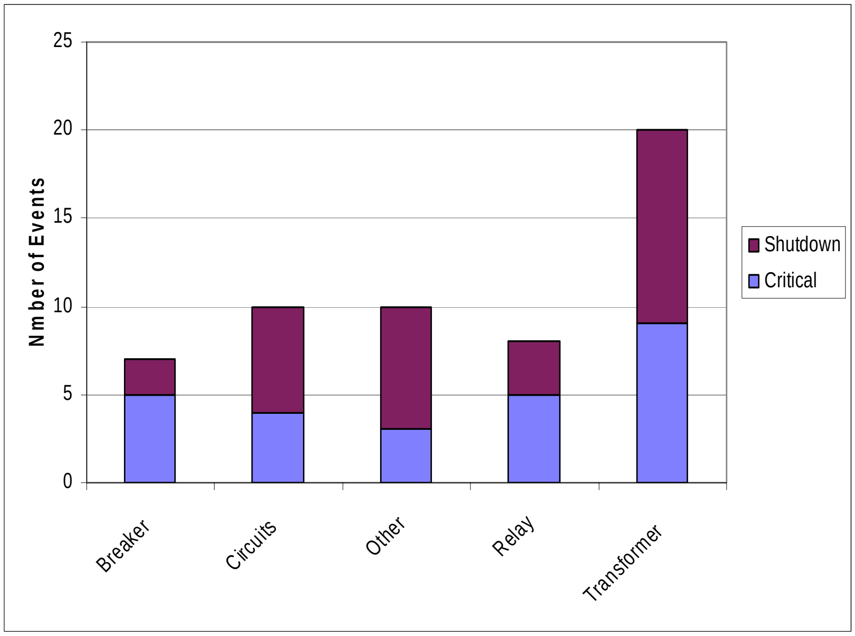


Figure 7-3. LOOP equipment failure cause breakdown.

Table 7-1. LOOP event counts by cause breakdown.

Cause Category	Extreme Weather	Equipment	Grid	Human Error	Human Error (Shutdown)	Severe Weather	Total	Percent
Grid Related	0	3	11	1	0	0	15	11%
Plant Centered	0	11		8	12	3	34	24%
Switchyard Centered	0	41	1	3	21	7	73	52%
Weather Related	3	0	0	0	0	15	18	13%
Total	3	55	12	12	33	25	140	100%
Percent	2%	39%	9%	9%	24%	18%	100%	

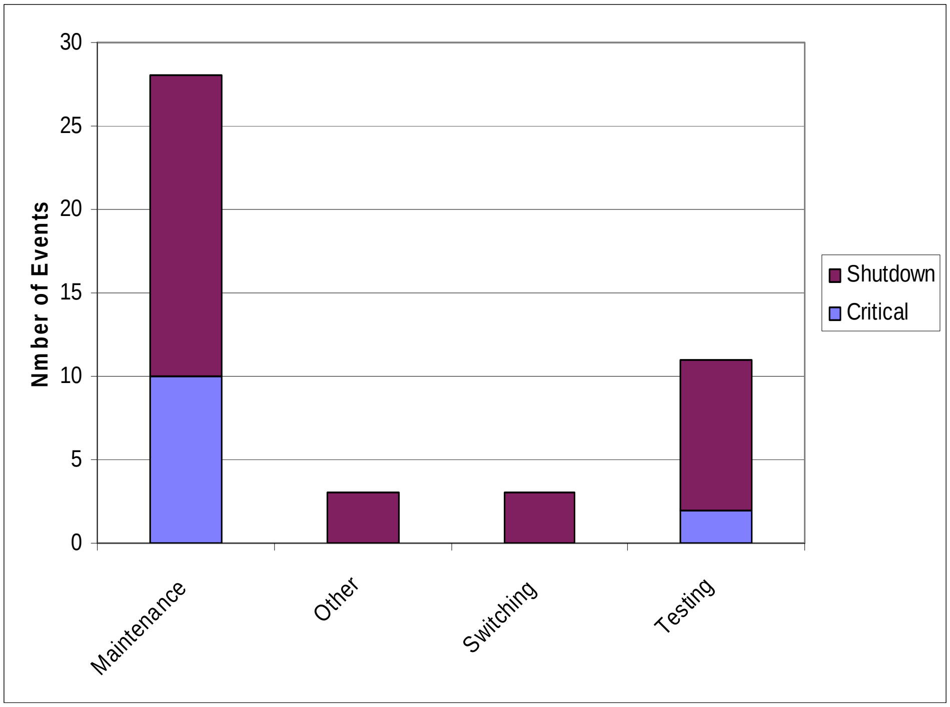


Figure 7-4. LOOP human error cause breakdown.

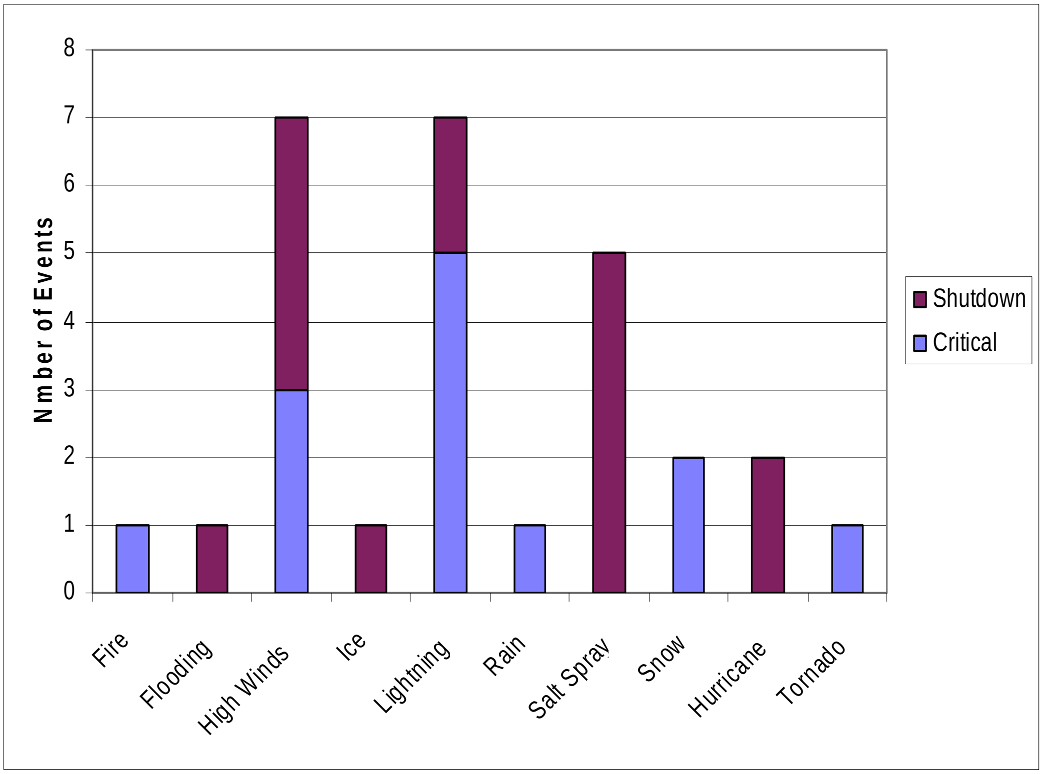


Figure 7-5. LOOP weather cause breakdown.

8. SUMMARY AND CONCLUSIONS

LOOP data over the period 1986 – 2003 were collected and analyzed. Frequency and duration estimates for critical and shutdown operations were generated for five categories of LOOPs: plant centered, switchyard centered, grid related, severe weather related, and extreme weather related. Five categories were used (rather than three or four in previous studies) because the frequency and duration results are statistically different for each of these categories. Because of trends in three of the five categories for critical operation, the more recent data (1997 – 2003) were used to estimate frequencies for plant-centered, switchyard-centered, and grid-related LOOPs during critical operation. Industry performance improved significantly for plant-centered and switchyard-centered LOOPs (lower frequency of occurrence) but degraded with respect to grid-related LOOPs. However, the degraded grid performance is the result of one large grid blackout, the August 14, 2003 event that resulted in LOOPs at nine plants. Because this one event dominates the grid-related LOOPs over the period 1997 – 2003, industry performance needs to be monitored over the next few years to help determine whether such events will occur with regularity.

LOOP duration data were also analyzed to generate probability of exceedance versus duration curves and summary statistics such as mean and median duration. Plant-centered LOOPs have the lowest mean duration, while extreme-weather-related LOOPs have the highest. Similarly, the plant-centered probability of exceedance versus duration curve lies below those for the other four categories, while the extreme-weather-related curve lies above the others.

LOOP frequency and duration information were combined in frequency of exceedance versus duration curves. These curves indicate that the grid-related LOOPs are most significant with respect to frequency and duration for critical operation up to six hours, while extreme-weather-related LOOPs dominate beyond six hours. Switchyard-centered LOOPs are most significant for shutdown operation up to five hours, while severe-weather-related LOOPs dominate beyond five hours.

Where possible, LOOP frequency and duration results from the present study were compared with those from two previous studies: NUREG-1032 (data over 1968 – 1985) and NUREG/CR-5496 (data over 1980 – 1996). Overall, LOOP frequencies during critical operation have decreased significantly, while LOOP durations have increased. The overall combined impact as presented in frequency of exceedance versus duration curves indicates that the current results predict lower frequencies of exceedance up to approximately two hours (compared with NUREG-1032) and higher frequencies of exceedance beyond that duration.

Various topics of interest were also addressed. These topics include such things as comparison of results with NUREG-1784, seasonal impacts on LOOP frequencies, consequential LOOPs, and others. Finally, additional engineering analyses of the LOOP data were presented.

Overall, this report successfully updates estimates for LOOP frequencies for both critical and shutdown operation. In addition, LOOP duration information was successfully transformed into probability of exceedance versus duration curves. Both types of information are needed in PRA models of U.S. commercial nuclear power plants to accurately model current risk from LOOP and associated SBO scenarios. Additionally, this report provides information to modify LOOP frequencies for event analyses specific to the time of the year (summer or winter months).

9. REFERENCES

1. Baranowsky, P.W., *Evaluation of Station Blackout Accidents at Nuclear Power Plants*, U.S. Nuclear Regulatory Commission, NUREG-1032, June 1988.

2. Atwood, C.L. et al., *Evaluation of Loss of Offsite Power Events at Nuclear Power Plants: 1980 – 1996*, U.S. Nuclear Regulatory Commission, NUREG/CR-5496, November 1998.

3. Poloski, J.P. et al., *Rates of Initiating Events at U.S. Nuclear Power Plants: 1987 – 1995*, U.S. Nuclear Regulatory Commission, NUREG/CR-5750, February 1999.

4. Wyckoff, H.L., *Losses of Off-Site Power at U.S. Nuclear Power Plants – Through 2003*, Electric Power Research Institute, March 2004.

5. Raughley, W.S. 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.

6. *NRC Inspection Manual*, Temporary Instruction 2515/156, " Offsite Power System Operational Readiness," U.S. Nuclear Regulatory Commission, April 29, 2004.

7. Atwood, C.L., "Constrained Noninformative Priors in Risk Assessment," *Reliability Engineering and System Safety*, Vol. 53, 1996, pp. 37 – 46.

8. Minarick, J.W., *Revised LOOP Recovery and PWR Seal LOCA Models*, Oak Ridge National Laboratory, ORNL/NRC/LTR-89/11, August 1989.

References

Appendix A

LOOP Event Database

APPENDIX A

LOOP Event Database

A.1 INTRODUCTION

LOOP events were identified from Licensee Event Reports (LERs) and other sources for the period 1986 – 2003 for U.S. commercial nuclear power plants. Those events are listed in this appendix, along with regional information concerning the nuclear power plant locations. Seven tables are presented, each representing a different breakdown of the information. Those seven tables are summarized below:

Table A-1	Listing of all LOOP events for 1986 – 2003, sorted by plant name
Table A-2	Similar to Table A-1, but covering only 1997 – 2003
Table A-3	Listing of nuclear power plants and their regional assignments (regions as defined in this study, such as coast versus non-coast, and various electrical grid geographical breakdowns)
Table A-4	Listing of all LOOP events for 1986 – 2003 (with LOOP-NT events removed), sorted by category, and date. This table supports the LOOP category frequencies presented in Table 1 in the main report.
Table A-5	Listing of all LOOP events for 1986 – 2003 aggregated at the site level (with LOOP-NT events removed), sorted by site name
Table A-6	Similar to Table A-5, but sorted by category and site name. This table supports the Weibull curve fits to restoration time data and resultant probability of exceedance versus duration curves.
Table A-7	Similar to Table A-5, but with information concerning the uncertainty in each of the three restoration times listed. This table supports the potential bus restoration time sensitivity study discussed in Section 6.7.

A.2 EXPLANATION OF COLUMN HEADINGS

A.2.1 LER

The Licensee Event Report (LER) number describing the LOOP event. If the number ends in "000", there is no LER.

A.2.2 PLANT NAME

The name of the plant experiencing the LOOP event.

A.2.3 DATE

The date of the LOOP event.

A.2.4 OPERATIONAL MODE

These trip and shutdown classifications are from NUREG/CR-5496. TRIP and TRIP* are considered to be LOOPs that occurred during critical operation, while SHUTDOWN and SHUTDOWN* are considered to be LOOPs that occurred during shutdown operation. The NO TRIP LOOPs are not included in the frequency or duration analyses.

TRIP	The LOOP event caused a plant trip from power.
TRIP*	The event occurred during plant hot shutdown. The event characteristics and plant configuration apply to power operation conditions. This includes cases in which the trip preceded the LOOP.
SHUTDOWN	The LOOP event occurred during unit cold shutdown.
SHUTDOWN*	The LOOP event occurred during unit hot shutdown or during unit startup. The event characteristics and plant configuration apply to shutdown conditions.
NO TRIP	The LOOP event occurred during plant power operation and the unit remained at power (termed POWER OP in NUREG/CR-5496).

A.2.5 LOOP CLASS

The classification (see Figure 1 in the main report) is used to determine which LOOP events to include in the frequency calculations. LOOP-NT events were not used in the frequency or duration analyses.

LOOP-SD — a LOOP occurring while a plant is shutdown.

LOOP-NT — a LOOP occurring while a plant is at power but not involving a reactor trip. (Depending upon plant design, the plant status at the time of the LOOP, and the specific characteristics of the LOOP event, some plants have been able to remain at power given a LOOP.)

LOOP-IE-I — a LOOP-IE in which the LOOP event causes the reactor to trip. LOOP-IE-I is a subset of LOOP-IE events. A LOOP-IE is a LOOP occurring while a plant is at power and involving a reactor trip. The LOOP can cause the reactor to trip or both the LOOP event and the reactor trip can be part of the same transient. Note that this is the definition of a functional impact LOOP initiating event (as opposed to an initial plant fault LOOP initiating event), as discussed in NUREG/CR-5750.

LOOP-IE-C — a LOOP-IE in which the LOOP is the direct or indirect result of a plant trip. For example, the event is consequential if the LOOP occurred during a switching transient (i.e., main generator tripping) after a unit trip from an unrelated cause.

In this case, the LOOP would not have occurred if the unit remained operating. LOOP-IE-C is a subset of LOOP-IE events.

LOOP-IE-NC a LOOP-IE in which the LOOP occurs following but is not related to the reactor trip. LOOP-IE-NC is a subset of LOOP-IE events.

A.2.6 LOOP CATEGORY

Plant centered – a LOOP event in which the design and operational characteristics of the nuclear power plant unit itself play the major role in the cause and duration of the loss of offsite power. Plant-centered failures typically involve hardware failures, design deficiencies, human errors, and localized weather-induced faults such as lightning. The line of demarcation between plant-centered and switchyard-centered events is the nuclear power plant main and station power transformers high-voltage terminals. Both transformers are considered part of the switchyard.

Switchyard centered – a LOOP event in which the equipment or human-induced failures of equipment in the switchyard play the major role in the loss of offsite power. The line of demarcation between switchyard-related events and grid-related events is the output bus bar in the switchyard. The bus bar is considered part of the switchyard.

Grid related – a LOOP event in which the initial failure occurs in the interconnected transmission grid that is outside the direct control of plant personnel. Failures that involve transmission lines from the site switchyard are usually classified as switchyard-centered events if plant personnel can take actions to restore power when the fault is cleared. However, the event should be classified as grid related if the transmission lines fail from voltage or frequency instabilities, overload, or other causes that require restoration efforts or corrective action by the transmission operator.

Severe weather related – a LOOP event caused by severe weather, in which the weather was widespread, not just centered on the site, and capable of major disruption. Severe weather is defined to be weather with forceful and non-localized effects. A LOOP is classified as a severe-weather event if it was judged that the weather was widespread, not just centered at the power plant site, and capable of major disruption. An example is storm damage to transmission lines instead of just debris blown into a transformer. This does not mean that the event had to actually result in widespread damage, as long as the potential is there. Examples of severe weather include thunderstorms, snow, and ice storms. Lightning strikes, though forceful, are normally localized to one unit, and so are coded as plant centered or switchyard centered. Hurricanes, strong winds greater than 125 miles per hour and tornadoes are included in a separate category – extreme-weather-related LOOPs.

Extreme weather related – a LOOP event caused by extreme weather. Examples of extreme weather include hurricanes, strong winds greater than 125 miles per hour, and tornadoes. Extreme-weather-related LOOP events are generally distinguished from severe-weather-related LOOP events by their long (> 24 hours) offsite power restoration times.

A.2.7 RESTORATION TIME

Switchyard Restoration Time – the duration, in minutes, from the event initiation until the first offsite electrical power was actually restored (or could have been restored, whichever time is shorter) to the switchyard. Such items as no further interruptions to the switchyard, adequacy of the frequency and voltage levels to the switchyard, and no transients that could be disruptive to plant electrical equipment should be considered in determining the time.

Potential Bus Restoration Time – the duration, in minutes, from the event initiation until the first offsite electrical power could have been restored to a safety bus. This time estimate is less than or equal to the actual bus restoration time.

Actual Bus Restoration Time – the duration, in minutes, from the event initiation until the first offsite electrical power was restored to a safety bus. This is the actual time taken to restore offsite power from the first available source to a safety bus.

A.2.8 RESTORATION TIME UNCERTAINTY

C the restoration time is certain.

U no information is available concerning the restoration time.

E the restoration time was estimated based on some information in the LER.

A.2.9 DURATION CATEGORY

NUREG/CR-5496 divided LOOP events into these two categories based on the duration of the LOOP event. In that report, LOOP frequencies were generated separately for momentary LOOPs and sustained LOOPs. In addition, duration analyses in that report used only the sustained LOOPs. The frequency and duration analyses in the present report use both categories of LOOPs.

Momentary a LOOP event in which the potential bus restoration time is less than two minutes.

Sustained a LOOP event in which the potential bus restoration time is equal to or greater than two minutes.

A.2.10 CAUSE

Acronym	Description
G	Interconnected grid transmission line events, outside direct plant control.
EQUIP	Hardware related failures
HE	Human error during any operating mode.
HES	Human error during any shutdown mode.
EEE	Extreme External Events: Hurricane, Winds > 125 mph, Tornado, Earthquake > R7, Flooding > 500 year flood for the site, Sabotage.
SEE	Severe External Events: Lightening, High Winds, Snow and Ice, Salt Spray, Dust Contamination, Fires and Smoke Contamination, Earthquake < R7, Flooding < 500 year flood for the site.

A.2.11 SPECIFIC CAUSE

Cause Group	Specific Cause	Specific Cause Description
EEE	Hurricane	Hurricane, Winds > 125 mph
EEE	Tornado	Tornado
EQUIP	Breaker	Direct circuit breaker failure or failure of controls specific to one circuit breaker
EQUIP	Circuits	Failure of general protective/sensing circuits such as blackout detection

Cause Group	Specific Cause	Specific Cause Description
		or generator voltage regulator failures, etc.
EQUIP	Other	All other equipment failures, including discovery of design failures
EQUIP	Relay	All relay failures, except relays for transformer or individual circuit breaker controls
EQUIP	Transformer	Direct transformer failure or failure of transformer auxiliary equipment
G	Equip - other	Grid equipment failure
G	Other - fire	Grid-centered fire
G	Other - load	Grid power reduction (brownout)
HE	Maintenance	Errors by maintenance personnel that directly or indirectly caused an event.
HE	Other	All other human errors
HE	Switching	Errors during electrical switching operations, not directly required by testing, generally involving breaker manipulation.
HE	Testing	Errors by test personnel including errors while establishing or restoring from testing lineups including electrical distribution changes.
HES	Maintenance	Errors by maintenance personnel that directly or indirectly caused an event.
HES	Other	All other human errors
HES	Switching	Errors during electrical switching operations, not directly required by testing, generally involving breaker manipulation.
HES	Testing	Errors by test personnel including errors while establishing or restoring from testing lineups including electrical distribution changes.
Other	Mayflies	Mayflies
SEE	Fire	Fire
SEE	Ice	Ice
SEE	Lightning	Lighting
SEE	Rain	Rain
SEE	Snow	Snow
SEE	Snow and Wind	Combination of snow and wind
EEE	Earthquake > 7.0	Earthquake greater than 7.0 on the Richter Scale.
EEE	Flooding > 500 year	Flooding greater than the 500-year flood for the site.
Other	Sabotage	Sabotage
SEE	Earthquake	< 7.0
SEE	Flooding	< 500 year
SEE	Smoke	Smoke contamination
SEE	Dust	Dust raised up by the wind
SEE	Salt Spray	Salt Spray
SEE	High Winds	High winds < 125 mph

A.2.12 ABNORMAL ELECTRICAL CONFIGURATION

No — the offsite power alignment into the switchyard and to the safety buses is in its normal configuration.

Yes — the offsite power alignment into the switchyard and to the safety buses is in an abnormal configuration, usually resulting in a reduction of actual or potential electrical paths.

A.2.13 PLANT REGIONAL ASSIGNMENTS

	State Group	States
MidC	Mid Central	(IA, IL, MN, MO, NE, WI)
NE	Northeast	(CT, MA, MD, ME, MI, NH, NJ, NY, OH, PA, VT)
SE	Southeast	(AL, FL, GA, LA, MS, NC, SC, TN)
SW	Southwest	(AR, KS, TX)
W	West	(AZ, CA, OR, WA)

A.2.14 Coastal

(See 3-7 in the main report)

Coastal — the east and gulf coast (up to approximately 100 miles inland).

Non-coastal — all other plant locations.

A.2.15 NERC Reliability Council Interconnection

(See Figure 3-8 in the main report)

E Eastern
W Western
T Texas

A.2.16 NERC Reliability Council

(See Figure 3-9 in the main report)

Abbreviation	Description
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 Electric Coordinating Council

A.2.17 NERC Sub Regions

(See Figure 3-10 in the main report)

Abbreviation	Description
AZNMSNV	Arizona New Mexico Southern Nevada
CA	California
ECAR	East Central Area Reliability Coordination Agreement
EES	Entergy
ERCOT	Electric Reliability Council of Texas
FRCC	Florida Reliability Coordinating Council
MAAC	Mid-Atlantic Area Council
MAIN	Mid-America Interconnected Network
MAPP-US	Mid-Continent Area Power Pool - US
NWPP-US	Western Electric Coordinating Council - US
NY	New York
NewEngl	New England
SERC-S	Southeastern Electric Reliability Council - South
SPP-N	Southwest Power Pool - North
SPP-S	Southwest Power Pool - South
TVA	Tennessee Valley Authority
VACAR	Virginia Carolina

A.3 DATA TABLES

Table A-1. LOOP events for 1986 - 2003.

LER	Plant Name	Date	Operational Mode	LOOP Class	LOOP Category	Switchyard Restoration Time	Potential Bus Restoration Time	Actual Bus Restoration Time	Duration Category	Cause	Specific Cause	Abnormal Electrical Configuration
3341993013	Beaver Valley 1	10/12/1993	Shutdown	LOOP-SD	Switchyard Centered	10	11	11	Sustained	HES	Maintenance	Yes
4121987036	Beaver Valley 2	11/17/1987	Trip	LOOP-IE-I	Switchyard Centered	3	4	4	Sustained	Equip	Breaker	No
3341993013	Beaver Valley 2	10/12/1993	Trip	LOOP-IE-I	Switchyard Centered	15	16	28	Sustained	HES	Maintenance	Yes
1551992000	Big Rock Point	1/29/1992	Shutdown	LOOP-SD	Switchyard Centered	77	78	78	Sustained	Equip	Other	Yes
4561987048	Braidwood 1	9/11/1987	Shutdown*	LOOP-SD	Switchyard Centered	0	1	53	Momentary	Equip	Transformer	No
4561988022	Braidwood 1	10/16/1988	Trip	LOOP-IE-I	Switchyard Centered	95	118	213	Sustained	Equip	Breaker	No
4561998003	Braidwood 1	9/6/1998	Shutdown	LOOP-SD	Severe Weather Related	528	528	528	Sustained	SEE	High Winds	No
4571996001	Braidwood 2	1/18/1996	No Trip	LOOP-NT	Switchyard Centered	113	113	113	Sustained	SEE	High Winds	No
2961997001	Browns Ferry 3	3/5/1997	Shutdown	LOOP-SD	Switchyard Centered	43	44	44	Sustained	Equip	Transformer	Yes
3251986024	Brunswick 1	9/13/1986	Trip	LOOP-IE-I	Plant Centered	0	1	159	Momentary	HE	Maintenance	No
3251993008	Brunswick 1	3/17/1993	Shutdown	LOOP-SD	Severe Weather Related	1120	1121	1508	Sustained	SEE	Salt Spray	No
3252000001	Brunswick 1	3/3/2000	Shutdown	LOOP-SD	Switchyard Centered	15	16	136	Sustained	HES	Testing	Yes
3241989009	Brunswick 2	6/17/1989	Trip	LOOP-IE-I	Switchyard Centered	90	90	403	Sustained	HE	Maintenance	No
3251993008	Brunswick 2	3/16/1993	Shutdown	LOOP-SD	Severe Weather Related	813	814	1018	Sustained	SEE	Salt Spray	No
3241994008	Brunswick 2	5/21/1994	Shutdown	LOOP-SD	Plant Centered	2	3	64	Sustained	HES	Testing	Yes
4541996007	Byron 1	5/23/1996	Shutdown*	LOOP-SD	Switchyard Centered	720	721	1763	Sustained	Equip	Transformer	No
4541998017	Byron 1	8/4/1998	No Trip	LOOP-NT	Plant Centered	502	503	554	Sustained	SEE	Lightning	No
4551987019	Byron 2	10/2/1987	Shutdown*	LOOP-SD	Switchyard Centered	1	2	507	Sustained	HES	Switching	No
3171987012	Calvert Cliffs 1	7/23/1987	Trip	LOOP-IE-I	Switchyard Centered	117	118	118	Sustained	Equip	Circuits	No
3171987012	Calvert Cliffs 2	7/23/1987	Trip	LOOP-IE-I	Switchyard Centered	117	118	118	Sustained	Equip	Circuits	No
4141996001	Catawba 2	2/6/1996	Trip	LOOP-IE-I	Switchyard Centered	120	121	330	Sustained	Equip	Transformer	No
4611999002	Clinton 1	1/6/1999	Shutdown*	LOOP-SD	Switchyard Centered	270	271	492	Sustained	Equip	Other	Yes
3971989016	Columbia 2	5/14/1989	Shutdown	LOOP-SD	Switchyard Centered	28	29	29	Sustained	HES	Maintenance	Yes
3151991004	Cook 1	5/12/1991	Trip	LOOP-IE-I	Plant Centered	0	1	81	Momentary	Equip	Other	Yes
3021987025	Crystal River 3	10/16/1987	Shutdown	LOOP-SD	Switchyard Centered	18	19	59	Sustained	HES	Maintenance	Yes
3021989023	Crystal River 3	6/16/1989	Shutdown*	LOOP-SD	Switchyard Centered	60	61	61	Sustained	HES	Testing	No
3021989025	Crystal River 3	6/29/1989	Shutdown*	LOOP-SD	Switchyard Centered	1	2	2	Sustained	SEE	Lightning	No
3021991010	Crystal River 3	10/20/1991	Shutdown	LOOP-SD	Plant Centered	3	4	4	Sustained	HES	Other	No
3021992001	Crystal River 3	3/27/1992	Trip	LOOP-IE-I	Plant Centered	20	21	150	Sustained	HE	Maintenance	No
3021993000	Crystal River 3	3/17/1993	Shutdown	LOOP-SD	Severe Weather Related	72	73	102	Sustained	SEE	Salt Spray	Yes
3021993002	Crystal River 3	3/29/1993	Shutdown	LOOP-SD	Severe Weather	4	5	37	Sustained	SEE	Flooding	Yes

Table A-1. LOOP events for 1986 - 2003. (continued)

LER	Plant Name	Date	Operational Mode	LOOP Class	LOOP Category	Switchyard Restoration Time	Potential Bus Restoration Time	Actual Bus Restoration Time	Duration Category	Cause	Specific Cause	Abnormal Electrical Configuration
					Related							
3021993004	Crystal River 3	4/8/1993	Shutdown	LOOP-SD	Plant Centered	1	2	136	Sustained	HES	Maintenance	Yes
3461998006	Davis-Besse	6/24/1998	Trip	LOOP-IE-I	Extreme Weather Related	1364	1428	1495	Sustained	EEE	Tornado	No
3462000004	Davis-Besse	4/22/2000	Shutdown*	LOOP-SD	Plant Centered	10	11	11	Sustained	HES	Testing	Yes
3462003009	Davis-Besse	8/14/2003	Shutdown*	LOOP-SD	Grid Related	652	653	849	Sustained	G	Other - load	No
2751991004	Diablo Canyon 1	3/7/1991	Shutdown	LOOP-SD	Switchyard Centered	261	285	285	Sustained	HES	Maintenance	Yes
2751995014	Diablo Canyon 1	10/21/1995	Shutdown	LOOP-SD	Switchyard Centered	30	31	951	Sustained	HES	Maintenance	Yes
2752000004	Diablo Canyon 1	5/15/2000	Trip	LOOP-IE-I	Plant Centered	1901	1902	1996	Sustained	Equip	Other	No
3231988008	Diablo Canyon 2	7/17/1988	Trip	LOOP-IE-I	Switchyard Centered	37	38	38	Sustained	Equip	Transformer	Yes
2371990002	Dresden 2	1/16/1990	Trip*	LOOP-IE-C	Switchyard Centered	45	45	759	Sustained	Equip	Transformer	No
2491989001	Dresden 3	3/25/1989	Trip	LOOP-IE-I	Switchyard Centered	45	46	0	Sustained	Equip	Breaker	No
3311990007	Duane Arnold	7/9/1990	Shutdown	LOOP-SD	Switchyard Centered	37	38	38	Sustained	HES	Testing	Yes
3482000005	Farley 1	4/9/2000	Shutdown*	LOOP-SD	Switchyard Centered	18	19	19	Sustained	Equip	Relay	Yes
3412003002	Fermi 2	8/14/2003	Trip	LOOP-IE-I	Grid Related	379	380	582	Sustained	G	Other - load	No
3331988011	FitzPatrick	10/31/1988	Shutdown	LOOP-SD	Severe Weather Related	1	2	85	Sustained	SEE	High Winds	Yes
3332003001	FitzPatrick	8/14/2003	Trip	LOOP-IE-I	Grid Related	167	168	414	Sustained	G	Other - load	No
2851987008	Fort Calhoun	3/21/1987	Shutdown	LOOP-SD	Switchyard Centered	37	38	38	Sustained	HES	Maintenance	Yes
2851987009	Fort Calhoun	4/4/1987	Shutdown	LOOP-SD	Switchyard Centered	0	4	4	Sustained	HES	Maintenance	Yes
2851990006	Fort Calhoun	2/26/1990	Shutdown	LOOP-SD	Switchyard Centered	13	14	14	Sustained	HES	Maintenance	Yes
2851998005	Fort Calhoun	5/20/1998	Shutdown	LOOP-SD	Switchyard Centered	109	109	109	Sustained	Equip	Transformer	No
2851999004	Fort Calhoun	10/26/1999	Shutdown	LOOP-SD	Plant Centered	2	2	2	Sustained	Equip	Other	Yes
2441988006	Ginna	7/16/1988	No Trip	LOOP-NT	Switchyard Centered	65	66	225	Sustained	Equip	Transformer	No
2442003002	Ginna	8/14/2003	Trip	LOOP-IE-I	Grid Related	49	50	297	Sustained	G	Other - load	No
2131993009	Haddam Neck	6/22/1993	Shutdown	LOOP-SD	Plant Centered	12	13	35	Sustained	Equip	Circuits	Yes
2131993010	Haddam Neck	6/26/1993	Shutdown	LOOP-SD	Plant Centered	3	4	40	Sustained	Equip	Circuits	Yes
2471991006	Indian Point 2	3/20/1991	Shutdown	LOOP-SD	Switchyard Centered	0	1	29	Momentary	Equip	Other	No
2471991010	Indian Point 2	6/22/1991	Shutdown	LOOP-SD	Plant Centered	0	60	60	Sustained	Equip	Breaker	Yes
2471998013	Indian Point 2	9/1/1998	Shutdown*	LOOP-SD	Plant Centered	1	2	67	Sustained	HES	Testing	Yes
2471999015	Indian Point 2	8/31/1999	Trip*	LOOP-IE-C	Switchyard Centered	0	1	689	Momentary	Equip	Circuits	No
2472003005	Indian Point 2	8/14/2003	Trip	LOOP-IE-I	Grid Related	98	99	214	Sustained	G	Other - load	No
2861995004	Indian Point 3	2/27/1995	Shutdown	LOOP-SD	Switchyard Centered	30	31	132	Sustained	HES	Maintenance	No
2861996002	Indian Point 3	1/20/1996	Shutdown	LOOP-SD	Switchyard Centered	30	31	145	Sustained	Equip	Transformer	No
2861997008	Indian Point 3	6/16/1997	Shutdown	LOOP-SD	Grid Related	41	42	42	Sustained	HE	Maintenance	No
2862003005	Indian Point 3	8/14/2003	Trip	LOOP-IE-I	Grid Related	98	99	241	Sustained	G	Other - load	No

Table A-1. LOOP events for 1986 - 2003. (continued)

LER	Plant Name	Date	Operational Mode	LOOP Class	LOOP Category	Switchyard Restoration Time	Potential Bus Restoration Time	Actual Bus Restoration Time	Duration Category	Cause	Specific Cause	Abnormal Electrical Configuration
4091986023	La Crosse[1]	7/19/1986	Shutdown	LOOP-SD	Switchyard Centered	12	13	15	Sustained	SEE	Lightning	No
3731993015	La Salle 1	9/14/1993	Trip	LOOP-IE-I	Switchyard Centered	15	16	70	Sustained	Equip	Transformer	No
3091988006	Maine Yankee	8/13/1988	Trip	LOOP-IE-I	Switchyard Centered	14	15	15	Sustained	Equip	Transformer	No
3691987021	McGuire 1	9/16/1987	Shutdown	LOOP-SD	Plant Centered	0	1	7	Momentary	HES	Testing	Yes
3691991001	McGuire 1	2/11/1991	Trip	LOOP-IE-I	Plant Centered	0	40	0	Sustained	HE	Testing	No
3691988014	McGuire 2	6/24/1988	Shutdown	LOOP-SD	Switchyard Centered	8	8	8	Sustained	HES	Switching	Yes
3701993008	McGuire 2	12/27/1993	Trip	LOOP-IE-I	Switchyard Centered	96	97	131	Sustained	Equip	Transformer	No
2451989012	Millstone 1	4/29/1989	Shutdown	LOOP-SD	Switchyard Centered	0	1	0	Momentary	HES	Other	Yes
3361986017	Millstone 2	11/5/1986	Shutdown	LOOP-SD	Switchyard Centered	0	0	0	Momentary	HES	Maintenance	Yes
3361988011	Millstone 2	10/25/1988	Trip	LOOP-IE-I	Plant Centered	19	20	20	Sustained	HE	Maintenance	No
2201990023	Nine Mile Pt. 1	11/12/1990	No Trip	LOOP-NT	Switchyard Centered	355	356	356	Sustained	Equip	Transformer	No
2201993007	Nine Mile Pt. 1	8/31/1993	No Trip	LOOP-NT	Plant Centered	1	2	18	Sustained	SEE	Lightning	No
2202002001	Nine Mile Pt. 1	11/1/2002	No Trip	LOOP-NT	Switchyard Centered	0	1	482	Momentary	G	Equip - other	Yes
2202003002	Nine Mile Pt. 1	8/14/2003	Trip	LOOP-IE-I	Grid Related	56	57	448	Sustained	G	Other - load	No
4101988062	Nine Mile Pt. 2	12/26/1988	Shutdown	LOOP-SD	Switchyard Centered	9	10	54	Sustained	Equip	Transformer	Yes
4101992006	Nine Mile Pt. 2	3/23/1992	Shutdown	LOOP-SD	Plant Centered	20	21	50	Sustained	HES	Maintenance	No
4102003002	Nine Mile Pt. 2	8/14/2003	Trip	LOOP-IE-I	Grid Related	384	385	551	Sustained	G	Other - load	No
2701992004	Oconee 2	10/19/1992	Trip	LOOP-IE-I	Plant Centered	56	57	207	Sustained	HE	Maintenance	No
2871987002	Oconee 3	3/5/1987	Shutdown	LOOP-SD	Switchyard Centered	155	155	155	Sustained	HES	Maintenance	No
2191989015	Oyster Creek	5/18/1989	Trip	LOOP-IE-I	Plant Centered	1	2	54	Sustained	HE	Maintenance	No
2191992005	Oyster Creek	5/3/1992	Trip	LOOP-IE-I	Plant Centered	5	6	1029	Sustained	SEE	Fire	No
2191997010	Oyster Creek	8/1/1997	Trip	LOOP-IE-C	Switchyard Centered	39	40	40	Sustained	Equip	Relay	No
2551987024	Palisades	7/14/1987	Trip	LOOP-IE-I	Switchyard Centered	388	388	446	Sustained	HE	Maintenance	No
2551992032	Palisades	4/6/1992	Shutdown	LOOP-SD	Plant Centered	0	1	30	Momentary	HES	Testing	No
2551998013	Palisades	12/22/1998	Shutdown	LOOP-SD	Plant Centered	20	21	0	Sustained	Equip	Transformer	No
2552003003	Palisades	3/25/2003	Shutdown	LOOP-SD	Plant Centered	91	92	3261	Sustained	HES	Maintenance	Yes
5291989001	Palo Verde 2	1/3/1989	No Trip	LOOP-NT	Switchyard Centered	1138	1139	1266	Sustained	SEE	Rain	No
2771988020	Peach Bottom 2	7/29/1988	Shutdown	LOOP-SD	Switchyard Centered	23	24	125	Sustained	Equip	Transformer	Yes
2772003004	Peach Bottom 2	9/15/2003	Trip	LOOP-IE-I	Grid Related	1	31	41	Sustained	Equip	Relay	No
2771988020	Peach Bottom 3	7/29/1988	Shutdown	LOOP-SD	Switchyard Centered	23	24	125	Sustained	Equip	Transformer	Yes
2772003004	Peach Bottom 3	9/15/2003	Trip	LOOP-IE-I	Grid Related	1	2	103	Sustained	Equip	Relay	No
4402003002	Perry	8/14/2003	Trip	LOOP-IE-I	Grid Related	87	88	123	Sustained	G	Other – load	No
2931986027	Pilgrim	11/19/1986	Shutdown	LOOP-SD	Severe Weather Related	0	1	213	Momentary	SEE	Ice	No

[1] The La Crosse LOOP event is shown here, but is not included in the calculations since the plant is atypical.

Table A-1. LOOP events for 1986 - 2003. (continued)

LER	Plant Name	Date	Operational Mode	LOOP Class	LOOP Category	Switchyard Restoration Time	Potential Bus Restoration Time	Actual Bus Restoration Time	Duration Category	Cause	Specific Cause	Abnormal Electrical Configuration
2931986029	Pilgrim	12/23/1986	Shutdown	LOOP-SD	Switchyard Centered	0	1	1	Momentary	HES	Maintenance	No
2931987005	Pilgrim	3/31/1987	Shutdown	LOOP-SD	Severe Weather Related	1	2	45	Sustained	SEE	High Winds	Yes
2931987014	Pilgrim[2]	11/12/1987	Shutdown	LOOP-SD	Severe Weather Related	1262	1263	1263	Sustained	SEE	Salt Spray	No
2931989010	Pilgrim	2/21/1989	Shutdown	LOOP-SD	Switchyard Centered	1	2	920	Sustained	Equip	Other	No
2931991024	Pilgrim[2]	10/30/1991	Trip*	LOOP-IE-I	Severe Weather Related	109	110	152	Sustained	SEE	Salt Spray	No
2931993004	Pilgrim	3/13/1993	Trip	LOOP-IE-I	Severe Weather Related	30	31	298	Sustained	SEE	Snow	No
2931993010	Pilgrim	5/19/1993	Shutdown	LOOP-SD	Switchyard Centered	36	37	37	Sustained	HES	Testing	No
2931993022	Pilgrim	9/10/1993	Trip	LOOP-IE-I	Switchyard Centered	10	11	200	Sustained	SEE	Lightning	No
2931997007	Pilgrim	4/1/1997	Shutdown	LOOP-SD	Severe Weather Related	347	1200	1208	Sustained	SEE	High Winds	No
2661992003	Point Beach 1	4/28/1992	Shutdown	LOOP-SD	Plant Centered	0	30	30	Sustained	HES	Maintenance	Yes
2661998002	Point Beach 1	1/8/1998	No Trip	LOOP-NT	Switchyard Centered	341	342	342	Sustained	Equip	Other	No
3011989002	Point Beach 2	3/29/1989	Trip	LOOP-IE-C	Switchyard Centered	90	91	202	Sustained	HE	Maintenance	No
2661994010	Point Beach 2	9/27/1994	Shutdown	LOOP-SD	Plant Centered	0	1	1	Momentary	HES	Switching	Yes
2821996012	Prairie Island 1	6/29/1996	Trip	LOOP-IE-I	Severe Weather Related	296	297	297	Sustained	SEE	High Winds	No
2821996012	Prairie Island 2	6/29/1996	Trip	LOOP-IE-I	Severe Weather Related	296	297	297	Sustained	SEE	High Winds	No
2651992011	Quad Cities 2	4/2/1992	Shutdown	LOOP-SD	Plant Centered	35	35	35	Sustained	Equip	Transformer	No
2652001001	Quad Cities 2	8/2/2001	Trip	LOOP-IE-I	Switchyard Centered	15	16	154	Sustained	SEE	Lightning	No
4581986002	River Bend	1/1/1986	Trip*	LOOP-IE-I	Switchyard Centered	46	47	47	Sustained	Equip	Circuits	No
2611986005	Robinson 2	1/28/1986	Trip	LOOP-IE-C	Plant Centered	117	118	403	Sustained	Equip	Relay	No
2611992017	Robinson 2	8/22/1992	Trip	LOOP-IE-I	Switchyard Centered	453	454	914	Sustained	Equip	Transformer	No
2722003002	Salem 1	7/29/2003	Trip	LOOP-IE-C	Switchyard Centered	30	31	480	Sustained	Equip	Circuits	No
3111986007	Salem 2	8/26/1986	Trip*	LOOP-IE-C	Plant Centered	0	1	0	Momentary	Equip	Other	No
3111994007	Salem 2	4/11/1994	No Trip	LOOP-NT	Plant Centered	0	1	385	Momentary	HE	Testing	No
3111994014	Salem 2	11/18/1994	Shutdown	LOOP-SD	Switchyard Centered	299	300	1675	Sustained	Equip	Relay	Yes
4431991008	Seabrook	6/27/1991	Trip	LOOP-IE-I	Switchyard Centered	19	20	20	Sustained	Equip	Relay	No
4432001002	Seabrook	3/5/2001	Trip	LOOP-IE-I	Severe Weather Related	1	2	2122	Sustained	SEE	Snow	No
3271992027	Sequoyah 1	12/31/1992	Trip	LOOP-IE-I	Switchyard Centered	95	96	116	Sustained	Equip	Breaker	No

[2] The Pilgrim salt spray LOOP events are shown here, but are not included in the calculations since the plant has made modifications and has not had any further events of this type.

Table A-1. LOOP events for 1986 - 2003. (continued)

LER	Plant Name	Date	Operational Mode	LOOP Class	LOOP Category	Switchyard Restoration Time	Potential Bus Restoration Time	Actual Bus Restoration Time	Duration Category	Cause	Specific Cause	Abnormal Electrical Configuration
3271992027	Sequoyah 2	12/31/1992	Trip	LOOP-IE-I	Switchyard Centered	95	96	116	Sustained	Equip	Breaker	No
3951989012	Summer	7/11/1989	Trip*	LOOP-IE-C	Grid Related	95	96	120	Sustained	G	Equip - other	No
2891997007	Three Mile Isl 1	6/21/1997	Trip	LOOP-IE-C	Switchyard Centered	89	90	90	Sustained	Equip	Circuits	No
2501991003	Turkey Point 3	7/24/1991	Shutdown	LOOP-SD	Switchyard Centered	10	11	11	Sustained	Equip	Breaker	Yes
2501992000	Turkey Point 3	8/24/1992	Trip*	LOOP-IE-I	Extreme Weather Related	7920	7921	7921	Sustained	EEE	Hurricane	No
2511991001	Turkey Point 4	3/13/1991	Shutdown	LOOP-SD	Plant Centered	66	67	67	Sustained	Equip	Relay	Yes
2501992000	Turkey Point 4	8/24/1992	Trip*	LOOP-IE-I	Extreme Weather Related	7920	7921	7921	Sustained	EEE	Hurricane	No
2512000004	Turkey Point 4	10/21/2000	Shutdown*	LOOP-SD	Switchyard Centered	1	2	111	Sustained	Equip	Circuits	No
2711987008	Vermont Yankee	8/17/1987	Shutdown	LOOP-SD	Grid Related	2	3	0	Sustained	Equip	Other	Yes
2711991009	Vermont Yankee	4/23/1991	Trip	LOOP-IE-I	Plant Centered	277	278	822	Sustained	HE	Maintenance	No
4241990006	Vogtle 1	3/20/1990	Shutdown	LOOP-SD	Switchyard Centered	139	140	140	Sustained	HES	Other	Yes
3902002005	Watts Bar 1	9/27/2002	No Trip	LOOP-NT	Grid Related	1	2	1003	Sustained	G	Other – fire	No
4821987048	Wolf Creek	10/14/1987	Shutdown	LOOP-SD	Plant Centered	0	1	17	Momentary	HES	Maintenance	Yes
0291991002	Yankee-Rowe	6/15/1991	Trip	LOOP-IE-I	Switchyard Centered	24	25	25	Sustained	SEE	Lightning	No
2951997007	Zion 1	3/11/1997	Shutdown	LOOP-SD	Switchyard Centered	239	240	240	Sustained	Equip	Circuits	No
3041991002	Zion 2	3/21/1991	Trip	LOOP-IE-I	Switchyard Centered	0	60	60	Sustained	Equip	Transformer	No

Table A-2. LOOP events for 1997 - 2003.

LER	Plant Name	Date	Operational Mode	LOOP Class	LOOP Category	Switchyard Restoration Time	Potential Bus Restoration Time	Actual Bus Restoration Time	Duration Category	Cause	Specific Cause	Abnormal Electrical Configuration
4561998003	Braidwood 1	9/6/1998	Shutdown	LOOP-SD	Severe Weather Related	528	528	528	Sustained	SEE	High Winds	No
2961997001	Browns Ferry 3	3/5/1997	Shutdown	LOOP-SD	Switchyard Centered	43	44	44	Sustained	Equip	Transformer	Yes
3252000001	Brunswick 1	3/3/2000	Shutdown	LOOP-SD	Switchyard Centered	15	16	136	Sustained	HES	Testing	Yes
4541998017	Byron 1	8/4/1998	No Trip	LOOP-NT	Plant Centered	502	503	554	Sustained	SEE	Lightning	No
4611999002	Clinton 1	1/6/1999	Shutdown*	LOOP-SD	Switchyard Centered	270	271	492	Sustained	Equip	Other	Yes
3461998006	Davis-Besse	6/24/1998	Trip	LOOP-IE-I	Extreme Weather Related	1364	1428	1495	Sustained	EEE	Tornado	No
3462000004	Davis-Besse	4/22/2000	Shutdown*	LOOP-SD	Plant Centered	10	11	11	Sustained	HES	Testing	Yes
3462003009	Davis-Besse	8/14/2003	Shutdown*	LOOP-SD	Grid Related	652	653	849	Sustained	G	Other – load	No
2752000004	Diablo Canyon 1	5/15/2000	Trip	LOOP-IE-I	Plant Centered	1901	1902	1996	Sustained	Equip	Other	No
3482000005	Farley 1	4/9/2000	Shutdown*	LOOP-SD	Switchyard Centered	18	19	19	Sustained	Equip	Relay	Yes
3412003002	Fermi 2	8/14/2003	Trip	LOOP-IE-I	Grid Related	379	380	582	Sustained	G	Other – load	No
3332003001	FitzPatrick	8/14/2003	Trip	LOOP-IE-I	Grid Related	167	168	414	Sustained	G	Other – load	No
2851998005	Fort Calhoun	5/20/1998	Shutdown	LOOP-SD	Switchyard Centered	109	109	109	Sustained	Equip	Transformer	No
2851999004	Fort Calhoun	10/26/1999	Shutdown	LOOP-SD	Plant Centered	2	2	2	Sustained	Equip	Other	Yes
2442003002	Ginna	8/14/2003	Trip	LOOP-IE-I	Grid Related	49	50	297	Sustained	G	Other – load	No
2471998013	Indian Point 2	9/1/1998	Shutdown*	LOOP-SD	Plant Centered	1	2	67	Sustained	HES	Testing	Yes
2471999015	Indian Point 2	8/31/1999	Trip*	LOOP-IE-C	Switchyard Centered	0	1	689	Momentary	Equip	Circuits	No
2472003005	Indian Point 2	8/14/2003	Trip	LOOP-IE-I	Grid Related	98	99	214	Sustained	G	Other – load	No

Table A-2. LOOP events for 1997 - 2003. (continued)

LER	Plant Name	Date	Operational Mode	LOOP Class	LOOP Category	Switchyard Restoration Time	Potential Bus Restoration Time	Actual Bus Restoration Time	Duration Category	Cause	Specific Cause	Abnormal Electrical Configuration
2861997008	Indian Point 3	6/16/1997	Shutdown	LOOP-SD	Grid Related	41	42	42	Sustained	HE	Maintenance	No
2862003005	Indian Point 3	8/14/2003	Trip	LOOP-IE-I	Grid Related	98	99	241	Sustained	G	Other – load	No
2202002001	Nine Mile Pt. 1	11/1/2002	No Trip	LOOP-NT	Switchyard Centered	0	1	482	Momentary	G	Equip – other	Yes
2202003002	Nine Mile Pt. 1	8/14/2003	Trip	LOOP-IE-I	Grid Related	56	57	448	Sustained	G	Other – load	No
4102003002	Nine Mile Pt. 2	8/14/2003	Trip	LOOP-IE-I	Grid Related	384	385	551	Sustained	G	Other – load	No
2191997010	Oyster Creek	8/1/1997	Trip	LOOP-IE-C	Switchyard Centered	39	40	40	Sustained	Equip	Relay	No
2551998013	Palisades	12/22/1998	Shutdown	LOOP-SD	Plant Centered	20	21	0	Sustained	Equip	Transformer	No
2552003003	Palisades	3/25/2003	Shutdown	LOOP-SD	Plant Centered	91	92	3261	Sustained	HES	Maintenance	Yes
2772003004	Peach Bottom 2	9/15/2003	Trip	LOOP-IE-I	Grid Related	1	31	41	Sustained	Equip	Relay	No
2772003004	Peach Bottom 3	9/15/2003	Trip	LOOP-IE-I	Grid Related	1	2	103	Sustained	Equip	Relay	No
4402003002	Perry	8/14/2003	Trip	LOOP-IE-I	Grid Related	87	88	123	Sustained	G	Other – load	No
2931997007	Pilgrim	4/1/1997	Shutdown	LOOP-SD	Severe Weather Related	347	1200	1208	Sustained	SEE	High Winds	No
2661998002	Point Beach 1	1/8/1998	No Trip	LOOP-NT	Switchyard Centered	341	342	342	Sustained	Equip	Other	No
2652001001	Quad Cities 2	8/2/2001	Trip	LOOP-IE-I	Switchyard Centered	15	16	154	Sustained	SEE	Lightning	No
2722003002	Salem 1	7/29/2003	Trip	LOOP-IE-C	Switchyard Centered	30	31	480	Sustained	Equip	Circuits	No
4432001002	Seabrook	3/5/2001	Trip	LOOP-IE-I	Severe Weather Related	1	2	2122	Sustained	SEE	Snow	No
2891997007	Three Mile Isl 1	6/21/1997	Trip	LOOP-IE-C	Switchyard Centered	89	90	90	Sustained	Equip	Circuits	No
2512000004	Turkey Point 4	10/21/2000	Shutdown*	LOOP-SD	Switchyard Centered	1	2	111	Sustained	Equip	Circuits	No
3902002005	Watts Bar 1	9/27/2002	No Trip	LOOP-NT	Grid Related	1	2	1003	Sustained	G	Other - fire	No
2951997007	Zion 1	3/11/1997	Shutdown	LOOP-SD	Switchyard Centered	239	240	240	Sustained	Equip	Circuits	No

Table A-3. Plant regional assignments.

Plant Name	State	State Group	Coastal?	NERC Subregion	Reliability Council	Inter-Connection	NUREG-1032 Design Group
Arkansas 1	AR	SW	F	SPP-S	SPP	E	I2
Arkansas 2	AR	SW	F	SPP-S	SPP	E	I2
Beaver Valley 1	PA	NE	F	ECAR	ECAR	E	I2
Beaver Valley 2	PA	NE	F	ECAR	ECAR	E	I2
Big Rock Point	MI	NE	F	ECAR	ECAR	E	I2*
Braidwood 1	IL	MidC	F	MAIN	MAIN	E	I3*
Braidwood 2	IL	MidC	F	MAIN	MAIN	E	I3*
Browns Ferry 2	AL	SE	F	TVA	SERC	E	I2
Browns Ferry 3	AL	SE	F	TVA	SERC	E	I2*
Brunswick 1	NC	SE	T	VACAR	SERC	E	I2
Brunswick 2	NC	SE	T	VACAR	SERC	E	I2
Byron 1	IL	MidC	F	MAIN	MAIN	E	I3*
Byron 2	IL	MidC	F	MAIN	MAIN	E	I3*
Callaway	MO	MidC	F	MAIN	MAIN	E	I3
Calvert Cliffs 1	MD	NE	T	MAAC	MAAC	E	I3
Calvert Cliffs 2	MD	NE	T	MAAC	MAAC	E	I3*
Catawba 1	SC	SE	F	VACAR	SERC	E	I3
Catawba 2	SC	SE	F	VACAR	SERC	E	I3*
Clinton 1	IL	MidC	F	MAIN	MAIN	E	I3
Columbia 2	WA	W	F	NWPP-US	WECC	W	I2*
Comanche Peak 1	TX	SW	F	ERCOT	ERCOT	T	I3
Comanche Peak 2	TX	SW	F	ERCOT	ERCOT	T	I3
Cook 1	MI	NE	F	ECAR	ECAR	E	I2*
Cook 2	MI	NE	F	ECAR	ECAR	E	I2
Cooper	NE	MidC	F	MAPP-US	MAPP	E	I1
Crystal River 3	FL	SE	T	FRCC	FRCC	E	I2*
Davis-Besse	OH	NE	F	ECAR	ECAR	E	I1
Diablo Canyon 1	CA	W	F	CA	WECC	W	I2*
Diablo Canyon 2	CA	W	F	CA	WECC	W	I2*
Dresden 2	IL	MidC	F	MAIN	MAIN	E	I2
Dresden 3	IL	MidC	F	MAIN	MAIN	E	I2
Duane Arnold	IA	MidC	F	MAPP-US	MAPP	E	I3*
Farley 1	AL	SE	T	SERC-S	SERC	E	I3

Table A-3. Plant regional assignments. (continued)

Plant Name	State	State Group	Coastal?	NERC Subregion	Reliability Council	Inter-Connection	NUREG-1032 Design Group
Farley 2	AL	SE	T	SERC-S	SERC	E	I3
Fermi 2	MI	NE	F	ECAR	ECAR	E	I3
FitzPatrick	NY	NE	F	NY	NPCC	E	I2*
Fort Calhoun	NE	MidC	F	MAPP-US	MAPP	E	I3
Ginna	NY	NE	F	NY	NPCC	E	I2
Grand Gulf	MS	SE	T	EES	SERC	E	I2*
Haddam Neck	CT	NE	T	NewEngl	NPCC	E	I1
Harris	NC	SE	T	VACAR	SERC	E	I3
Hatch 1	GA	SE	T	SERC-S	SERC	E	I2*
Hatch 2	GA	SE	T	SERC-S	SERC	E	I2
Hope Creek	NJ	NE	T	MAAC	MAAC	E	I1*
Indian Point 2	NY	NE	T	NY	NPCC	E	I1
Indian Point 3	NY	NE	T	NY	NPCC	E	I1
Kewaunee	WI	MidC	F	MAIN	MAIN	E	I3
La Salle 1	IL	MidC	F	MAIN	MAIN	E	I2*
La Salle 2	IL	MidC	F	MAIN	MAIN	E	I2
Limerick 1	PA	NE	T	MAAC	MAAC	E	I3
Limerick 2	PA	NE	T	MAAC	MAAC	E	I3
Maine Yankee	ME	NE	T	NewEngl	NPCC	E	I2*
McGuire 1	NC	SE	F	VACAR	SERC	E	I2
McGuire 2	NC	SE	F	VACAR	SERC	E	I2
Millstone 1	CT	NE	T	NewEngl	NPCC	E	I1
Millstone 2	CT	NE	T	NewEngl	NPCC	E	I1
Millstone 3	CT	NE	T	NewEngl	NPCC	E	I1
Monticello	MN	MidC	F	MAPP-US	MAPP	E	I1
Nine Mile Pt. 1	NY	NE	F	NY	NPCC	E	I1
Nine Mile Pt. 2	NY	NE	F	NY	NPCC	E	I1
North Anna 1	VA	SE	T	VACAR	SERC	E	I3
North Anna 2	VA	SE	T	VACAR	SERC	E	I3
Oconee 1	SC	SE	F	VACAR	SERC	E	I1
Oconee 2	SC	SE	F	VACAR	SERC	E	I1
Oconee 3	SC	SE	F	VACAR	SERC	E	I1
Oyster Creek	NJ	NE	T	MAAC	MAAC	E	I2
Palisades	MI	NE	F	ECAR	ECAR	E	I3

Table A-3. Plant regional assignments. (continued)

Plant Name	State	State Group	Coastal?	NERC Subregion	Reliability Council	Inter-Connection	NUREG-1032 Design Group
Palo Verde 1	AZ	W	F	AZNMSNV	WECC	W	I3
Palo Verde 2	AZ	W	F	AZNMSNV	WECC	W	I3
Palo Verde 3	AZ	W	F	AZNMSNV	WECC	W	I3
Peach Bottom 2	PA	NE	T	MAAC	MAAC	E	I2
Peach Bottom 3	PA	NE	T	MAAC	MAAC	E	I2*
Perry	OH	NE	F	ECAR	ECAR	E	I3
Pilgrim	MA	NE	T	NewEngl	NPCC	E	I3*
Point Beach 1	WI	MidC	F	MAIN	MAIN	E	I2
Point Beach 2	WI	MidC	F	MAIN	MAIN	E	I2
Prairie Island 1	MN	MidC	F	MAPP-US	MAPP	E	I2
Prairie Island 2	MN	MidC	F	MAPP-US	MAPP	E	I2
Quad Cities 1	IL	MidC	F	MAIN	MAIN	E	I3
Quad Cities 2	IL	MidC	F	MAIN	MAIN	E	I3
Rancho Seco	CA	W	F	CA	WECC	W	I2*
River Bend	LA	SE	T	EES	SERC	E	I2*
Robinson 2	SC	SE	T	VACAR	SERC	E	I1*
Salem 1	NJ	NE	T	MAAC	MAAC	E	I2*
Salem 2	NJ	NE	T	MAAC	MAAC	E	I2*
San Onofre 1	CA	W	F	CA	WECC	W	I3
San Onofre 2	CA	W	F	CA	WECC	W	I3
San Onofre 3	CA	W	F	CA	WECC	W	I3
Seabrook	NH	NE	T	NewEngl	NPCC	E	I3*
Sequoyah 1	TN	SE	F	TVA	SERC	E	I3
Sequoyah 2	TN	SE	F	TVA	SERC	E	I3*
South Texas 1	TX	SW	T	ERCOT	ERCOT	T	I3
South Texas 2	TX	SW	T	ERCOT	ERCOT	T	I3
St. Lucie 1	FL	SE	T	FRCC	FRCC	E	I3*
St. Lucie 2	FL	SE	T	FRCC	FRCC	E	I3
Summer	SC	SE	F	VACAR	SERC	E	I2*
Surry 1	VA	SE	T	VACAR	SERC	E	I3
Surry 2	VA	SE	T	VACAR	SERC	E	I3
Susquehanna 1	PA	NE	F	MAAC	MAAC	E	I1
Susquehanna 2	PA	NE	F	MAAC	MAAC	E	I1
Three Mile Isl 1	PA	NE	F	MAAC	MAAC	E	I3

Table A-3. Plant regional assignments. (continued)

Plant Name	State	State Group	Coastal?	NERC Subregion	Reliability Council	Inter-Connection	NUREG-1032 Design Group
Trojan	OR	W	F	NWPP-US	WECC	W	I3
Turkey Point 3	FL	SE	T	FRCC	FRCC	E	I2
Turkey Point 4	FL	SE	T	FRCC	FRCC	E	I2
Vermont Yankee	VT	NE	F	NewEngl	NPCC	E	I2*
Vogtle 1	GA	SE	T	SERC-S	SERC	E	I2*
Vogtle 2	GA	SE	T	SERC-S	SERC	E	I2
Waterford 3	LA	SE	T	EES	SERC	E	I3*
Watts Bar 1	TN	SE	F	TVA	SERC	E	I3
Wolf Creek	KS	SW	F	SPP-N	SPP	E	I3*
Yankee-Rowe	MA	NE	F	NewEngl	NPCC	E	I1*
Zion 1	IL	MidC	F	MAIN	MAIN	E	I3
Zion 2	IL	MidC	F	MAIN	MAIN	E	I3*

Table A-4. LOOP events grouped by category and operational mode for 1986 - 2003.

LOOP Category	Operation	Date	LER	Plant Name	Operational Mode	LOOP Class	Switchyard Restoration Time	Potential Bus Restoration Time	Actual Bus Restoration Time	Duration Category	Cause	Specific Cause
Switchyard Centered	Critical	01-Jan-86	4581986002	River Bend	Trip*	LOOP-IE-I	46	47	47	Sustained	Equip	Circuits
Switchyard Centered	Shutdown	19-Jul-86	4091986023	La Crosse[3]	Shutdown	LOOP-SD	12	13	15	Sustained	SEE	Lightning
Switchyard Centered	Shutdown	05-Nov-86	3361986017	Millstone 2	Shutdown	LOOP-SD	0	0	0	Momentary	HES	Maintenance
Switchyard Centered	Shutdown	23-Dec-86	2931986029	Pilgrim	Shutdown	LOOP-SD	0	1	1	Momentary	HES	Maintenance
Switchyard Centered	Shutdown	05-Mar-87	2871987002	Oconee 3	Shutdown	LOOP-SD	155	155	155	Sustained	HES	Maintenance
Switchyard Centered	Shutdown	21-Mar-87	2851987008	Fort Calhoun	Shutdown	LOOP-SD	37	38	38	Sustained	HES	Maintenance
Switchyard Centered	Shutdown	04-Apr-87	2851987009	Fort Calhoun	Shutdown	LOOP-SD	0	4	4	Sustained	HES	Maintenance
Switchyard Centered	Critical	14-Jul-87	2551987024	Palisades	Trip	LOOP-IE-I	388	388	446	Sustained	HE	Maintenance
Switchyard Centered	Critical	23-Jul-87	3171987012	Calvert Cliffs 1	Trip	LOOP-IE-I	117	118	118	Sustained	Equip	Circuits
Switchyard Centered	Critical	23-Jul-87	3171987012	Calvert Cliffs 2	Trip	LOOP-IE-I	117	118	118	Sustained	Equip	Circuits
Switchyard Centered	Shutdown	11-Sep-87	4561987048	Braidwood 1	Shutdown*	LOOP-SD	0	1	53	Momentary	Equip	Transformer
Switchyard Centered	Shutdown	02-Oct-87	4551987019	Byron 2	Shutdown*	LOOP-SD	1	2	507	Sustained	HES	Switching
Switchyard Centered	Shutdown	16-Oct-87	3021987025	Crystal River 3	Shutdown	LOOP-SD	18	19	59	Sustained	HES	Maintenance
Switchyard Centered	Critical	17-Nov-87	4121987036	Beaver Valley 2	Trip	LOOP-IE-I	3	4	4	Sustained	Equip	Breaker
Switchyard Centered	Shutdown	24-Jun-88	3691988014	McGuire 2	Shutdown	LOOP-SD	8	8	8	Sustained	HES	Switching
Switchyard Centered	Critical	17-Jul-88	3231988008	Diablo Canyon 2	Trip	LOOP-IE-I	37	38	38	Sustained	Equip	Transformer
Switchyard Centered	Shutdown	29-Jul-88	2771988020	Peach Bottom 2	Shutdown	LOOP-SD	23	24	125	Sustained	Equip	Transformer
Switchyard Centered	Shutdown	29-Jul-88	2771988020	Peach Bottom 3	Shutdown	LOOP-SD	23	24	125	Sustained	Equip	Transformer
Switchyard Centered	Critical	13-Aug-88	3091988006	Maine Yankee	Trip	LOOP-IE-I	14	15	15	Sustained	Equip	Transformer
Switchyard Centered	Critical	16-Oct-88	4561988022	Braidwood 1	Trip	LOOP-IE-I	95	118	213	Sustained	Equip	Breaker
Switchyard Centered	Shutdown	26-Dec-88	4101988062	Nine Mile Pt. 2	Shutdown	LOOP-SD	9	10	54	Sustained	Equip	Transformer
Switchyard Centered	Shutdown	21-Feb-89	2931989010	Pilgrim	Shutdown	LOOP-SD	1	2	920	Sustained	Equip	Other
Switchyard Centered	Critical	25-Mar-89	2491989001	Dresden 3	Trip	LOOP-IE-I	45	46	0	Sustained	Equip	Breaker
Switchyard Centered	Critical	29-Mar-89	3011989002	Point Beach 2	Trip	LOOP-IE-I	90	91	202	Sustained	HE	Maintenance
Switchyard Centered	Shutdown	29-Apr-89	2451989012	Millstone 1	Shutdown	LOOP-SD	0	1	0	Momentary	HES	Other

[3] The La Crosse LOOP event is shown here, but is not included in the calculations since the plant is atypical.

Table A-4. LOOP events grouped by category and operational mode for 1986 - 2003. (continued)

LOOP Category	Operation	Date	LER	Plant Name	Operational Mode	LOOP Class	Switchyard Restoration Time	Potential Bus Restoration Time	Actual Bus Restoration Time	Duration Category	Cause	Specific Cause
Switchyard Centered	Shutdown	14-May-89	3971989016	Columbia 2	Shutdown	LOOP-SD	28	29	29	Sustained	HES	Maintenance
Switchyard Centered	Shutdown	16-Jun-89	3021989023	Crystal River 3	Shutdown*	LOOP-SD	60	61	61	Sustained	HES	Testing
Switchyard Centered	Critical	17-Jun-89	3241989009	Brunswick 2	Trip	LOOP-IE-I	90	90	403	Sustained	HE	Maintenance
Switchyard Centered	Shutdown	29-Jun-89	3021989025	Crystal River 3	Shutdown*	LOOP-SD	1	2	2	Sustained	SEE	Lightning
Switchyard Centered	Critical	16-Jan-90	2371990002	Dresden 2	Trip*	LOOP-IE-NC	45	45	759	Sustained	Equip	Transformer
Switchyard Centered	Shutdown	26-Feb-90	2851990006	Fort Calhoun	Shutdown	LOOP-SD	13	14	14	Sustained	HES	Maintenance
Switchyard Centered	Shutdown	20-Mar-90	4241990006	Vogtle 1	Shutdown	LOOP-SD	139	140	140	Sustained	HES	Other
Switchyard Centered	Shutdown	09-Jul-90	3311990007	Duane Arnold	Shutdown	LOOP-SD	37	38	38	Sustained	HES	Testing
Switchyard Centered	Shutdown	07-Mar-91	2751991004	Diablo Canyon 1	Shutdown	LOOP-SD	261	285	285	Sustained	HES	Maintenance
Switchyard Centered	Shutdown	20-Mar-91	2471991006	Indian Point 2	Shutdown	LOOP-SD	0	1	29	Momentary	Equip	Other
Switchyard Centered	Critical	21-Mar-91	3041991002	Zion 2	Trip	LOOP-IE-I	0	60	60	Sustained	Equip	Transformer
Switchyard Centered	Critical	15-Jun-91	0291991002	Yankee-Rowe	Trip	LOOP-IE-I	24	25	25	Sustained	SEE	Lightning
Switchyard Centered	Critical	27-Jun-91	4431991008	Seabrook	Trip	LOOP-IE-I	19	20	20	Sustained	Equip	Relay
Switchyard Centered	Shutdown	24-Jul-91	2501991003	Turkey Point 3	Shutdown	LOOP-SD	10	11	11	Sustained	Equip	Breaker
Switchyard Centered	Shutdown	29-Jan-92	1551992000	Big Rock Point	Shutdown	LOOP-SD	77	78	78	Sustained	Equip	Other
Switchyard Centered	Critical	22-Aug-92	2611992017	Robinson 2	Trip	LOOP-IE-I	453	454	914	Sustained	Equip	Transformer
Switchyard Centered	Critical	31-Dec-92	3271992027	Sequoyah 1	Trip	LOOP-IE-I	95	96	116	Sustained	Equip	Breaker
Switchyard Centered	Critical	31-Dec-92	3271992027	Sequoyah 2	Trip	LOOP-IE-I	95	96	116	Sustained	Equip	Breaker
Switchyard Centered	Shutdown	19-May-93	2931993010	Pilgrim	Shutdown	LOOP-SD	36	37	37	Sustained	HES	Testing
Switchyard Centered	Critical	10-Sep-93	2931993022	Pilgrim	Trip	LOOP-IE-I	10	11	200	Sustained	SEE	Lightning
Switchyard Centered	Critical	14-Sep-93	3731993015	La Salle 1	Trip	LOOP-IE-I	15	16	70	Sustained	Equip	Transformer
Switchyard Centered	Critical	12-Oct-93	3341993013	Beaver Valley 2	Trip	LOOP-IE-I	15	16	28	Sustained	HES	Maintenance
Switchyard Centered	Shutdown	12-Oct-93	3341993013	Beaver Valley 1	Shutdown	LOOP-SD	10	11	11	Sustained	HES	Maintenance
Switchyard Centered	Critical	27-Dec-93	3701993008	McGuire 2	Trip	LOOP-IE-I	96	97	131	Sustained	Equip	Transformer
Switchyard Centered	Shutdown	18-Nov-94	3111994014	Salem 2	Shutdown	LOOP-SD	299	300	1675	Sustained	Equip	Relay
Switchyard Centered	Shutdown	27-Feb-95	2861995004	Indian Point 3	Shutdown	LOOP-SD	30	31	132	Sustained	HES	Maintenance
Switchyard Centered	Shutdown	21-Oct-95	2751995014	Diablo Canyon 1	Shutdown	LOOP-SD	30	31	951	Sustained	HES	Maintenance

Table A-4. LOOP events grouped by category and operational mode for 1986 - 2003. (continued)

LOOP Category	Operation	Date	LER	Plant Name	Operational Mode	LOOP Class	Switchyard Restoration Time	Potential Bus Restoration Time	Actual Bus Restoration Time	Duration Category	Cause	Specific Cause
Switchyard Centered	Shutdown	20-Jan-96	2861996002	Indian Point 3	Shutdown	LOOP-SD	30	31	145	Sustained	Equip	Transformer
Switchyard Centered	Critical	06-Feb-96	4141996001	Catawba 2	Trip	LOOP-IE-I	120	121	330	Sustained	Equip	Transformer
Switchyard Centered	Shutdown	23-May-96	4541996007	Byron 1	Shutdown*	LOOP-SD	720	721	1763	Sustained	Equip	Transformer
Switchyard Centered	Shutdown	05-Mar-97	2961997001	Browns Ferry 3	Shutdown	LOOP-SD	43	44	44	Sustained	Equip	Transformer
Switchyard Centered	Shutdown	11-Mar-97	2951997007	Zion 1	Shutdown	LOOP-SD	239	240	240	Sustained	Equip	Circuits
Switchyard Centered	Critical	21-Jun-97	2891997007	Three Mile Isl 1	Trip	LOOP-IE-C	89	90	90	Sustained	Equip	Circuits
Switchyard Centered	Critical	01-Aug-97	2191997010	Oyster Creek	Trip	LOOP-IE-C	39	40	40	Sustained	Equip	Relay
Switchyard Centered	Shutdown	20-May-98	2851998005	Fort Calhoun	Shutdown	LOOP-SD	109	109	109	Sustained	Equip	Transformer
Switchyard Centered	Shutdown	06-Jan-99	4611999002	Clinton 1	Shutdown*	LOOP-SD	270	271	492	Sustained	Equip	Other
Switchyard Centered	Critical	31-Aug-99	2471999015	Indian Point 2	Trip*	LOOP-IE-C	0	1	689	Momentary	Equip	Circuits
Switchyard Centered	Shutdown	03-Mar-00	3252000001	Brunswick 1	Shutdown	LOOP-SD	15	16	136	Sustained	HES	Testing
Switchyard Centered	Shutdown	09-Apr-00	3482000005	Farley 1	Shutdown*	LOOP-SD	18	19	19	Sustained	Equip	Relay
Switchyard Centered	Shutdown	21-Oct-00	2512000004	Turkey Point 4	Shutdown*	LOOP-SD	1	2	111	Sustained	Equip	Circuits
Switchyard Centered	Critical	02-Aug-01	2652001001	Quad Cities 2	Trip	LOOP-IE-I	15	16	154	Sustained	SEE	Lightning
Switchyard Centered	Critical	29-Jul-03	2722003002	Salem 1	Trip	LOOP-IE-C	30	31	480	Sustained	Equip	Circuits
Severe Weather Related	Shutdown	19-Nov-86	2931986027	Pilgrim	Shutdown	LOOP-SD	0	1	213	Momentary	SEE	Ice
Severe Weather Related	Shutdown	31-Mar-87	2931987005	Pilgrim	Shutdown	LOOP-SD	1	2	45	Sustained	SEE	High Winds
Severe Weather Related	Shutdown	12-Nov-87	2931987014	Pilgrim[4]	Shutdown	LOOP-SD	1262	1263	1263	Sustained	SEE	Salt Spray
Severe Weather Related	Shutdown	31-Oct-88	3331988011	FitzPatrick	Shutdown	LOOP-SD	1	2	85	Sustained	SEE	High Winds
Severe Weather Related	Critical	30-Oct-91	2931991024	Pilgrim[4]	Trip*	LOOP-IE-I	109	110	152	Sustained	SEE	Salt Spray
Severe Weather Related	Critical	13-Mar-93	2931993004	Pilgrim	Trip	LOOP-IE-I	30	31	298	Sustained	SEE	Snow
Severe Weather Related	Shutdown	16-Mar-93	3251993008	Brunswick 2	Shutdown	LOOP-SD	813	814	1018	Sustained	SEE	Salt Spray
Severe Weather Related	Shutdown	17-Mar-93	3251993008	Brunswick 1	Shutdown	LOOP-SD	1120	1121	1508	Sustained	SEE	Salt Spray
Severe Weather Related	Shutdown	17-Mar-93	3021993000	Crystal River 3	Shutdown	LOOP-SD	72	73	102	Sustained	SEE	Salt Spray

[4] The Pilgrim salt spray LOOP events are shown here, but are not included in the calculations since the plant has made modifications and has not had any further events of this type

.

Table A-4. LOOP events grouped by category and operational mode for 1986 - 2003. (continued)

LOOP Category	Operation	Date	LER	Plant Name	Operational Mode	LOOP Class	Switchyard Restoration Time	Potential Bus Restoration Time	Actual Bus Restoration Time	Duration Category	Cause	Specific Cause
Severe Weather Related	Shutdown	29-Mar-93	3021993002	Crystal River 3	Shutdown	LOOP-SD	4	5	37	Sustained	SEE	Flooding
Severe Weather Related	Critical	29-Jun-96	2821996012	Prairie Island 1	Trip	LOOP-IE-I	296	297	297	Sustained	SEE	High Winds
Severe Weather Related	Critical	29-Jun-96	2821996012	Prairie Island 2	Trip	LOOP-IE-I	296	297	297	Sustained	SEE	High Winds
Severe Weather Related	Shutdown	01-Apr-97	2931997007	Pilgrim	Shutdown	LOOP-SD	347	1200	1208	Sustained	SEE	High Winds
Severe Weather Related	Shutdown	06-Sep-98	4561998003	Braidwood 1	Shutdown	LOOP-SD	528	528	528	Sustained	SEE	High Winds
Severe Weather Related	Critical	05-Mar-01	4432001002	Seabrook	Trip	LOOP-IE-I	1	2	2122	Sustained	SEE	Snow
Plant Centered	Critical	28-Jan-86	2611986005	Robinson 2	Trip	LOOP-IE-I	117	118	403	Sustained	Equip	Relay
Plant Centered	Critical	26-Aug-86	3111986007	Salem 2	Trip*	LOOP-IE-NC	0	1	0	Momentary	Equip	Other
Plant Centered	Critical	13-Sep-86	3251986024	Brunswick 1	Trip	LOOP-IE-I	0	1	159	Momentary	HE	Maintenance
Plant Centered	Shutdown	16-Sep-87	3691987021	McGuire 1	Shutdown	LOOP-SD	0	1	7	Momentary	HES	Testing
Plant Centered	Shutdown	14-Oct-87	4821987048	Wolf Creek	Shutdown	LOOP-SD	0	1	17	Momentary	HES	Maintenance
Plant Centered	Critical	25-Oct-88	3361988011	Millstone 2	Trip	LOOP-IE-I	19	20	20	Sustained	HE	Maintenance
Plant Centered	Critical	18-May-89	2191989015	Oyster Creek	Trip	LOOP-IE-I	1	2	54	Sustained	HE	Maintenance
Plant Centered	Critical	11-Feb-91	3691991001	McGuire 1	Trip	LOOP-IE-I	0	40	0	Sustained	HE	Testing
Plant Centered	Shutdown	13-Mar-91	2511991001	Turkey Point 4	Shutdown	LOOP-SD	66	67	67	Sustained	Equip	Relay
Plant Centered	Critical	23-Apr-91	2711991009	Vermont Yankee	Trip	LOOP-IE-I	277	278	822	Sustained	HE	Maintenance
Plant Centered	Critical	12-May-91	3151991004	Cook 1	Trip	LOOP-IE-I	0	1	81	Momentary	Equip	Other
Plant Centered	Shutdown	22-Jun-91	2471991010	Indian Point 2	Shutdown	LOOP-SD	0	60	60	Sustained	Equip	Breaker
Plant Centered	Shutdown	20-Oct-91	3021991010	Crystal River 3	Shutdown	LOOP-SD	3	4	4	Sustained	HES	Other
Plant Centered	Shutdown	23-Mar-92	4101992006	Nine Mile Pt. 2	Shutdown	LOOP-SD	20	21	50	Sustained	HES	Maintenance
Plant Centered	Critical	27-Mar-92	3021992001	Crystal River 3	Trip	LOOP-IE-I	20	21	150	Sustained	HE	Maintenance
Plant Centered	Shutdown	02-Apr-92	2651992011	Quad Cities 2	Shutdown	LOOP-SD	35	35	35	Sustained	Equip	Transformer
Plant Centered	Shutdown	06-Apr-92	2551992032	Palisades	Shutdown	LOOP-SD	0	1	30	Momentary	HES	Testing
Plant Centered	Shutdown	28-Apr-92	2661992003	Point Beach 1	Shutdown	LOOP-SD	0	30	30	Sustained	HES	Maintenance
Plant Centered	Critical	03-May-92	2191992005	Oyster Creek	Trip	LOOP-IE-I	5	6	1029	Sustained	SEE	Fire
Plant Centered	Critical	19-Oct-92	2701992004	Oconee 2	Trip	LOOP-IE-I	56	57	207	Sustained	HE	Maintenance
Plant Centered	Shutdown	08-Apr-93	3021993004	Crystal River 3	Shutdown	LOOP-SD	1	2	136	Sustained	HES	Maintenance

Table A-4. LOOP events grouped by category and operational mode for 1986 - 2003. (continued)

LOOP Category	Operation	Date	LER	Plant Name	Operational Mode	LOOP Class	Switchyard Restoration Time	Potential Bus Restoration Time	Actual Bus Restoration Time	Duration Category	Cause	Specific Cause
Plant Centered	Shutdown	22-Jun-93	2131993009	Haddam Neck	Shutdown	LOOP-SD	12	13	35	Sustained	Equip	Circuits
Plant Centered	Shutdown	26-Jun-93	2131993010	Haddam Neck	Shutdown	LOOP-SD	3	4	40	Sustained	Equip	Circuits
Plant Centered	Shutdown	21-May-94	3241994008	Brunswick 2	Shutdown	LOOP-SD	2	3	64	Sustained	HES	Testing
Plant Centered	Shutdown	27-Sep-94	2661994010	Point Beach 2	Shutdown	LOOP-SD	0	1	1	Momentary	HES	Switching
Plant Centered	Shutdown	01-Sep-98	2471998013	Indian Point 2	Shutdown*	LOOP-SD	1	2	67	Sustained	HES	Testing
Plant Centered	Shutdown	22-Dec-98	2551998013	Palisades	Shutdown	LOOP-SD	20	21	0	Sustained	Equip	Transformer
Plant Centered	Shutdown	26-Oct-99	2851999004	Fort Calhoun	Shutdown	LOOP-SD	2	2	2	Sustained	Equip	Other
Plant Centered	Shutdown	22-Apr-00	3462000004	Davis-Besse	Shutdown*	LOOP-SD	10	11	11	Sustained	HES	Testing
Plant Centered	Critical	15-May-00	2752000004	Diablo Canyon 1	Trip	LOOP-IE-I	1901	1902	1996	Sustained	Equip	Other
Plant Centered	Shutdown	25-Mar-03	2552003003	Palisades	Shutdown	LOOP-SD	91	92	3261	Sustained	HES	Maintenance
Grid Related	Shutdown	17-Aug-87	2711987008	Vermont Yankee	Shutdown	LOOP-SD	2	3	0	Sustained	Equip	Other
Grid Related	Critical	11-Jul-89	3951989012	Summer	Trip*	LOOP-IE-C	95	96	120	Sustained	G	Equip – other
Grid Related	Shutdown	16-Jun-97	2861997008	Indian Point 3	Shutdown	LOOP-SD	41	42	42	Sustained	HE	Maintenance
Grid Related	Critical	14-Aug-03	3412003002	Fermi 2	Trip	LOOP-IE-I	379	380	582	Sustained	G	Other – load
Grid Related	Critical	14-Aug-03	3332003001	FitzPatrick	Trip	LOOP-IE-I	167	168	414	Sustained	G	Other – load
Grid Related	Critical	14-Aug-03	2442003002	Ginna	Trip	LOOP-IE-I	49	50	297	Sustained	G	Other – load
Grid Related	Critical	14-Aug-03	2472003005	Indian Point 2	Trip	LOOP-IE-I	98	99	214	Sustained	G	Other – load
Grid Related	Critical	14-Aug-03	2862003005	Indian Point 3	Trip	LOOP-IE-I	98	99	241	Sustained	G	Other – load
Grid Related	Critical	14-Aug-03	2202003002	Nine Mile Pt. 1	Trip	LOOP-IE-I	56	57	448	Sustained	G	Other – load
Grid Related	Critical	14-Aug-03	4102003002	Nine Mile Pt. 2	Trip	LOOP-IE-I	384	385	551	Sustained	G	Other – load
Grid Related	Critical	14-Aug-03	4402003002	Perry	Trip	LOOP-IE-I	87	88	123	Sustained	G	Other – load
Grid Related	Shutdown	14-Aug-03	3462003009	Davis-Besse	Shutdown*	LOOP-SD	652	653	849	Sustained	G	Other – load
Grid Related	Critical	15-Sep-03	2772003004	Peach Bottom 2	Trip	LOOP-IE-I	1	31	41	Sustained	Equip	Relay
Grid Related	Critical	15-Sep-03	2772003004	Peach Bottom 3	Trip	LOOP-IE-I	1	2	103	Sustained	Equip	Relay
Extreme Weather Related	Critical	24-Aug-92	2501992000	Turkey Point 3	Trip*	LOOP-IE-I	7920	7921	7921	Sustained	EEE	Hurricane
Extreme Weather Related	Critical	24-Aug-92	2501992000	Turkey Point 4	Trip*	LOOP-IE-I	7920	7921	7921	Sustained	EEE	Hurricane
Extreme Weather Related	Critical	24-Jun-98	3461998006	Davis-Besse	Trip	LOOP-IE-I	1364	1428	1495	Sustained	EEE	Tornado

Table A-5. LOOP events aggregated at site level for 1986 - 2003.

Plant Site	Date	LER	Operational Mode	LOOP Category	LOOP Class	Switchyard Restoration Time	Potential Bus Restoration Time	Actual Bus Restoration Time	Duration Category	Cause	Specific Cause
Beaver Valley	11/17/1987	4121987036	Trip	Switchyard Centered	LOOP-IE-I	3	4	4	Sustained	Equip	Breaker
Beaver Valley	10/12/1993	3341993013	Trip/Shutdown	Switchyard Centered	LOOP-IE-I/LOOP-SD	13	14	20	Sustained	HES	Maintenance
Big Rock Point	1/29/1992	1551992000	Shutdown	Switchyard Centered	LOOP-SD	77	78	78	Sustained	Equip	Other
Braidwood	9/11/1987	4561987048	Shutdown*	Switchyard Centered	LOOP-SD	0	1	53	Momentary	Equip	Transformer
Braidwood	10/16/1988	4561988022	Trip	Switchyard Centered	LOOP-IE-I	95	118	213	Sustained	Equip	Breaker
Braidwood	9/6/1998	4561998003	Shutdown	Severe Weather Related	LOOP-SD	528	528	528	Sustained	SEE	High Winds
Browns Ferry	3/5/1997	2961997001	Shutdown	Switchyard Centered	LOOP-SD	43	44	44	Sustained	Equip	Transformer
Brunswick	9/13/1986	3251986024	Trip	Plant Centered	LOOP-IE-I	0	1	159	Momentary	HE	Maintenance
Brunswick	6/17/1989	3241989009	Trip	Switchyard Centered	LOOP-IE-I	90	90	403	Sustained	HE	Maintenance
Brunswick	3/16/1993 and 3/17/1993	3251993008	Shutdown	Severe Weather Related	LOOP-SD	967	967	1263	Sustained	SEE	Salt Spray
Brunswick	5/21/1994	3241994008	Shutdown	Plant Centered	LOOP-SD	2	3	64	Sustained	HES	Testing
Brunswick	3/3/2000	3252000001	Shutdown	Switchyard Centered	LOOP-SD	15	16	136	Sustained	HES	Testing
Byron	10/2/1987	4551987019	Shutdown*	Switchyard Centered	LOOP-SD	1	2	507	Momentary	HES	Switching
Byron	5/23/1996	4541996007	Shutdown*	Switchyard Centered	LOOP-SD	720	721	1763	Sustained	Equip	Transformer
Calvert Cliffs	7/23/1987	3171987012	Trip	Switchyard Centered	LOOP-IE-I	117	118	118	Sustained	Equip	Circuits
Catawba	2/6/1996	4141996001	Trip	Switchyard Centered	LOOP-IE-I	120	121	330	Sustained	Equip	Transformer
Clinton	1/6/1999	4611999002	Shutdown*	Switchyard Centered	LOOP-SD	270	271	492	Sustained	Equip	Other
Columbia	5/14/1989	3971989016	Shutdown	Switchyard Centered	LOOP-SD	28	29	29	Sustained	HES	Maintenance
Cook	5/12/1991	3151991004	Trip	Plant Centered	LOOP-IE-I	0	1	81	Momentary	Equip	Other
Crystal River	10/16/1987	3021987025	Shutdown	Switchyard Centered	LOOP-SD	18	19	59	Sustained	HES	Maintenance
Crystal River	6/16/1989	3021989023	Shutdown*	Switchyard Centered	LOOP-SD	60	61	61	Sustained	HES	Testing
Crystal River	6/29/1989	3021989025	Shutdown*	Severe Weather Related	LOOP-SD	1	2	2	Momentary	SEE	Lightning
Crystal River	10/20/1991	3021991010	Shutdown	Plant Centered	LOOP-SD	3	4	4	Sustained	HES	Other
Crystal River	3/27/1992	3021992001	Trip	Plant Centered	LOOP-IE-I	20	21	150	Sustained	HE	Maintenance
Crystal River	3/17/1993	3021993000	Shutdown	Severe Weather Related	LOOP-SD	72	73	102	Sustained	SEE	Salt Spray
Crystal River	3/29/1993	3021993002	Shutdown	Severe Weather Related	LOOP-SD	4	5	37	Sustained	SEE	Flooding
Crystal River	4/8/1993	3021993004	Shutdown	Plant Centered	LOOP-SD	1	2	136	Momentary	HES	Maintenance
Davis-Besse	6/24/1998	3461998006	Trip	Extreme Weather Related	LOOP-IE-I	1364	1428	1495	Sustained	EEE	Tornado
Davis-Besse	4/22/2000	3462000004	Shutdown*	Plant Centered	LOOP-SD	10	11	11	Sustained	HES	Testing
Davis-Besse	8/14/2003	3462003009	Shutdown*	Grid Related	LOOP-SD	652	653	849	Sustained	G	Other - load
Diablo Canyon	7/17/1988	3231988008	Trip	Switchyard Centered	LOOP-IE-I	37	38	38	Sustained	Equip	Transformer
Diablo Canyon	3/7/1991	2751991004	Shutdown	Switchyard Centered	LOOP-SD	261	285	285	Sustained	HES	Maintenance

Table A-5. LOOP events aggregated at site level for 1986 - 2003. (continued)

Plant Site	Date	LER	Operational Mode	LOOP Category	LOOP Class	Switchyard Restoration Time	Potential Bus Restoration Time	Actual Bus Restoration Time	Duration Category	Cause	Specific Cause
Diablo Canyon	10/21/1995	2751995014	Shutdown	Switchyard Centered	LOOP-SD	30	31	951	Sustained	HES	Maintenance
Diablo Canyon	5/15/2000	2752000004	Trip	Plant Centered	LOOP-IE-I	1901	1902	1996	Sustained	Equip	Other
Dresden	3/25/1989	2491989001	Trip	Switchyard Centered	LOOP-IE-I	45	46	0	Sustained	Equip	Breaker
Dresden	1/16/1990	2371990002	Trip*	Switchyard Centered	LOOP-IE-C	45	45	759	Sustained	Equip	Transformer
Duane Arnold	7/9/1990	3311990007	Shutdown	Switchyard Centered	LOOP-SD	37	38	38	Sustained	HES	Testing
Farley	4/9/2000	3482000005	Shutdown*	Switchyard Centered	LOOP-SD	18	19	19	Sustained	Equip	Relay
Fermi	8/14/2003	3412003002	Trip	Grid Related	LOOP-IE-I	379	380	582	Sustained	G	Other - load
Fitzpatrick	10/31/1988	3331988011	Shutdown	Severe Weather Related	LOOP-SD	1	2	85	Momentary	SEE	High Winds
Fitzpatrick	12/26/1988	4101988062	Shutdown	Switchyard Centered	LOOP-SD	9	10	54	Sustained	Equip	Transformer
Fitzpatrick	3/23/1992	4101992006	Shutdown	Plant Centered	LOOP-SD	20	21	50	Sustained	HES	Maintenance
Fitzpatrick	8/14/2003	4102003002, 2202003002, 3332003001	Trip	Grid Related	LOOP-IE-I	202	203	471	Sustained	G	Other - load
Fort Calhoun	3/21/1987	2851987008	Shutdown	Switchyard Centered	LOOP-SD	37	38	38	Sustained	HES	Maintenance
Fort Calhoun	4/4/1987	2851987009	Shutdown	Switchyard Centered	LOOP-SD	0	4	4	Sustained	HES	Maintenance
Fort Calhoun	2/26/1990	2851990006	Shutdown	Switchyard Centered	LOOP-SD	13	14	14	Sustained	HES	Maintenance
Fort Calhoun	5/20/1998	2851998005	Shutdown	Switchyard Centered	LOOP-SD	109	109	109	Sustained	Equip	Transformer
Fort Calhoun	10/26/1999	2851999004	Shutdown	Plant Centered	LOOP-SD	2	2	2	Momentary	Equip	Other
Ginna	8/14/2003	2442003002	Trip	Grid Related	LOOP-IE-I	49	50	297	Sustained	G	Other - load
Haddam Neck	6/22/1993	2131993009	Shutdown	Plant Centered	LOOP-SD	12	13	35	Sustained	Equip	Circuits
Haddam Neck	6/26/1993	2131993010	Shutdown	Plant Centered	LOOP-SD	3	4	40	Sustained	Equip	Circuits
Indian Point	3/20/1991	2471991006	Shutdown	Switchyard Centered	LOOP-SD	0	1	29	Momentary	Equip	Other
Indian Point	6/22/1991	2471991010	Shutdown	Plant Centered	LOOP-SD	0	60	60	Sustained	Equip	Breaker
Indian Point	2/27/1995	2861995004	Shutdown	Switchyard Centered	LOOP-SD	30	31	132	Sustained	HES	Maintenance
Indian Point	1/20/1996	2861996002	Shutdown	Switchyard Centered	LOOP-SD	30	31	145	Sustained	Equip	Transformer
Indian Point	6/16/1997	2861997008	Shutdown	Grid Related	LOOP-SD	41	42	42	Sustained	HE	Maintenance
Indian Point	9/1/1998	2471998013	Shutdown*	Plant Centered	LOOP-SD	1	2	67	Momentary	HES	Testing
Indian Point	8/31/1999	2471999015	Trip*	Switchyard Centered	LOOP-IE-C	0	1	689	Momentary	Equip	Circuits
Indian Point	8/14/2003	2472003005	Trip	Grid Related	LOOP-IE-I	98	99	228	Sustained	G	Other - load
La Crosse[5]	7/19/1986	4091986023	Shutdown	Severe Weather Related	LOOP-SD	12	13	15	Sustained	SEE	Lightning
LaSalle	9/14/1993	3731993015	Trip	Switchyard Centered	LOOP-IE-I	15	16	70	Sustained	Equip	Transformer
Maine Yankee	8/13/1988	3091988006	Trip	Switchyard Centered	LOOP-IE-I	14	15	15	Sustained	Equip	Transformer
McGuire	9/16/1987	3691987021	Shutdown	Plant Centered	LOOP-SD	0	1	7	Momentary	HES	Testing
McGuire	6/24/1988	3691988014	Shutdown	Switchyard Centered	LOOP-SD	8	8	8	Sustained	HES	Switching

[5] The La Crosse LOOP event is shown here, but is not included in the calculations since the plant is atypical.

Table A-5. LOOP events aggregated at site level for 1986 - 2003. (continued)

Plant Site	Date	LER	Operational Mode	LOOP Category	LOOP Class	Switchyard Restoration Time	Potential Bus Restoration Time	Actual Bus Restoration Time	Duration Category	Cause	Specific Cause
McGuire	2/11/1991	3691991001	Trip	Plant Centered	LOOP-IE-I	0	40	0	Sustained	HE	Testing
McGuire	12/27/1993	3701993008	Trip	Switchyard Centered	LOOP-IE-I	96	97	131	Sustained	Equip	Transformer
Millstone	11/5/1986	3361986017	Shutdown	Switchyard Centered	LOOP-SD	0	0	0	Momentary	HES	Maintenance
Millstone	10/25/1988	3361988011	Trip	Plant Centered	LOOP-IE-I	19	20	20	Sustained	HE	Maintenance
Millstone	4/29/1989	2451989012	Shutdown	Switchyard Centered	LOOP-SD	0	1	0	Momentary	HES	Other
Oconee	3/5/1987	2871987002	Shutdown	Switchyard Centered	LOOP-SD	155	155	155	Sustained	HES	Maintenance
Oconee	10/19/1992	2701992004	Trip	Plant Centered	LOOP-IE-I	56	57	207	Sustained	HE	Maintenance
Oyster Creek	5/18/1989	2191989015	Trip	Plant Centered	LOOP-IE-I	1	2	54	Momentary	HE	Maintenance
Oyster Creek	5/3/1992	2191992005	Trip	Severe Weather Related	LOOP-IE-I	5	6	1029	Sustained	SEE	Fire
Oyster Creek	8/1/1997	2191997010	Trip	Switchyard Centered	LOOP-IE-C	39	40	40	Sustained	Equip	Relay
Palisades	7/14/1987	2551987024	Trip	Switchyard Centered	LOOP-IE-I	388	388	446	Sustained	HE	Maintenance
Palisades	4/6/1992	2551992032	Shutdown	Plant Centered	LOOP-SD	0	1	30	Momentary	HES	Testing
Palisades	12/22/1998	2551998013	Shutdown	Plant Centered	LOOP-SD	20	21	0	Sustained	Equip	Transformer
Palisades	3/25/2003	2552003003	Shutdown	Plant Centered	LOOP-SD	91	92	3261	Sustained	HES	Maintenance
Peach Bottom	7/29/1988	2771988020	Shutdown	Switchyard Centered	LOOP-SD	23	24	125	Sustained	Equip	Transformer
Peach Bottom	9/15/2003	2772003004	Trip	Grid Related	LOOP-IE-I	1	17	72	Sustained	Equip	Relay
Perry	8/14/2003	4402003002	Trip	Grid Related	LOOP-IE-I	87	88	123	Sustained	G	Other - load
Pilgrim	11/19/1986	2931986027	Shutdown	Severe Weather Related	LOOP-SD	0	1	213	Momentary	SEE	Ice
Pilgrim	12/23/1986	2931986029	Shutdown	Switchyard Centered	LOOP-SD	0	1	1	Momentary	HES	Maintenance
Pilgrim	3/31/1987	2931987005	Shutdown	Severe Weather Related	LOOP-SD	1	2	45	Momentary	SEE	High Winds
Pilgrim[6]	11/12/1987	2931987014	Shutdown	Severe Weather Related	LOOP-SD	1262	1263	1263	Sustained	SEE	Salt Spray
Pilgrim	2/21/1989	2931989010	Shutdown	Switchyard Centered	LOOP-SD	1	2	920	Momentary	Equip	Other
Pilgrim[6]	10/30/1991	2931991024	Trip*	Severe Weather Related	LOOP-IE-I	109	110	152	Sustained	SEE	Salt Spray
Pilgrim	3/13/1993	2931993004	Trip	Severe Weather Related	LOOP-IE-I	30	31	298	Sustained	SEE	Snow
Pilgrim	5/19/1993	2931993010	Shutdown	Switchyard Centered	LOOP-SD	36	37	37	Sustained	HES	Testing
Pilgrim	9/10/1993	2931993022	Trip	Severe Weather Related	LOOP-IE-I	10	11	200	Sustained	SEE	Lightning
Pilgrim	4/1/1997	2931997007	Shutdown	Severe Weather Related	LOOP-SD	347	1200	1208	Sustained	SEE	High Winds
Point Beach	3/29/1989	3011989002	Trip	Switchyard Centered	LOOP-IE-C	90	91	202	Sustained	HE	Maintenance
Point Beach	4/28/1992	2661992003	Shutdown	Plant Centered	LOOP-SD	0	30	30	Sustained	HES	Maintenance
Point Beach	9/27/1994	2661994010	Shutdown	Plant Centered	LOOP-SD	0	1	1	Momentary	HES	Switching
Prairie Island	6/29/1996	2821996012	Trip	Severe Weather Related	LOOP-IE-I	296	297	297	Sustained	SEE	High Winds
Quad Cities	4/2/1992	2651992011	Shutdown	Plant Centered	LOOP-SD	35	35	35	Sustained	Equip	Transformer
Quad Cities	8/2/2001	2652001001	Trip	Severe Weather Related	LOOP-IE-I	15	16	154	Sustained	SEE	Lightning

[6] The Pilgrim salt spray LOOP events are shown here, but are not included in the calculations since the plant has made modifications and has not had any further events of this type.

Table A-5. LOOP events aggregated at site level for 1986 - 2003. (continued)

Plant Site	Date	LER	Operational Mode	LOOP Category	LOOP Class	Switchyard Restoration Time	Potential Bus Restoration Time	Actual Bus Restoration Time	Duration Category	Cause	Specific Cause
River Bend	1/1/1986	4581986002	Trip*	Switchyard Centered	LOOP-IE-I	46	47	47	Sustained	Equip	Circuits
Robinson	1/28/1986	2611986005	Trip	Plant Centered	LOOP-IE-C	117	118	403	Sustained	Equip	Relay
Robinson	8/22/1992	2611992017	Trip	Switchyard Centered	LOOP-IE-I	453	454	914	Sustained	Equip	Transformer
Salem	8/26/1986	3111986007	Trip*	Plant Centered	LOOP-IE-C	0	1	0	Momentary	Equip	Other
Salem	11/18/1994	3111994014	Shutdown	Switchyard Centered	LOOP-SD	299	300	1675	Sustained	Equip	Relay
Salem	7/29/2003	2722003002	Trip	Switchyard Centered	LOOP-IE-C	30	31	480	Sustained	Equip	Circuits
Seabrook	6/27/1991	4431991008	Trip	Switchyard Centered	LOOP-IE-I	19	20	20	Sustained	Equip	Relay
Seabrook	3/5/2001	4432001002	Trip	Severe Weather Related	LOOP-IE-I	1	2	2122	Momentary	SEE	Snow
Sequoyah	12/31/1992	3271992027	Trip	Switchyard Centered	LOOP-IE-I	95	96	116	Sustained	Equip	Breaker
Summer	7/11/1989	3951989012	Trip*	Grid Related	LOOP-IE-C	95	96	120	Sustained	G	Equip - other
Three Mile Isl	6/21/1997	2891997007	Trip	Switchyard Centered	LOOP-IE-C	89	90	90	Sustained	Equip	Circuits
Turkey Point	3/13/1991	2511991001	Shutdown	Plant Centered	LOOP-SD	66	67	67	Sustained	Equip	Relay
Turkey Point	7/24/1991	2501991003	Shutdown	Switchyard Centered	LOOP-SD	10	11	11	Sustained	Equip	Breaker
Turkey Point	8/24/1992	2501992000	Trip*	Extreme Weather Related	LOOP-IE-I	7920	7921	7921	Sustained	EEE	Hurricane
Turkey Point	10/21/2000	2512000004	Shutdown*	Switchyard Centered	LOOP-SD	1	2	111	Momentary	Equip	Circuits
Vermont Yankee	8/17/1987	2711987008	Shutdown	Grid Related	LOOP-SD	2	3	0	Sustained	Equip	Other
Vermont Yankee	4/23/1991	2711991009	Trip	Plant Centered	LOOP-IE-I	277	278	822	Sustained	HE	Maintenance
Vogtle	3/20/1990	4241990006	Shutdown	Switchyard Centered	LOOP-SD	139	140	140	Sustained	HES	Other
Wolf Creek	10/14/1987	4821987048	Shutdown	Plant Centered	LOOP-SD	0	1	17	Momentary	HES	Maintenance
Yankee-Rowe	6/15/1991	0291991002	Trip	Severe Weather Related	LOOP-IE-I	24	25	25	Sustained	SEE	Lightning
Zion	3/21/1991	3041991002	Trip	Switchyard Centered	LOOP-IE-I	0	60	60	Sustained	Equip	Transformer
Zion	3/11/1997	2951997007	Shutdown	Switchyard Centered	LOOP-SD	239	240	240	Sustained	Equip	Circuits

Table A-6. Site level LOOP events listed by category for 1986 - 2003.

LOOP Category	Plant Site	Date	LER	Operational Mode	LOOP Class	Switchyard Restoration Time	Potential Bus Restoration Time	Actual Bus Restoration Time	Duration Category	Cause	Specific Cause
Extreme Weather Related	Davis-Besse	6/24/1998	3461998006	Trip	LOOP-IE-I	1364	1428	1495	Sustained	EEE	Tornado
Extreme Weather Related	Turkey Point	8/24/1992	2501992000	Trip*	LOOP-IE-I	7920	7921	7921	Sustained	EEE	Hurricane
Grid Related	Davis-Besse	8/14/2003	3462003009	Shutdown*	LOOP-SD	652	653	849	Sustained	G	Other - load
Grid Related	Fermi	8/14/2003	3412003002	Trip	LOOP-IE-I	379	380	582	Sustained	G	Other - load
Grid Related	Fitzpatrick	8/14/2003	4102003002, 2202003002, 3332003001	Trip	LOOP-IE-I	202	203	471	Sustained	G	Other - load
Grid Related	Ginna	8/14/2003	2442003002	Trip	LOOP-IE-I	49	50	297	Sustained	G	Other - load
Grid Related	Indian Point	6/16/1997	2861997008	Shutdown	LOOP-SD	41	42	42	Sustained	HE	Maintenance
Grid Related	Indian Point	8/14/2003	2472003005	Trip	LOOP-IE-I	98	99	228	Sustained	G	Other - load
Grid Related	Peach Bottom	9/15/2003	2772003004	Trip	LOOP-IE-I	1	17	72	Sustained	Equip	Relay
Grid Related	Perry	8/14/2003	4402003002	Trip	LOOP-IE-I	87	88	123	Sustained	G	Other - load
Grid Related	Summer	7/11/1989	3951989012	Trip*	LOOP-IE-C	95	96	120	Sustained	G	Equip - other
Grid Related	Vermont Yankee	8/17/1987	2711987008	Shutdown	LOOP-SD	2	3	0	Sustained	Equip	Other
Plant Centered	Brunswick	9/13/1986	3251986024	Trip	LOOP-IE-I	0	1	159	Momentary	HE	Maintenance
Plant Centered	Brunswick	5/21/1994	3241994008	Shutdown	LOOP-SD	2	3	64	Sustained	HES	Testing
Plant Centered	Cook	5/12/1991	3151991004	Trip	LOOP-IE-I	0	1	81	Momentary	Equip	Other
Plant Centered	Crystal River	10/20/1991	3021991010	Shutdown	LOOP-SD	3	4	4	Sustained	HES	Other
Plant Centered	Crystal River	3/27/1992	3021992001	Trip	LOOP-IE-I	20	21	150	Sustained	HE	Maintenance
Plant Centered	Crystal River	4/8/1993	3021993004	Shutdown	LOOP-SD	1	2	136	Momentary	HES	Maintenance
Plant Centered	Davis-Besse	4/22/2000	3462000004	Shutdown*	LOOP-SD	10	11	11	Sustained	HES	Testing
Plant Centered	Diablo Canyon	5/15/2000	2752000004	Trip	LOOP-IE-I	1901	1902	1996	Sustained	Equip	Other
Plant Centered	Fitzpatrick	3/23/1992	4101992006	Shutdown	LOOP-SD	20	21	50	Sustained	HES	Maintenance
Plant Centered	Fort Calhoun	10/26/1999	2851999004	Shutdown	LOOP-SD	2	2	2	Momentary	Equip	Other
Plant Centered	Haddam Neck	6/22/1993	2131993009	Shutdown	LOOP-SD	12	13	35	Sustained	Equip	Circuits
Plant Centered	Haddam Neck	6/26/1993	2131993010	Shutdown	LOOP-SD	3	4	40	Sustained	Equip	Circuits
Plant Centered	Indian Point	6/22/1991	2471991010	Shutdown	LOOP-SD	0	60	60	Sustained	Equip	Breaker
Plant Centered	Indian Point	9/1/1998	2471998013	Shutdown*	LOOP-SD	1	2	67	Momentary	HES	Testing
Plant Centered	McGuire	9/16/1987	3691987021	Shutdown	LOOP-SD	0	1	7	Momentary	HES	Testing
Plant Centered	McGuire	2/11/1991	3691991001	Trip	LOOP-IE-I	0	40	0	Sustained	HE	Testing
Plant Centered	Millstone	10/25/1988	3361988011	Trip	LOOP-IE-I	19	20	20	Sustained	HE	Maintenance
Plant Centered	Oconee	10/19/1992	2701992004	Trip	LOOP-IE-I	56	57	207	Sustained	HE	Maintenance
Plant Centered	Oyster Creek	5/18/1989	2191989015	Trip	LOOP-IE-I	1	2	54	Momentary	HE	Maintenance
Plant Centered	Palisades	4/6/1992	2551992032	Shutdown	LOOP-SD	0	1	30	Momentary	HES	Testing
Plant Centered	Palisades	12/22/1998	2551998013	Shutdown	LOOP-SD	20	21	0	Sustained	Equip	Transformer

Table A-6. Site level LOOP events listed by category for 1986 - 2003. (continued)

LOOP Category	Plant Site	Date	LER	Operational Mode	LOOP Class	Switchyard Restoration Time	Potential Bus Restoration Time	Actual Bus Restoration Time	Duration Category	Cause	Specific Cause
Plant Centered	Palisades	3/25/2003	2552003003	Shutdown	LOOP-SD	91	92	3261	Sustained	HES	Maintenance
Plant Centered	Point Beach	4/28/1992	2661992003	Shutdown	LOOP-SD	0	30	30	Sustained	HES	Maintenance
Plant Centered	Point Beach	9/27/1994	2661994010	Shutdown	LOOP-SD	0	1	1	Momentary	HES	Switching
Plant Centered	Quad Cities	4/2/1992	2651992011	Shutdown	LOOP-SD	35	35	35	Sustained	Equip	Transformer
Plant Centered	Robinson	1/28/1986	2611986005	Trip	LOOP-IE-C	117	118	403	Sustained	Equip	Relay
Plant Centered	Salem	8/26/1986	3111986007	Trip*	LOOP-IE-C	0	1	0	Momentary	Equip	Other
Plant Centered	Turkey Point	3/13/1991	2511991001	Shutdown	LOOP-SD	66	67	67	Sustained	Equip	Relay
Plant Centered	Vermont Yankee	4/23/1991	2711991009	Trip	LOOP-IE-I	277	278	822	Sustained	HE	Maintenance
Plant Centered	Wolf Creek	10/14/1987	4821987048	Shutdown	LOOP-SD	0	1	17	Momentary	HES	Maintenance
Severe Weather Related	Braidwood	9/6/1998	4561998003	Shutdown	LOOP-SD	528	528	528	Sustained	SEE	High Winds
Severe Weather Related	Brunswick	3/16/1993 and 3/17/1993	3251993008	Shutdown	LOOP-SD	967	967	1263	Sustained	SEE	Salt Spray
Severe Weather Related	Crystal River	6/29/1989	3021989025	Shutdown*	LOOP-SD	1	2	2	Momentary	SEE	Lightning
Severe Weather Related	Crystal River	3/17/1993	3021993000	Shutdown	LOOP-SD	72	73	102	Sustained	SEE	Salt Spray
Severe Weather Related	Crystal River	3/29/1993	3021993002	Shutdown	LOOP-SD	4	5	37	Sustained	SEE	Flooding
Severe Weather Related	Fitzpatrick	10/31/1988	3331988011	Shutdown	LOOP-SD	1	2	85	Momentary	SEE	High Winds
Severe Weather Related	La Crosse[7]	7/19/1986	4091986023	Shutdown	LOOP-SD	12	13	15	Sustained	SEE	Lightning
Severe Weather Related	Oyster Creek	5/3/1992	2191992005	Trip	LOOP-IE-I	5	6	1029	Sustained	SEE	Fire
Severe Weather Related	Pilgrim	11/19/1986	2931986027	Shutdown	LOOP-SD	0	1	213	Momentary	SEE	Ice
Severe Weather Related	Pilgrim	3/31/1987	2931987005	Shutdown	LOOP-SD	1	2	45	Momentary	SEE	High Winds
Severe Weather Related	Pilgrim	3/13/1993	2931993004	Trip	LOOP-IE-I	30	31	298	Sustained	SEE	Snow
Severe Weather Related	Pilgrim	9/10/1993	2931993022	Trip	LOOP-IE-I	10	11	200	Sustained	SEE	Lightning
Severe Weather Related	Pilgrim	4/1/1997	2931997007	Shutdown	LOOP-SD	347	1200	1208	Sustained	SEE	High Winds
Severe Weather Related	Pilgrim[8]	11/12/1987	2931987014	Shutdown	LOOP-SD	1262	1263	1263	Sustained	SEE	Salt Spray
Severe Weather Related	Pilgrim[8]	10/30/1991	2931991024	Trip*	LOOP-IE-I	109	110	152	Sustained	SEE	Salt Spray
Severe Weather Related	Prairie Island	6/29/1996	2821996012	Trip	LOOP-IE-I	296	297	297	Sustained	SEE	High Winds
Severe Weather Related	Quad Cities	8/2/2001	2652001001	Trip	LOOP-IE-I	15	16	154	Sustained	SEE	Lightning
Severe Weather Related	Seabrook	3/5/2001	4432001002	Trip	LOOP-IE-I	1	2	2122	Momentary	SEE	Snow
Severe Weather Related	Yankee-Rowe	6/15/1991	0291991002	Trip	LOOP-IE-I	24	25	25	Sustained	SEE	Lightning
Switchyard Centered	Beaver Valley	11/17/1987	4121987036	Trip	LOOP-IE-I	3	4	4	Sustained	Equip	Breaker

[7] The La Crosse LOOP event is shown here, but is not included in the calculations since the plant is atypical.

[8] The Pilgrim salt spray LOOP events are shown here, but are not included in the calculations since the plant has made modifications and has not had any further events of this type.

Table A-6. Site level LOOP events listed by category for 1986 - 2003. (continued)

LOOP Category	Plant Site	Date	LER	Operational Mode	LOOP Class	Switchyard Restoration Time	Potential Bus Restoration Time	Actual Bus Restoration Time	Duration Category	Cause	Specific Cause
Switchyard Centered	Beaver Valley	10/12/1993	3341993013	Trip/Shutdown	LOOP-IE-I/ LOOP-SD	13	14	20	Sustained	HES	Maintenance
Switchyard Centered	Big Rock Point	1/29/1992	1551992000	Shutdown	LOOP-SD	77	78	78	Sustained	Equip	Other
Switchyard Centered	Braidwood	9/11/1987	4561987048	Shutdown*	LOOP-SD	0	1	53	Momentary	Equip	Transformer
Switchyard Centered	Braidwood	10/16/1988	4561988022	Trip	LOOP-IE-I	95	118	213	Sustained	Equip	Breaker
Switchyard Centered	Browns Ferry	3/5/1997	2961997001	Shutdown	LOOP-SD	43	44	44	Sustained	Equip	Transformer
Switchyard Centered	Brunswick	6/17/1989	3241989009	Trip	LOOP-IE-I	90	90	403	Sustained	HE	Maintenance
Switchyard Centered	Brunswick	3/3/2000	3252000001	Shutdown	LOOP-SD	15	16	136	Sustained	HES	Testing
Switchyard Centered	Byron	10/2/1987	4551987019	Shutdown*	LOOP-SD	1	2	507	Momentary	HES	Switching
Switchyard Centered	Byron	5/23/1996	4541996007	Shutdown*	LOOP-SD	720	721	1763	Sustained	Equip	Transformer
Switchyard Centered	Calvert Cliffs	7/23/1987	3171987012	Trip	LOOP-IE-I	117	118	118	Sustained	Equip	Circuits
Switchyard Centered	Catawba	2/6/1996	4141996001	Trip	LOOP-IE-I	120	121	330	Sustained	Equip	Transformer
Switchyard Centered	Clinton	1/6/1999	4611999002	Shutdown*	LOOP-SD	270	271	492	Sustained	Equip	Other
Switchyard Centered	Columbia	5/14/1989	3971989016	Shutdown	LOOP-SD	28	29	29	Sustained	HES	Maintenance
Switchyard Centered	Crystal River	10/16/1987	3021987025	Shutdown	LOOP-SD	18	19	59	Sustained	HES	Maintenance
Switchyard Centered	Crystal River	6/16/1989	3021989023	Shutdown*	LOOP-SD	60	61	61	Sustained	HES	Testing
Switchyard Centered	Diablo Canyon	7/17/1988	3231988008	Trip	LOOP-IE-I	37	38	38	Sustained	Equip	Transformer
Switchyard Centered	Diablo Canyon	3/7/1991	2751991004	Shutdown	LOOP-SD	261	285	285	Sustained	HES	Maintenance
Switchyard Centered	Diablo Canyon	10/21/1995	2751995014	Shutdown	LOOP-SD	30	31	951	Sustained	HES	Maintenance
Switchyard Centered	Dresden	3/25/1989	2491989001	Trip	LOOP-IE-I	45	46	0	Sustained	Equip	Breaker
Switchyard Centered	Dresden	1/16/1990	2371990002	Trip*	LOOP-IE-C	45	45	759	Sustained	Equip	Transformer
Switchyard Centered	Duane Arnold	7/9/1990	3311990007	Shutdown	LOOP-SD	37	38	38	Sustained	HES	Testing
Switchyard Centered	Farley	4/9/2000	3482000005	Shutdown*	LOOP-SD	18	19	19	Sustained	Equip	Relay
Switchyard Centered	Fitzpatrick	12/26/1988	4101988062	Shutdown	LOOP-SD	9	10	54	Sustained	Equip	Transformer
Switchyard Centered	Fort Calhoun	3/21/1987	2851987008	Shutdown	LOOP-SD	37	38	38	Sustained	HES	Maintenance
Switchyard Centered	Fort Calhoun	4/4/1987	2851987009	Shutdown	LOOP-SD	0	4	4	Sustained	HES	Maintenance
Switchyard Centered	Fort Calhoun	2/26/1990	2851990006	Shutdown	LOOP-SD	13	14	14	Sustained	HES	Maintenance
Switchyard Centered	Fort Calhoun	5/20/1998	2851998005	Shutdown	LOOP-SD	109	109	109	Sustained	Equip	Transformer
Switchyard Centered	Indian Point	3/20/1991	2471991006	Shutdown	LOOP-SD	0	1	29	Momentary	Equip	Other
Switchyard Centered	Indian Point	2/27/1995	2861995004	Shutdown	LOOP-SD	30	31	132	Sustained	HES	Maintenance
Switchyard Centered	Indian Point	1/20/1996	2861996002	Shutdown	LOOP-SD	30	31	145	Sustained	Equip	Transformer
Switchyard Centered	Indian Point	8/31/1999	2471999015	Trip*	LOOP-IE-C	0	1	689	Momentary	Equip	Circuits
Switchyard Centered	LaSalle	9/14/1993	3731993015	Trip	LOOP-IE-I	15	16	70	Sustained	Equip	Transformer

Table A-6. Site level LOOP events listed by category for 1986 - 2003. (continued)

LOOP Category	Plant Site	Date	LER	Operational Mode	LOOP Class	Switchyard Restoration Time	Potential Bus Restoration Time	Actual Bus Restoration Time	Duration Category	Cause	Specific Cause
Switchyard Centered	Maine Yankee	8/13/1988	3091988006	Trip	LOOP-IE-I	14	15	15	Sustained	Equip	Transformer
Switchyard Centered	McGuire	6/24/1988	3691988014	Shutdown	LOOP-SD	8	8	8	Sustained	HES	Switching
Switchyard Centered	McGuire	12/27/1993	3701993008	Trip	LOOP-IE-I	96	97	131	Sustained	Equip	Transformer
Switchyard Centered	Millstone	11/5/1986	3361986017	Shutdown	LOOP-SD	0	0	0	Momentary	HES	Maintenance
Switchyard Centered	Millstone	4/29/1989	2451989012	Shutdown	LOOP-SD	0	1	0	Momentary	HES	Other
Switchyard Centered	Oconee	3/5/1987	2871987002	Shutdown	LOOP-SD	155	155	155	Sustained	HES	Maintenance
Switchyard Centered	Oyster Creek	8/1/1997	2191997010	Trip	LOOP-IE-C	39	40	40	Sustained	Equip	Relay
Switchyard Centered	Palisades	7/14/1987	2551987024	Trip	LOOP-IE-I	388	388	446	Sustained	HE	Maintenance
Switchyard Centered	Peach Bottom	7/29/1988	2771988020	Shutdown	LOOP-SD	23	24	125	Sustained	Equip	Transformer
Switchyard Centered	Pilgrim	12/23/1986	2931986029	Shutdown	LOOP-SD	0	1	1	Momentary	HES	Maintenance
Switchyard Centered	Pilgrim	2/21/1989	2931989010	Shutdown	LOOP-SD	1	2	920	Momentary	Equip	Other
Switchyard Centered	Pilgrim	5/19/1993	2931993010	Shutdown	LOOP-SD	36	37	37	Sustained	HES	Testing
Switchyard Centered	Point Beach	3/29/1989	3011989002	Trip	LOOP-IE-C	90	91	202	Sustained	HE	Maintenance
Switchyard Centered	River Bend	1/1/1986	4581986002	Trip*	LOOP-IE-I	46	47	47	Sustained	Equip	Circuits
Switchyard Centered	Robinson	8/22/1992	2611992017	Trip	LOOP-IE-I	453	454	914	Sustained	Equip	Transformer
Switchyard Centered	Salem	11/18/1994	3111994014	Shutdown	LOOP-SD	299	300	1675	Sustained	Equip	Relay
Switchyard Centered	Salem	7/29/2003	2722003002	Trip	LOOP-IE-C	30	31	480	Sustained	Equip	Circuits
Switchyard Centered	Seabrook	6/27/1991	4431991008	Trip	LOOP-IE-I	19	20	20	Sustained	Equip	Relay
Switchyard Centered	Sequoyah	12/31/1992	3271992027	Trip	LOOP-IE-I	95	96	116	Sustained	Equip	Breaker
Switchyard Centered	Three Mile Isl	6/21/1997	2891997007	Trip	LOOP-IE-C	89	90	90	Sustained	Equip	Circuits
Switchyard Centered	Turkey Point	7/24/1991	2501991003	Shutdown	LOOP-SD	10	11	11	Sustained	Equip	Breaker
Switchyard Centered	Turkey Point	10/21/2000	2512000004	Shutdown*	LOOP-SD	1	2	111	Momentary	Equip	Circuits
Switchyard Centered	Vogtle	3/20/1990	4241990006	Shutdown	LOOP-SD	139	140	140	Sustained	HES	Other
Switchyard Centered	Zion	3/21/1991	3041991002	Trip	LOOP-IE-I	0	60	60	Sustained	Equip	Transformer
Switchyard Centered	Zion	3/11/1997	2951997007	Shutdown	LOOP-SD	239	240	240	Sustained	Equip	Circuits

Table A-7. Site level LOOP events showing restoration time uncertainty for 1986 to 2003.

LER	Site	Date	Operational Mode	LOOP Category	Switchyard Restoration Time	Switchyard Restoration Certainty[9]	Potential Bus Restoration Time	Potential Bus Restoration Certainty[9]	Actual Bus Restoration Time	Actual Bus Restoration Certainty[9]
4121987036	Beaver Valley	11/17/1987	Trip	Switchyard Centered	3	E	4	C	4	C
3341993013	Beaver Valley	10/12/1993	Trip	Switchyard Centered	13	C	14	E	20	C
1551992000	Big Rock Point	1/29/1992	Shutdown	Switchyard Centered	77	E	78	E	78	E
4561987048	Braidwood	9/11/1987	Shutdown*	Switchyard Centered	0	C	1	E	53	C
4561988022	Braidwood	10/16/1988	Trip	Switchyard Centered	95	C	118	E	213	C
4561998003	Braidwood	9/6/1998	Shutdown	Severe Weather Related	528	E	528	E	528	E
2961997001	Browns Ferry	3/5/1997	Shutdown	Switchyard Centered	43	E	44	E	44	C
3251986024	Brunswick	9/13/1986	Trip	Plant Centered	0	C	1	E	159	C
3241989009	Brunswick	6/17/1989	Trip	Switchyard Centered	90	E	90	E	403	C
3251993008	Brunswick	3/16/1993 and 3/17/1993	Shutdown	Severe Weather Related	967	C	967	E	1263	C
3241994008	Brunswick	5/21/1994	Shutdown	Plant Centered	2	C	3	C	64	C
3252000001	Brunswick	3/3/2000	Shutdown	Switchyard Centered	15	E	16	E	136	C
4551987019	Byron	10/2/1987	Shutdown*	Switchyard Centered	1	E	2	E	507	C
4541996007	Byron	5/23/1996	Shutdown*	Switchyard Centered	720	E	721	E	1763	E
3171987012	Calvert Cliffs	7/23/1987	Trip	Switchyard Centered	117	E	118	C	118	C
4141996001	Catawba	2/6/1996	Trip	Switchyard Centered	120	E	121	E	330	C
4611999002	Clinton	1/6/1999	Shutdown*	Switchyard Centered	270	C	271	E	492	C
3971989016	Columbia	5/14/1989	Shutdown	Switchyard Centered	28	E	29	C	29	C
3151991004	Cook	5/12/1991	Trip	Plant Centered	0	C	1	E	81	C
3021987025	Crystal River	10/16/1987	Shutdown	Switchyard Centered	18	C	19	E	59	C
3021989023	Crystal River	6/16/1989	Shutdown*	Switchyard Centered	60	C	61	E	61	E
3021989025	Crystal River	6/29/1989	Shutdown*	Severe Weather Related	1	E	2	C	2	C
3021991010	Crystal River	10/20/1991	Shutdown	Plant Centered	3	E	4	C	4	C
3021992001	Crystal River	3/27/1992	Trip	Plant Centered	20	E	21	E	150	C
3021993000	Crystal River	3/17/1993	Shutdown	Severe Weather Related	72	C	73	E	102	E
3021993002	Crystal River	3/29/1993	Shutdown	Severe Weather Related	4	E	5	C	37	C
3021993004	Crystal River	4/8/1993	Shutdown	Plant Centered	1	E	2	E	136	C

9 C – the restoration time is certain.
U – no information is available concerning the restoration time.
E – the restoration time was estimated based on some information in the LER.

Table A-7. Site level LOOP events showing restoration time uncertainty for 1986 to 2003. (continued)

LER	Site	Date	Operational Mode	LOOP Category	Switchyard Restoration		Potential Bus Restoration		Actual Bus Restoration	
					Time	Certainty[9]	Time	Certainty[9]	Time	Certainty[9]
3461998006	Davis-Besse	6/24/1998	Trip	Extreme Weather Related	1364	C	1428	C	1495	C
3462000004	Davis-Besse	4/22/2000	Shutdown*	Plant Centered	10	E	11	E	11	E
3462003009	Davis-Besse	8/14/2003	Shutdown*	Grid Related	652	C	653	E	849	C
3231988008	Diablo Canyon	7/17/1988	Trip	Switchyard Centered	37	E	38	C	38	C
2751991004	Diablo Canyon	3/7/1991	Shutdown	Switchyard Centered	261	C	285	C	285	C
2751995014	Diablo Canyon	10/21/1995	Shutdown	Switchyard Centered	30	E	31	E	951	C
2752000004	Diablo Canyon	5/15/2000	Trip	Plant Centered	1901	C	1902	E	1996	C
2491989001	Dresden	3/25/1989	Trip	Switchyard Centered	45	E	46	E	0	E
2371990002	Dresden	1/16/1990	Trip*	Switchyard Centered	45	E	45	E	759	C
3311990007	Duane Arnold	7/9/1990	Shutdown	Switchyard Centered	37	C	38	E	38	E
3482000005	Farley	4/9/2000	Shutdown*	Switchyard Centered	18	E	19	C	19	C
3412003002	Fermi	8/14/2003	Trip	Grid Related	379	C	380	E	582	C
3331988011	Fitzpatrick	10/31/1988	Shutdown	Severe Weather Related	1	C	2	E	85	C
4101988062	Fitzpatrick	12/26/1988	Shutdown	Switchyard Centered	9	C	10	E	54	C
4101992006	Fitzpatrick	3/23/1992	Shutdown	Plant Centered	20	C	21	E	50	E
4102003002, 2202003002, 3332003001	Fitzpatrick	8/14/2003	Trip	Grid Related	202	C	203	E	471	C
2851987008	Fort Calhoun	3/21/1987	Shutdown	Switchyard Centered	37	C	38	E	38	C
2851987009	Fort Calhoun	4/4/1987	Shutdown	Switchyard Centered	0	C	4	C	4	C
2851990006	Fort Calhoun	2/26/1990	Shutdown	Switchyard Centered	13	E	14	C	14	C
2851998005	Fort Calhoun	5/20/1998	Shutdown	Switchyard Centered	109	E	109	E	109	C
2851999004	Fort Calhoun	10/26/1999	Shutdown	Plant Centered	2	C	2	C	2	C
2442003002	Ginna	8/14/2003	Trip	Grid Related	49	C	50	E	297	C
2131993009	Haddam Neck	6/22/1993	Shutdown	Plant Centered	12	C	13	E	35	C
2131993010	Haddam Neck	6/26/1993	Shutdown	Plant Centered	3	E	4	E	40	E
2471991006	Indian Point	3/20/1991	Shutdown	Switchyard Centered	0	C	1	E	29	C
2471991010	Indian Point	6/22/1991	Shutdown	Plant Centered	0	C	60	C	60	C
2861995004	Indian Point	2/27/1995	Shutdown	Switchyard Centered	30	E	31	E	132	C
2861996002	Indian Point	1/20/1996	Shutdown	Switchyard Centered	30	E	31	E	145	C
2861997008	Indian Point	6/16/1997	Shutdown	Grid Related	41	E	42	E	42	E
2471998013	Indian Point	9/1/1998	Shutdown*	Plant Centered	1	E	2	E	67	C
2471999015	Indian Point	8/31/1999	Trip*	Switchyard Centered	0	E	1	E	689	C
2472003005, 2862003005	Indian Point	8/14/2003	Trip	Grid Related	98	C	99	E	228	C
4091986023	La Crosse	7/19/1986	Shutdown	Severe Weather Related	12	C	13	E	15	C

Table A-7. Site level LOOP events showing restoration time uncertainty for 1986 to 2003. (continued)

LER	Site	Date	Operational Mode	LOOP Category	Switchyard Restoration		Potential Bus Restoration		Actual Bus Restoration	
					Time	Certainty[9]	Time	Certainty[9]	Time	Certainty[9]
3731993015	LaSalle	9/14/1993	Trip	Switchyard Centered	15	E	16	E	70	C
3091988006	Maine Yankee	8/13/1988	Trip	Switchyard Centered	14	C	15	E	15	C
3691987021	McGuire	9/16/1987	Shutdown	Plant Centered	0	C	1	E	7	C
3691988014	McGuire	6/24/1988	Shutdown	Switchyard Centered	8	C	8	C	8	C
3691991001	McGuire	2/11/1991	Trip	Plant Centered	0	E	40	C	0	E
3701993008	McGuire	12/27/1993	Trip	Switchyard Centered	96	C	97	E	131	C
3361986017	Millstone	11/5/1986	Shutdown	Switchyard Centered	0	E	0	E	0	E
3361988011	Millstone	10/25/1988	Trip	Plant Centered	19	E	20	E	20	E
2451989012	Millstone	4/29/1989	Shutdown	Switchyard Centered	0	E	1	E	0	E
2871987002	Oconee	3/5/1987	Shutdown	Switchyard Centered	155	E	155	E	155	C
2701992004	Oconee	10/19/1992	Trip	Plant Centered	56	E	57	C	207	C
2191989015	Oyster Creek	5/18/1989	Trip	Plant Centered	1	E	2	E	54	C
2191992005	Oyster Creek	5/3/1992	Trip	Severe Weather Related	5	C	6	C	1029	C
2191997010	Oyster Creek	8/1/1997	Trip	Switchyard Centered	39	E	40	C	40	E
2551987024	Palisades	7/14/1987	Trip	Switchyard Centered	388	C	388	C	446	C
2551992032	Palisades	4/6/1992	Shutdown	Plant Centered	0	E	1	E	30	E
2551998013	Palisades	12/22/1998	Shutdown	Plant Centered	20	E	21	E	0	E
2552003003	Palisades	3/25/2003	Shutdown	Plant Centered	91	E	92	E	3261	C
2771988020	Peach Bottom	7/29/1988	Shutdown	Switchyard Centered	23	E	24	C	125	C
2772003004	Peach Bottom	9/15/2003	Trip	Grid Related	1	C	17	E	72	E
4402003002	Perry	8/14/2003	Trip	Grid Related	87	C	88	E	123	C
2931986027	Pilgrim	11/19/1986	Shutdown	Severe Weather Related	0	C	1	E	213	C
2931986029	Pilgrim	12/23/1986	Shutdown	Switchyard Centered	0	C	1	E	1	C
2931987005	Pilgrim	3/31/1987	Shutdown	Severe Weather Related	1	E	2	E	45	C
2931987014	Pilgrim	11/12/1987	Shutdown	Severe Weather Related	1262	E	1263	C	1263	C
2931989010	Pilgrim	2/21/1989	Shutdown	Switchyard Centered	1	E	2	E	920	C
2931991024	Pilgrim	10/30/1991	Trip*	Severe Weather Related	109	C	110	E	152	C
2931993004	Pilgrim	3/13/1993	Trip	Severe Weather Related	30	E	31	E	298	C
2931993010	Pilgrim	5/19/1993	Shutdown	Switchyard Centered	36	C	37	C	37	C
2931993022	Pilgrim	9/10/1993	Trip	Severe Weather Related	10	C	11	C	200	C
2931997007	Pilgrim	4/1/1997	Shutdown	Severe Weather Related	347	C	1200	C	1208	C
3011989002	Point Beach	3/29/1989	Trip	Switchyard Centered	90	E	91	E	202	C
2661992003	Point Beach	4/28/1992	Shutdown	Plant Centered	0	C	30	C	30	C
2661994010	Point Beach	9/27/1994	Shutdown	Plant Centered	0	C	1	E	1	E
2821996012	Prairie Island	6/29/1996	Trip	Severe Weather Related	296	E	297	E	297	C
2651992011	Quad Cities	4/2/1992	Shutdown	Plant Centered	35	C	35	C	35	C

Table A-7. Site level LOOP events showing restoration time uncertainty for 1986 to 2003. (continued)

LER	Site	Date	Operational Mode	LOOP Category	Switchyard Restoration		Potential Bus Restoration		Actual Bus Restoration	
					Time	Certainty[9]	Time	Certainty[9]	Time	Certainty[9]
2652001001	Quad Cities	8/2/2001	Trip	Severe Weather Related	15	E	16	E	154	C
4581986002	River Bend	1/1/1986	Trip*	Switchyard Centered	46	C	47	E	47	E
2611986005	Robinson	1/28/1986	Trip	Plant Centered	117	C	118	E	403	C
2611992017	Robinson	8/22/1992	Trip	Switchyard Centered	453	E	454	E	914	C
3111986007	Salem	8/26/1986	Trip*	Plant Centered	0	C	1	E	0	E
3111994014	Salem	11/18/1994	Shutdown	Switchyard Centered	299	E	300	E	1675	C
2722003002	Salem	7/29/2003	Trip	Switchyard Centered	30	E	31	E	480	C
4431991008	Seabrook	6/27/1991	Trip	Switchyard Centered	19	E	20	C	20	C
4432001002	Seabrook	3/5/2001	Trip	Severe Weather Related	1	E	2	E	2122	C
3271992027	Sequoyah	12/31/1992	Trip	Switchyard Centered	95	C	96	E	116	E
3951989012	Summer	7/11/1989	Trip*	Grid Related	95	C	96	E	120	C
2891997007	Three Mile Isl	6/21/1997	Trip	Switchyard Centered	89	E	90	E	90	C
2511991001	Turkey Point	3/13/1991	Shutdown	Plant Centered	66	E	67	C	67	C
2501991003	Turkey Point	7/24/1991	Shutdown	Switchyard Centered	10	E	11	C	11	C
2501992000	Turkey Point	8/24/1992	Trip*	Extreme Weather Related	7920	E	7921	E	7921	E
2512000004	Turkey Point	10/21/2000	Shutdown*	Switchyard Centered	1	E	2	E	111	C
2711987008	Vermont Yankee	8/17/1987	Shutdown	Grid Related	2	C	3	E	0	E
2711991009	Vermont Yankee	4/23/1991	Trip	Plant Centered	277	C	278	E	822	C
4241990006	Vogtle	3/20/1990	Shutdown	Switchyard Centered	139	E	140	C	140	C
4821987048	Wolf Creek	10/14/1987	Shutdown	Plant Centered	0	C	1	E	17	C
0291991002	Yankee-Rowe	6/15/1991	Trip	Severe Weather Related	24	C	25	C	25	C
3041991002	Zion	3/21/1991	Trip	Switchyard Centered	0	C	60	C	60	C
2951997007	Zion	3/11/1997	Shutdown	Switchyard Centered	239	E	240	E	240	E

Appendix B

Methods of Data Analysis

APPENDIX B

Methods of Data Analysis

The LOOP database in Appendix A was analyzed to identify and summarize the behavior both of the frequencies of occurrence of LOOPs and their duration. In each case, the behavior was characterized in terms of overall means and uncertainty bounds, performance in various subgroups of the data, and whether trends exist. In addition, selected probabilities of occurrence, such as the probability of more than one unit being affected by a LOOP event at a multi-unit site, were studied.

This appendix provides details about the statistical methods used to analyzed the data. Methods for analysis of frequencies are discussed, followed by methods for analysis of durations and of probabilities. The methods are briefly presented, with references to sources with more detailed presentations. A primary reference is the *Handbook of Parameter Estimation for Probabilistic Risk Assessment* [1]. This reference is here denoted “HOPE.” Most of the methods can be found in many other books on reliability analysis.

Two software packages were used in the analysis of the data in addition to Microsoft Office products. SAS Institute’s basic analysis system, Version 9.1, and associated SAS/STAT package [2] provided much of the statistical analysis. @ Risk, Advanced Risk Analysis for Spreadsheets [3], provided curve fitting for the LOOP durations discussed below.

B.1 Analysis of Loop Occurrence Frequencies

In subsections below, analyses of LOOP frequencies or rates are described. First, the calculation of exposure time information for each plant is explained. The description of methods for basic estimates is followed by descriptions of analyses for differences in subgroups of the data, and for fitting uncertainty distributions. The trend analysis method is described. Finally, the calculation of plant-specific frequencies is explained.

B.1.1 Calculating Exposure Times

For each plant unit, hours of critical operation and of non-critical operation were obtained from the Monthly Operating Reports (MORP) submitted by the licensees to the NRC. Shutdown operation times were obtained as “reporting hours” minus the critical hours. The MORP data have been maintained in a data base at the INEEL since January of 1987.

Times were estimated for 1986. The plants were assumed to be operating two-thirds of the time. For the seven plants with low power license dates in 1986, the data were scaled down to reflect only the part of the year from the low power date to the end of the year.

All of the hourly data were converted to years up (rcry) and years down (rsy) for each plant, for each year of the study period. Within each of the data groupings considered for this report, exposure times appropriate for each level of the grouping variable were calculated by summing the critical years of operation and/or the shutdown years of the associated power plants. In each case, the time was bounded by the low power license dates and the decommission dates (if applicable) for the plants, and the 1986-2003 time span of the study.

B.1.2 Basic Estimates from Event Counts and Exposure Times

The simplest estimate for a frequency is the event count divided by the corresponding exposure time. When independent events occur at random, with a constant occurrence rate, they

are said to have a *Poisson* distribution. The simple estimate is called a maximum likelihood estimate (MLE), because this estimate of the mean of the corresponding Poisson distribution makes the Poisson distribution calculated probability associated with the observed failures and exposure time as large as possible.

When no events are observed, the MLE estimate is zero. This estimate is not the real occurrence rate, since the possibility of a LOOP exists in each data set analyzed. Furthermore, the need to assess how variation or uncertainty in inputs to a model (such as a fault tree) affect the outcomes of the model leads to the need for a probability distribution for each occurrence rate being studied. The probability distributions describe what is known about the rates; i.e., they express the current state of knowledge about the range of values that each rate can take on, and the probability of the rate being in any specified interval. From a classical statistics viewpoint, with homogeneous data, the rate is constant. Thus, any interval containing the constant has a 100% chance of having the rate, and any other interval has a 0% chance. However, since the constant is not known, the classical statistics approach is not useful for studying how the inputs affect the outputs of an unreliability model. The classical statistics approach just gives rise to a point estimate and confidence intervals.

A distribution can describe at least a portion of the state-of-knowledge (epistemic) uncertainty. Then, in a series of computer simulations, the estimate can take on different values as it is sampled from this distribution, and the effect on the outcome of the model as the input is varied can be seen. Thus, having distributions for rates allows some of the PRA uncertainties to be estimated.

This report starts with the raw data (event counts and times). Updating the *Jeffreys noninformative prior* using the observed data is one way to obtain a distribution reflecting the data. The percentiles of this distribution act in a manner similar to the confidence intervals of classical statistics. The term *updating* means to perform a *Bayesian update*. A Bayesian update is the process of going from a *prior* distribution to a *posterior* distribution, using Bayes Theorem. The prior distribution describes what is known about the rate before focusing on the observed data; and the posterior distribution describes the rate after the observed data set is taken into consideration. Bayes Theorem is based on the definition of conditional probability:

Prob(Event B given Event A) = Prob(Event A and Event B)/ Prob(Event A);

or, equivalently

Prob(Event A and Event B) = Prob(Event B given Event A) * Prob(Event A). (1)

In this case, Event A is the event that the rate being considered takes on certain values or lies in certain ranges. Event B is observing the actual data (i.e., the number of events in a known exposure time). “Event B given Event A” is the conditional likelihood of seeing the observed data given that the rate has a certain value, and given that the observed counts behave according to the Poisson distribution. Prob(Event A) is related to the prior distribution, and Prob(Event A and Event B) is related to the posterior distribution.

With Poisson occurrences in fixed exposure times, gamma distributions are a convenient distributional form for Bayesian analysis. Every gamma distribution covers the interval from zero to infinity. A gamma distribution is often described in terms of two parameters, a shape parameter, α (“alpha”) and an inverse scale parameter, β. The mean of a gamma distribution is α/β, and the variance is α/β^2.

The application of Bayes Theorem with a gamma prior distribution leads to a gamma distribution for the output posterior distribution. Thus, the gamma distribution family is the

conjugate prior for Poisson data. When n events occur in T exposure time, the output from the Bayesian update for a gamma (α, β) prior distribution has parameters ($\alpha + n, \beta + T$). Because β is in the denominator of this expression, it can be thought of as a rough measure of the exposure time associated with the prior distribution. The α parameter has a similar interpretation in terms of the number of occurrences. When α is less than one, the gamma density is "J"-shaped. The skewness increases as α approaches zero.

The *Jeffreys noninformative prior* is a relatively flat distribution that is often used as a prior distribution in applying Bayes Theorem when there is no preconceived distribution for the occurrence rate. This distribution carries very little information. The Jeffreys gamma prior is gamma (0.5, 0). Therefore, the posterior distribution is a gamma distribution with parameters (n+0.5, T). This distribution will be called the *updated Jeffreys noninformative distribution* (UJNID) in this report. The mean of this distribution is

$$(n+0.5)/(T) \qquad (2)$$

and its variance is $(n+0.5)/(T^2)$. Percentiles or quantiles of gamma distributions can easily be obtained using SAS, Microsoft Excel, and other software packages.

In summary, in this report Equation (2) is used for estimates of occurrence frequencies.

B.1.3 Identifying Differences in Groupings of the Data

The LOOP data were divided into five categories, due to differences in recovery durations (discussed in Section B.2). Within each of these categories, data were pooled by year, plant, site, National Electric Reliability Council (NERC) subregion, NERC regional reliability council, and by the high-level grid interconnections (three geographic areas in the US). Other groupings were also considered, such as plant mode (operating or shutdown), the plant electrical design classes used in NUREG-1032, and whether the plant was within approximately 100 miles of the Atlantic or Gulf coast. Within each of these groupings, exposure times appropriate for each level of the grouping variable could be calculated from the known critical hours of operation and shutdown hours of each power plant.

For each grouping, the following evaluation was performed:

- For each level of the grouping variable, compute the total number of LOOPs and the total plant (unit) time;
- Compute the chi-squared statistic for differences in the occurrence rates. If there are no differences, the counts should be proportional to the relative exposure times. The chi-squared statistic is the sum of squares of differences between observed and expected rates, normalized by the expected rates. The sum is compared with the expected behavior of a chi-squared random variable with (m-1) degrees of freedom, where m is the number of levels of the grouping variable. If the calculated chi-squared statistic is unusually large compared with its expected distribution, the differences are said to be statistically significant. The measure of whether the value is "unusually large" is the upper tail probability of the statistic's expected distribution. That is, the measure is the probability that the chi-squared (m-1) random variable equals or exceeds the calculated value. This probability is called a *p-value*. When it is small, the hypothesis of no differences between the levels of the grouping variable is rejected. The differences are said to be statistically significant. By convention, p-values less than or equal to 0.05 are generally considered statistically significant. HOPE, Section 6.2.3.1.2, provides further details.
- If m is less than or equal to 3, an exact test is performed. Conditioned on the total number of events observed, the data in the different groups is expected to follow a multinomial

distribution with probabilities in the different levels proportional to the exposure times when the groups have the same occurrence rate. The exact test considers various combinations, or different ways that the occurrences could be assigned to the levels of the groups. The SAS procedure FREQ computes a chi-squared statistic for each one. From these values, it generates a distribution that shows how the chi-square statistic behaves when the rates are the same. Again, a p-value is computed for the observed chi-square statistic, using the more accurate reference distribution. As before, a low p-value results in rejection of the idea that the LOOP occurrence frequency is the same in each level of the group. HOPE, Section 6.3.3.1.2, provides further details.

The hypothesis of sameness will be rejected if the rates from the different groups vary more than would be expected from a Poisson distribution, or if an outlier is present. In the latter case, the LOOP frequency for a single level of the grouping variable differs substantially from the other levels.

Evaluating differences was most important in determining whether particular subsets of the data should be the focus to derive estimates for use in risk assessments. Particularly the comparison of frequencies for the 1986-1996 period and the 1997-2003 period (since deregulation) was important. Another major distinction was the determination of whether operational data and shutdown data should be treated separately.

B.1.4 Uncertainty Distributions for the Frequencies

In addition to assessing the statistical difference in various groupings of the data for each LOOP category, an attempt was made to identify an empirical Bayes (EB) distribution to describe variability with regard to each grouping variable. The EB distribution is a gamma distribution, like the Jeffreys noninformative prior discussed in Section B.1.1. However, the parameters are selected so that the likelihood function for the observed data is as large as possible. The likelihood function is based on the assumption of a constant, independent occurrence rate within each grouping level, with the rate varying between levels as though it were sampled from the EB distribution. The likelihood function is thus a product of Poisson densities, each evaluated at one of the sets of observed number of events and exposure time in one level of the grouping variable. The product is regarded as a function of the Poisson mean, which in turn depends on the gamma distribution. The EB distribution is the gamma distribution whose parameters are maximum likelihood estimates for the observed data. The distribution describes variability associated with the frequencies for different levels of the grouping variable. Thus, an EB distribution describes uncertainty in the frequencies at an industry level. Further information on the EB method is in HOPE, Section 8.2 (especially 8.2.2).

An EB distribution can be updated with data from each of the several groupings used to develop the distribution, in order to identify group-specific distributions. As noted in Section B.1.2, the Bayesian update starts with the (prior) mean, α/β, and adds the number of events in the numerator and the observed time for a particular group in the denominator. In some cases, an adjustment was made to account for the fact that the gamma distribution mean and variance were estimated from the data. The adjustment, called the Kass-Steffey adjustment, preserves the mean but increases the variation for the group-level result. It is described further in HOPE, Section 8.2.4.1.

For each assessment, EB maximum likelihood estimates were sought. Such a distribution can be used to describe industry variation, even in the absence of a need to perform a group-level Bayesian update. However, in many cases a likelihood function is relatively flat, and no interior maximum can be found. In such cases, the data are typically sparse and the sampling variation is as large or larger than the between-grouping variation. The updated Jeffreys noninformative

distribution (UJNID) (see Section B.1.2) can be used in these cases to describe sampling variability.

The UJNID can be a narrow distribution that shows little uncertainty. Its coefficient of variation is only $1/T$, where T is the total exposure time. As its shape parameter increases with the number of events, the gamma distribution becomes narrowly centered over the estimate in Equation (2) above.

An alternate method that allows more uncertainty is the constrained noninformative prior method. It is explained in HOPE, Section 6.2.2.5.3. For frequencies, this method leads to a gamma uncertainty distribution for the industry, called the constrained noninformative distribution (CNID). The gamma shape parameter for the CNID turns out to be 0.5. The scale parameter is 0.5 divided by the mean, in order to meet the "constraint" that the mean have a particular value. The value selected for the mean is from Equation (2) above. This distribution has an error factor (95^{th} percentile divided by median) of 8.44, and remains broad even as more data accrue.

For the LOOP data in each category, a UJNID and a CNID were always potential candidates for describing uncertainty across the industry. In a number of cases, at least one and sometimes several EB distributions were also fit to the frequency data. The selection of a particular distribution was influenced by the fact that the LOOP data, particularly for grid and weather events, often fail a basic assumption of the EB and UJNID methods, namely, the assumption of independent events and constant occurrence rates within a group (EB) or the industry as a whole (UJNID). In cases where the dependence is strong, the CNID was selected to represent the industry variation.

In the main report, when an EB distribution was used in the calculation of an industry-level uncertainty distribution, the shape parameter (α) is the part of the distribution that was used. More specifically, the coefficient of variation (standard deviation divided by mean) from the EB distribution was preserved in the final distribution. For a gamma distribution, this variation is the reciprocal of the square root of α. The final distribution used the α from the EB distribution and Equation (2) above to estimate the mean (λ). The resulting estimated β parameter (α/λ) is no longer the maximum likelihood estimator, but the estimated value for λ no longer depends on the particular EB distribution selected for the analyses.

B.1.5 Testing for Frequency Trends

The method of generalized linear models was used to assess possible trends in the LOOP occurrence rates for each category [HOPE, Section 7.2.4]. SAS Procedure GENMOD was used to perform the calculations. The method assumes that the data have a constant occurrence rate in each year, with independent occurrences and no probability of two simultaneous occurrences. The data in each year are thus assumed to be Poisson distributed. The linear (trend) model with time applies to the log of the occurrence rates in each year. The null hypothesis is that these means are constant, while the possibility of a trend is tested in the procedure. More specifically, the procedure calculates a maximum likelihood estimate of the slope (m) in the equation

$$\log(\lambda(t)) = b + m\,t, \qquad (3)$$

where $\lambda(t)$ is the mean of the occurrence rate in year t (adjusted to center the observed data around zero) and b is an intercept term. The statistical test for the significance of the slope (and whether it could in fact be zero) is based on a chi-square statistic with one degree of freedom [1]. When the calculated statistic exceeds 3.84, the slope is said to be statistically significant (the p-value, or exceedance probability, is 0.05 in this case).

The method also includes tests for whether the data follow the assumptions built into the model. The tests, called goodness-of-fit tests, particularly assess whether the variance in the data is as expected for Poisson-distributed occurrences (the variance for a Poisson distribution equals its mean). There are two tests: the "Pearson chi-square" test, and the "deviance" test. When the model fits, each of these statistics calculated from the data have chi-square distributions with n-2 degrees of freedom, where n is the number of years. If the statistics are unusually small compared to their expected distribution, the data have less variation than expected in the Poisson model, and the model is said to overfit the data. Conversely, when the statistics are unusually large, in the upper tail of the reference chi-square distribution, the data have more variation than the Poisson model permits, and the model is an "underfit." In these cases, the test for the slope just discussed is not valid.

When the goodness of fit tests fail, several alternatives exist. When the data have little variation, a constant model can be fit (although this method does not provide a "p-value" for the slope). For data that have too much variation, the SAS GENMOD procedure provides an option that allows the procedure to estimate the extra-Poisson scatter. A "scale" parameter is estimated from the data, rather than assuming the Poisson distribution value of 1.0. Use of the scale parameter forces either the Pearson chi-square or the deviance to be exactly equal to the degrees of freedom, and thus to be in the center of their respective chi-square distributions. For data with too much scatter for the Poisson fit, the scale parameter is greater than 1. Such a scale parameter makes the confidence band for the regression wider, and increases the variance used in the chi-square calculation for assessing the statistical significance of the slope. The resulting computed chi-squared test statistic is smaller, and less likely to be significant.

B.2 Analysis of Loop Durations

Three recovery times associated with each LOOP were considered for this report: the time required to restore offsite power to the switchyard (SW), the potential safety bus restoration time (PR), and the actual bus restoration time (AR). The first of these may be zero (in some cases the switchyard did not lose offsite power). The AR time, on the other hand, may be longer than necessary in certain events because plant operators had other priorities and the diesels were running. The primary purpose for assessing these two times is to get bounds in particular events on the real time of interest, namely the PR time. For risk assessment, the time *required* to restore offsite power is the time during which the plant is at increased risk (for example, if diesel problems were to occur).

All three recovery times were studied at a site level. When two or more units at the same site experienced LOOP events on the same day, generally from the same switchyard, grid, or weather disturbance, an average was computed for each type of recovery time. Note that the site definitions make one site for Fitzpatrick and Nine Mile Point, and one site for Hope Creek and Salem.

The statistical methods discussed below were applied for all three recovery times, but the PR times are the primary focus. Approximately 73% of these were estimated. For one event among 116 site-level LOOPs, all three times were unknown. A time of one minute was assumed for each of the recovery times for this event.

B.2.1 Identifying Differences in Groupings of the Data

SAS procedure NPAR1Way was used to evaluate the statistical significance of differences in recovery durations for the five LOOP event categories. It was also used to evaluate differences in times within each category for different years, plant modes, causes, sites, NERC subregions, NERC regions, interconnections, whether a plant is near the coast, etc.

The SAS procedure is called NPAR1Way because it performs non-parametric analyses of data grouped in a one-way classification (one classification or grouping variable). Two tests were used for the evaluations in this report. The Kruskal-Wallis test sorts an entire data set from small to large and then assigns ranks to each observation (for example, the lowest observation is scored as a 1, the next a 2, and so forth). When the recovery times are similar in each category or level of the variable under study, the expected value of the sum of the ranks associated with each category can be computed. These expected values are a function of the total sample size and the possibly differing numbers of observations in each category. The test statistic is based on a sum of squares of differences between actual and expected values, appropriately normalized. Under the hypothesis of no differences, the test statistic has an approximately chi-squared distribution with (m-1) degrees of freedom, where m is the number of levels in the grouping. For further information, see HOPE Section 6.6.2.1.2.

The second test is the Kolmogorov-Smirnov (KS) test. This test is based on empirical distribution functions (EDFs). In any data set or subset, the empirical distribution function is obtained directly from the sorted data. It is the number of data points less than or equal to a specified value, divided by the total number of observations (n) in the data set. It is thus the empirical estimate of the probability of the data being less than or equal to each specified value. The EDF is zero for values less than the minimum value in a sample, and 1.0 for greater values. The function goes from zero to one in a series of steps that occur at each observed data value.

When there are two levels being compared, the KS test statistic is the maximum difference between the two corresponding EDFs. SAS calculates the probability of a difference as large or larger than the observed difference based on the null hypothesis that the two EDFs come from samples from a single distribution. When this p-value is small, the test shows significant differences.

When there are more than two classes, SAS compares the empirical distribution function (EDF) for a class with the EDF obtained from pooling the data and considering the entire data set as one entity. The root mean square of these differences, across the levels of the grouping variable, is evaluated at each data point. Weights in the calculation account for differences in the number of observations in each level of the grouping variable. The maximum of the calculated values, multiplied by the square root of the total sample size, is an asymptotic KS statistic ("*KSa*"). When the sample size is large and the underlying samples are from the same distribution, *KSa* is less than 1.36 with probability 0.95 and less than 1.63 with probability 0.99. Large values of *KSa* point to significant differences in the levels of the grouping variable.

B.2.2 Fitting Exceedance Distributions

The complement of the EDF just described, abbreviated "CEDF", is the probability of a recovery time being strictly less than a specified value. Directly from the data, it is estimated as the number of sample values less than an observed value, divided by the sample size. Numerically, CEDF(x) = 1-EDF(x) for each x. The complementary empirical distribution function is of interest because estimates of the probability of long recovery times are needed in risk assessments. Such probabilities are called "exceedances."

In risk assessments, having a smooth curve to describe the probability of long recovery times is often needed. Such a function can be evaluated at particular times of interest, such as the length of time needed to achieve adequate cooling of the reactor core after a shutdown, or the expected power supply time that can be obtained from the plant's batteries. The probability of non-recovery decreases as time increases, and is not by nature a step function. Thus, continuous complementary cumulative distribution functions (CCDFs) are estimated from the CEDF data. The CCDFs are obtained simply as one minus the cumulative distribution function (CDF).

In this report, two families of possible distribution functions are considered: lognormal, and Weibull. A particular lognormal distribution is matched to the data by computing the sample mean and standard deviation of the logarithms of the sample values. When the data are lognormal, the logarithms of the data are normally distributed. The normal distribution parameters are converted to lognormal parameters using simple equations:

Lognormal median = exp(underlying normal distribution mean);
Lognormal mean = exp(underlying normal distribution mean + its variance divided by 2);
Lognormal variance = (exp(normal dist. var.)-1)*exp(2*normal dist mean + normal dist. var.);
Lognormal error factor = EF = exp[1.645* sqrt(normal dist. var.)];
Lognormal 95th percentile = EF * lognormal median; and
Lognormal 5th percentile = lognormal median / EF.

One way to test the adequacy of the fit for a lognormal distribution is to see if the logarithms of the data adequately fit a normal distribution. SAS procedure “UNIVARIATE” is used to perform the Shapiro-Wilk test for this hypothesis. When the p-value associated with the test is not small, the hypothesis of normality can be accepted. Note that the test does not prove that the logarithms of the data are normally distributed. It just indicates that the data does not provide sufficient evidence to show that the logarithms of the recovery times are not normally distributed. This test is described in HOPE, Section 6.6.2.3.2.

The Weibull distribution was fit to the recovery times using the @ Risk plug-in [3] to Excel. The routine identifies the Weibull shape (a) and scale (b) parameters for which the probability of the observed data is a maximum. That probability is better known as a *likelihood function*, and consists of the product of the Weibull density evaluated at each of the data points, regarded as a function of the two parameters. An iterative search procedure is required to find the maximum, at which the derivatives with regard to the parameters are zero. The estimates are called maximum likelihood estimates (MLE). All the restoration events were used in this analysis; zeros were set equal to 1 minute, missing switchyard restoration times were set equal to 1 minute, and missing bus restoration times were set equal to the potential bus restoration times.

A chi-squared statistic is used to assess goodness of fit. This test is applicable to the lognormal fit as well as to the Weibull. It is also described in HOPE, Section 6.6.2.3.2.

Graphs of the fitted (smooth) distributions and the empirical distributions were considered in choosing which model best fits the data (see Figures 4-1 through 4-5 and 4-7 in the main report). The p-values were also considered.

B.2.3 Testing for Trends

For each LOOP category, the logarithms (base 10) of the site recovery times were studied to see if recent recovery times were longer or shorter than earlier times. For the potential bus recovery times, the one case that was unknown was assumed one minute. For the two other recovery times, unknown times were omitted from study. Also, the cases where the switchyard did not lose offsite power (so the switchyard recovery time was zero) were omitted from the study of trends for the switchyard recovery time. Finally, an event at Diablo Canyon 1 on May 15, 2000, with a potential restoration time exceeding 30 hours was omitted from the plant-centered analysis as an outlier.

Ordinary least squares regression was used to fit a line for the log recovery times, as a function of event date measured in days until (negative) or days after (positive) January 1, 1997. The line was fit through a scatter plot of (date, log duration) pairs. To assess the adequacy of the model, the Shapiro-Wilk test was used to see if the residuals could be normally distributed. SAS Procedure REG also implements a chi-square test for heteroscedasticity. This test checks whether

the data provide evidence to reject the regression assumption of homogeneity of variance across the range of event times. The final test statistic used in the recovery trend test is a t-statistic that measures the statistical significance of the slope.

B.2.4 Combining Frequencies and Durations

In this study, composite frequencies for operations and for shutdown were obtained by summing the corresponding frequencies for the five LOOP categories. Uncertainty distributions for the resulting mixture were obtained by simulation.

For each LOOP category, and for a list of specified possible recovery times, the frequency of trip-associated LOOP occurrences during operation was multiplied by the probability of recovery exceeding the possible recovery time. The resulting quantity is the frequency (in events per reactor critical year) of LOOP trip events for which the recovery time exceeds the specified time. Considered as a function of the possible times, the resulting series of products specifies a frequency of exceedance curve.

A composite frequency of exceedance curve is obtained by a pointwise summing of the frequency of exceedance curves for the five categories.

The analysis was repeated with the shutdown LOOP frequencies and associated recovery curves.

B.3 Analysis of LOOP-Related Probabilities

Selected probabilities were considered in the LOOP study. The probability of LOOP occurring during shutdown conditions or during critical operations was considered. Probabilities were considered for LOOPs occurring during the summer (May-September) rather than the winter (the remaining seven months). Probabilities associated with LOOPs that are directly or indirectly the result of reactor trips were studied. Finally, the probability of LOOPs affecting more than one unit at multiple-unit sites was considered.

In sections below, basic estimates, tests for differences in subgroups, uncertainty distributions, and conditional distributions for probabilities are discussed. Trend analysis is not discussed, because no probability trend analyses were conducted.

B.3.1 Basic Estimates from Event Counts and Demands

Probabilities are analyzed in a manner similar to frequencies (see Section B.1.2), except that there are demands rather than exposure times, and the distribution associated with the event counts is binomial rather than Poisson. The binomial distribution assumes a series of independent trials or opportunities for occurrence of the condition under study. The probability of occurrence is taken to be the same for each trial. Use of binomial distributions for event counts leads to beta distributions for the probabilities, rather than the gamma distributions associated with the frequencies. Beta distributions cover the interval from zero to one. Like gamma distributions, they are typically characterized by two parameters called α ("alpha") and β ("beta"). For the beta distribution, both of these are shape parameters. The mean of the distribution is $\alpha/(\alpha+\beta)$, and the variance is $\alpha/[(\alpha+\beta)(\alpha+\beta+1)]$.

The application of Bayes Theorem with a beta prior distribution and binomial data leads to a beta distribution for the output posterior distribution. Thus, the beta distribution family is the *conjugate prior* for binomial data. When n events occur in d demands, the output from the Bayesian update for a beta (α, β) prior distribution has parameters [$\alpha + n$, $\beta + (d-n)$]. When one of the parameters is less than 1, the beta density is "J"-shaped (leaning against zero, or against 1, depending on which parameter). When both are less than one, the distribution is U-shaped.

A relatively flat *Jeffreys noninformative prior* exists for a beta distribution, for Bayes Theorem use when there is no preconceived distribution for the probability being studied. The distribution is beta (0.5, 0.5). Therefore, the posterior distribution is a beta distribution with parameters (n+0.5, d-n+0.5). As in Section B.1.2 above, this distribution (for probabilities) will be called an *updated Jeffreys noninformative distribution* (UJNID) in this report. The distribution's mean is

$$(n+0.5)/(d+1) \tag{4}$$

and its variance is $(n+0.5)/[(d+1)(d+2)]$. Percentiles or quantiles of beta distributions can easily be obtained using SAS, Microsoft Excel, and other software packages. Further information on basic estimation and Bayesian updating with probabilities is found in HOPE, Section 6.3.

In this report, Equation (4) is used for estimates of probabilities.

B.3.2 Identifying Differences In Groupings Of The Data

The methods discussed in Section B.1.3 above have analogues for probabilities. The tests are slightly different because they involve the probability of non-occurrence as well as the probability of the occurrence under study. Details are provided in HOPE, Section 6.3.3.

B.3.3 Uncertainty Distributions for the Probabilities

The methods discussed in Section B.1.4 above also have analogues for probabilities. Maximum likelihood estimates, using the binomial distribution, lead to beta empirical Bayes (EB) uncertainty distributions for probabilities. These distributions may be used as prior distributions in further group-level (e.g. plant-level) Bayesian updates. The Kass-Steffey adjustment described in Section B.1.4 also has a beta-binomial analogue (see HOPE, Section 8.2.4.2).

The updated Jeffreys noninformative distribution (UJNID) results in an uncertainty distribution at an industry level. It is based on an assumption of a constant probability of the occurrence across the industry.

There is also a flatter distribution for industry uncertainties, the constrained noninformative (beta) distribution (CNID). For this distribution, the alpha parameter approaches 0.5 as the data get close to zero and to one. Between zero and 0.5, the parameter dips to around 0.3, and between 0.5 and 1 it increases to around 0.7. The beta parameter is what it needs to be for the mean of the CNID to meet its constraint, namely Equation (3). HOPE, Section 6.3.2.5.4, provides further information.

B.3.4 Conditional Distributions

A conditional probability for an event, by definition, is the probability of the event and the condition, divided by the probability of the condition. When the event and the condition are independent, the numerator is the product of the two separate entities and the condition probability drops out of the equation. That is, the probability of an event, given the occurrence of an independent other event, is unchanged.

An example of a conditional distribution is recovery times that are greater than zero. Both lognormal and Weibull times possess this characteristic. Some of the switchyard restoration times are zero. Therefore, the fitted switchyard time distribution is a conditional distribution, given "sustained" duration times (in this case, times greater than zero). If p is the probability that the switchyard times are zero, the probability that the switchyard time (T) is less than a time t is

Prob[T<= *t*] = { *p* } when *t* = 0 and

{ *p* + the integral of the fitted density over the interval (0, t]/ (1 - *p*) } when *t* > 0.

In the actual analysis of this study, the zero times were taken to be 1 minute and included in the distribution fits. The switchyard restoration times were not the important restoration times, and did not need the more precise analysis. However, they provide an example, since the "(1 - *p*)" in the denominator of the expression for *t*>0 is the probability of the specified condition.

B.4 References

1. Atwood, C. L., et. al, *Handbook of Parameter Estimation for Probabilistic Risk Assessment*, NUREG/CR-6823 (SAND2003-3348P), September, 2003.
2. *SAS (Base, STAT, and ACCESS modules),* Version 9.0. *Statistical SAS 9 Help and Documentation: Your Complete Guide to Syntax, How To, Examples, Procedures, Concepts, What's New, and Tutorials*. SAS Institute, Inc., Cary, NC, 2002.
3. @Risk: Advanced Risk Analysis for Spreadsheets, V. 4.5. Guide to Using @Risk Risk Analysis and Simulation Add-In for Microsoft Excel, Palisades Corp., N.Y., February, 2004.

Appendix C

Supplemental Data Analysis Results

APPENDIX C

Supplemental Data Analysis Results

Selected results for frequencies, durations, and LOOP-related probabilities are tabulated here. In these tables, p-values that are less than or equal to 0.05 are in bold. Also, rows of data in the tables that are used directly in the main report are in bold. The tabulations support the primary data groupings and summaries selected for the main report by showing these groupings in the context of other views of the data.

C.1 Analysis of LOOP Frequencies

In subsections below, analyses of LOOP frequencies or rates are described. First, plant mode differences are examined, then the frequencies in the time periods before and after deregulation are compared. These are followed by the results of statistical tests for differences with respect to several other attributes of the plants, such as their location in particular National Electric Reliability Council (NERC) reliability centers. The final subsection describes trend analysis for the frequencies.

C.1.1 Plant Mode Effects

Table C-1 shows the results of statistical tests for differences in LOOP occurrence frequencies based on plant mode. Separate event counts and reactor critical or shutdown year data for each category are in Table 3-1 in the main text, and in Table C-2. Table C-1 shows the results of an exact test for whether the two groupings of event data could come from the same Poisson distribution. For categories with potential differences based on time frames, the results are displayed for the (1986-2003) period and the 1997-2003 period.

The table shows extremely significant differences for plant-centered, switchyard-centered, and severe-weather-related LOOPs. The differences persist in the recent time span for the first two of these categories. For weather related LOOPs, the differences particularly show among the coastal plants. These p-values are in bold in Table C-1.

In the main report, the data were separated by plant mode for the grid- and extreme-weather-related categories as well. This choice simplifies the calculation of plant-specific rates for operating and for shutdown plants.

C.1.2 Use of Total Time or Period since Deregulation

Table C-2 shows the results of statistical tests for differences in LOOP occurrence frequencies based on differences between the (1986-1996) period and (1997-2003). The p-value column is based on Fisher's exact test for whether the occurrence rates in the two periods might be the same.

The time differences are extremely significant for switchyard and grid-related LOOPs, and persist in the operational (trip) data for these categories (note p-value entries in bold). There are also statistically significant differences in the plant-centered LOOP frequencies. For each of the five categories, these differences are not statistically significant for the shutdown (S/D) data. There are no noticeable differences for either weather category. Further information on time differences is in the trend section below.

Table C-1. Differences based on plant mode.

LOOP category	Total # of events	Total time (yr)	P-value for plant mode differences
Plant-centered LOOP freq. (1986-2003)	31	1886.9	**<0.00005**
Plant-centered LOOP freq.(1997-2003)	6	725.9	**0.0002**
Switchyard-centered LOOP freq. (1986-2003)	66	1886.9	**<0.00005**
Switchyard-centered LOOP freq.(1997-2003)	12	725.9	**0.0003**
Grid-related LOOP freq. (1986-2003)	14	1886.9	1.0000
Grid-related LOOP freq.(1997-2003)	12	725.9	1.0000
Severe-weather-related LOOP freq. (1986-2003)	13	1886.9	**0.0002**
Severe-weather-related LOOP freq.—coastal plants	9	683.6	**0.0003**
Severe-weather-related LOOP freq.—non-coastal plants	4	1203.4	0.1806
Extreme-weather-related LOOP freq. (1986-2003)	3	1886.9	0.3859

Table C-2. Differences based on time period (1986-1996 versus 1997-2003).

LOOP category and mode subset	1986-1996		1997-2003		Total		P-value for time period differences
	Events	Time (yr)	Events	Time (yr)	Events	Time (yr)	
Plant-centered	25	1161.0	6	725.9	31	1886.9	**0.0403**
Plant-centered trip	11	879.3	**1**	**629.5**	12	1508.8	**0.0188**
S/D plant-centered	14	281.7	5	96.5	**19**	**378.1**	1.0000
Switchyard-centered	54	1161.0	12	725.9	66	1886.9	**0.0009**
Switchyard-centered trip	23	879.3	**5**	**629.5**	28	1508.8	**0.0116**
S/D switchyard-centered	31	281.7	7	96.5	**38**	**378.1**	0.3587
Grid-related	2	1161.0	12	725.9	14	1886.9	**0.0004**
Grid-related trip	1	879.3	**10**	**629.5**	11	1508.8	**0.0011**
S/D grid-related	1	281.7	2	96.5	**3**	**378.1**	0.1620
Severe-weather-related	10	1161.0	3	725.9	13	1886.9	0.2774
Severe-weather-related trip	3	879.3	1	629.5	**4**	**1508.8**	0.6453
S/D severe-weather-related	7	281.7	2	96.5	**9**	**378.1**	1.0000
Extreme-weather-related	2	1161.0	1	725.9	3	1886.9	1.0000
Extreme-weather trip	2	879.3	1	629.5	**3**	**1508.8**	1.0000
S/D extreme-weather	0	281.7	0	96.5	**0**	**378.1**	1.0000

Bold event and time data mark the selections used in the main report. Bold p-values are <=0.05.

These evaluations resulted in the report's use of just the more recent period of data for plant, switchyard, and grid-related LOOP frequencies. The event and time figures used in the main report, resulting from the evaluation of plant mode and time period, are in bold in Table C-2.

C.1.3 Effects of Other Groupings of the Data

The LOOP data were divided into five categories, due to differences in recovery durations (discussed in Section C.2). Within each of these categories, data were pooled by year, plant, site, National Electric Reliability Council (NERC) subregion, NERC regional reliability council, and by the high-level grid interconnections (three geographic areas in the U. S.). Other groupings were also considered, such as the 1032 design groups (electrical design groups defined in NUREG-1032), and whether the plant was within approximately 100 miles of the Atlantic or Gulf coast. Within each of these groupings, exposure times appropriate for each level of the grouping variable could be calculated from the known critical hours of operation and shutdown hours of each power plant.

For each grouping, tests for differences in each category were performed. In addition, an attempt was made to fit an overall empirical Bayes (EB) distribution that would reflect industry uncertainty. The p-values for the statistical tests are in Table C-3 through Table C-5. The mean and bounds of the industry-wide empirical Bayes distribution(s), if identified, also show in the tables. The alpha parameter of the gamma distribution is given, for a quick assessment of the distribution's spread compared to other possible EB distributions fit using the same data set. (Alpha values less than 1 indicate skewed, J-shaped gamma distributions that tend to be broad). The beta parameter (which does not show in the tables) is always the alpha parameter divided by the mean. Finally, the tables also show for each data set the update of the Jeffreys noninformative prior (the UJNID), and the constrained noninformative distribution (the CNID).

Table C-3 describes evaluations for plant operations. In accordance with Table C-2, the time span for the data is the recent period for plant-centered, switchyard-centered, and grid-related events. It is the entire study period for both weather categories. Table C-4 provides evaluations for shutdown periods. The entire study period is used for these assessments. Since results differ for coastal plants for severe-weather-related events in shutdown periods, the results for the coastal subset for severe-weather-related LOOPs are also provided. Table C-5 applies to combined operations and shutdown data for the grid- and extreme-weather-related categories (for which no statistical significance was found for the differing plant mode). Here, the entire period is used for the evaluations. For the grid events, using the whole period lessens the impact of the one dependent event on 8/14/2003 that caused 9 LOOPs.

In each data grouping, the distribution selected to represent the industry variation is in bold. Also statistically significant p-values are in bold. In subsections following the tables, the results for each source of variation (other than sampling) are discussed.

Table C-3. Industry uncertainty distributions for LOOP frequencies (/rcry) during operations.

LOOP category	Source of variation	P-value for differences	Dist. type (Note a)	Industry gamma uncertainty distribution			
				5^{th}	Mean	95^{th}	Shape (α)
Plant-centered trip (1997-2003) — 1 event in 629.5 rcry							
	Sampling	—	UJNID	2.79E-04	2.38E-03	6.21E-03	1.5
	—	—	**CNID**	**9.37E-06**	**2.38E-03**	**9.15E-03**	**0.5**
	Year	0.7000	—	—	—	—	—
	Plant	0.6157	—	—	—	—	—
	Site	0.6755	—	—	—	—	—
	NERC subregion	—	—	—	—	—	—
	NERC region	0.3248	—	—	—	—	—

Table C-3. Industry uncertainty distributions for LOOP frequencies (/rcry) during operations.

LOOP category	Source of variation	P-value for differences	Dist. type (Note a)	Industry gamma uncertainty distribution			
				5th	Mean	95th	Shape (α)
((Plant-centered trim, continued)							
	Interconnection	0.1202	—	—	—	—	—
	Coast	1.0000	—	—	—	—	—
	1032 design group	—	—	—	—	—	—
Switchyard-centered trip (1997-2003) — 5 events in 629.5 rcry							
	Sampling	—	UJNID	3.63E-03	8.74E-03	1.56E-02	5.5
	—	—	**CNID**	**3.44E-05**	**8.74E-03**	**3.36E-02**	**0.5**
	Year	0.4953	—	—	—	—	—
	Plant	0.4023	—	—	—	—	—
	Site	0.4934	—	—	—	—	—
	NERC subregion	0.6189	EB	3.90E-04	7.19E-03	2.14E-02	1.0
	NERC region	0.2030	EB	3.73E-04	8.09E-03	2.46E-02	1.0
	Interconnection	0.7107	—	—	—	—	—
	Coast	1.0000	—	—	—	—	—
	1032 design group	1.0000	—	—	—	—	—
Grid-related trip (1997-2003) — 10 events in 629.5 rcry							
	Sampling	—	UJNID	9.21E-03	1.67E-02	2.60E-02	10.5
	—	—	**CNID**	**6.56E-05**	**1.67E-02**	**6.41E-02**	**0.5**
	Year	**<0.00005**	EB	6.50E-29	1.54E-02	8.04E-02	0.05
	Plant	0.7669	—	—	—	—	—
	Site	**0.0111**	EB	5.80E-11	1.55E-02	8.60E-02	0.14
	NERC subregion	**<0.00005**	EB	4.26E-11	1.56E-02	8.71E-02	0.14
	NERC region	**0.0001**	EB	3.92E-07	1.76E-02	8.44E-02	0.26
	Interconnection	0.5051	—	—	—	—	—
	Coast	1.0000	—	—	—	—	—
	1032 design group	**0.0454**	EB	8.02E-03	1.74E-02	2.97E-02	6.7
Severe-weather-related trip (1986-2003) — 4 events in 1508.8 rcry							
	Sampling	—	UJNID	1.10E-03	2.98E-03	5.61E-03	4.5
	—	—	**CNID**	**1.17E-05**	**2.98E-03**	**1.15E-02**	**0.5**
	Year	0.1892	EB	2.74E-05	2.62E-03	9.36E-03	0.61
	Plant	0.7020	—	—	—	—	—
	Site	**0.0044**	EB	3.09E-19	2.87E-03	1.67E-02	0.08
	NERC subregion	**0.0254**	EB	5.24E-12	2.91E-03	1.63E-02	0.14
	NERC region	**0.0120**	EB	7.10E-09	3.33E-03	1.69E-02	0.21
	Interconnection	0.7727	—	—	—	—	—
	Coast	0.6239	—	—	—	—	—
	1032 design group	0.6753	—	—	—	—	—
Extreme-weather-related trip (1986-2003) — 3 events in 1508.8 rcry							
	Sampling	—	UJNID	7.18E-04	2.32E-03	4.66E-03	3.5
	—	—	**CNID**	**9.12E-06**	**2.32E-03**	**8.91E-03**	**0.5**
	Year	0.0577	EB	1.19E-09	1.99E-03	1.04E-02	0.19
	Plant	0.6430	—	—	—	—	—
	Site	**0.0028**	EB	4.57E-34	2.08E-03	1.01E-02	0.04

Table C-3. Industry uncertainty distributions for LOOP frequencies (/rcry) during operations.

LOOP category	Source of variation	P-value for differences	Dist. type (Note a)	Industry gamma uncertainty distribution			
				5th	Mean	95th	Shape (α)
(Extreme-weather-related trip, continued)							
	NERC subregion	**0.0229**	EB	1.04E-09	2.31E-03	1.21E-02	0.19
	NERC region	**0.0006**	EB	6.98E-10	3.23E-03	1.71E-02	0.18
	Interconnection	0.8242	—	—	—	—	—
	Coast	0.5579	—	—	—	—	—
	1032 design group	0.2958	—	—	—	—	—

a. UJNID: Updated Jeffreys noninformative distribution. CNID: Constrained noninformative distribution. EB: Empirical Bayes distribution.

Table C-4. Industry uncertainty distributions LOOP frequencies (/rsy) during shutdown periods.

LOOP category	Source of variation	P-value for differences	Dist. type (Note a)	Industry gamma uncertainty distribution			
				5th	Mean	95th	Shape (α)
Plant-centered, shutdown (1986-2003) — 19 events in 378.1 rsy							
	Sampling	—	UJNID	3.40E-02	5.16E-02	7.22E-02	19.5
	—	—	CNID	2.03E-04	5.16E-02	1.98E-01	0.5
	Year	0.0997	EB	4.48E-03	5.20E-02	1.43E-01	1.3
	Plant	0.1176	EB	6.19E-05	4.90E-02	2.01E-01	0.41
	Site	**0.0026**	**EB**	**1.43E-04**	**5.25E-02**	**2.07E-01**	**0.47**
	NERC subregion	0.1612	—	—	—	—	—
	NERC region	0.0976	EB	1.77E-02	5.30E-02	1.04E-01	3.9
	Interconnection	0.3008	—	—	—	—	—
	Coast	0.6372	—	—	—	—	—
	1032 design group	0.3758	—	—	—	—	—
Switchyard-centered, shutdown (1986-2003) — 38 events in 378.1 rsy							
	Sampling	—	UJNID	7.64E-02	1.02E-01	1.30E-01	38.5
	—	—	CNID	4.00E-04	1.02E-01	3.91E-01	0.5
	Year	0.6586	—	—	—	—	—
	Plant	**0.0075**	EB	8.81E-03	1.00E-01	2.76E-01	1.3
	Site	**0.0001**	**EB**	**7.15E-03**	**1.04E-01**	**2.98E-01**	**1.1**
	NERC subregion	0.1613	EB	6.79E-02	1.02E-01	1.42E-01	20.3
	NERC region	**0.0274**	EB	6.05E-02	1.04E-01	1.56E-01	12.5
	Interconnection	0.5899	—	—	—	—	—
	Coast	0.1781	—	—	—	—	—
	1032 design group	0.8295	—	—	—	—	—
Grid-related, shutdown (1986-2003) — 3 events in 378.1 rsy							
	Sampling	—	UJNID	2.87E-03	9.26E-03	1.86E-02	3.5
	—	**—**	**CNID**	**3.64E-05**	**9.26E-03**	**3.56E-02**	**0.5**
	Year	0.3984	—	—	—	—	—
	Plant	0.5674	—	—	—	—	—

Table C-4. Industry uncertainty distributions LOOP frequencies (/rsy) during shutdown periods.

LOOP category	Source of variation	P-value for differences	Dist. type (Note a)	Industry gamma uncertainty distribution 5th	Mean	95th	Shape (α)
(Grid-related, shutdown, continued)							
	Site	**0.0105**	—	—	—	—	—
	NERC subregion	0.9322	—	—	—	—	—
	NERC region	0.5048	EB	5.95E-04	7.82E-03	2.20E-02	1.2
	Interconnection	0.8272	—	—	—	—	—
	Coast	1.0000	—	—	—	—	—
	1032 design group	0.0912	—	—	—	—	—
Severe-weather-related, shutdown (1986-2003) — 9 events in 378.1 rsy							
	Sampling	—	UJNID	1.34E-02	2.51E-02	3.99E-02	9.5
	—	—	**CNID**	**9.88E-05**	**2.51E-02**	**9.65E-02**	**0.5**
	Year	0.0575	EB	1.83E-03	2.31E-02	6.46E-02	1.2
	Plant	**0.0038**	EB	4.87E-14	2.23E-02	1.29E-01	0.10
	Site	**<0.00005**	EB	7.74E-17	2.48E-02	1.44E-01	0.08
	NERC subregion	0.3893	EB	5.19E-03	2.35E-02	5.25E-02	2.4
	NERC region	0.1138	EB	3.80E-03	2.33E-02	5.64E-02	1.9
	Interconnection	0.5661	—	—	—	—	—
	Coast	**0.0142**	EB	5.13E-03	2.79E-02	6.55E-02	2.1
	1032 design group	0.3157	—	—	—	—	—
Severe-weather-related (coast only), shutdown (1986-2003) — 7 events in 137.6 rsy							
	Sampling	—	UJNID	2.64E-02	5.45E-02	9.08E-02	7.5
	—	—	CNID	2.14E-04	5.45E-02	2.09E-01	0.5
	Year	**0.0135**	EB	8.97E-05	4.77E-02	1.92E-01	0.44
	Plant	**0.0244**	EB	2.84E-09	4.61E-02	2.48E-01	0.17
	Site	**0.0001**	EB	6.85E-14	5.51E-02	3.19E-01	0.10
	NERC subregion	0.5329	—	—	—	—	—
	NERC region	0.5048	—	—	—	—	—
	Interconnection	0.5495	—	—	—	—	—
	1032 design group	0.2565	—	—	—	—	—
Severe-weather-related (inland only), shutdown (1986-2003) — 2 events in 240.6 rsy							
	Sampling	—	UJNID	2.38E-03	1.04E-02	2.30E-02	2.5
	—	—	CNID	4.09E-05	1.04E-02	3.99E-02	0.5
	Year	0.6893	—	—	—	—	—
	Plant	0.4969	—	—	—	—	—
	Site	0.8824	—	—	—	—	—
	NERC subregion	0.8486	—	—	—	—	—
	NERC region	0.6024	—	—	—	—	—
	Interconnection	0.8398	—	—	—	—	—
	1032 design group	0.8320	—	—	—	—	—
Extreme-weather-related, shutdown (1986-2003) — no events in 378.1 rsy							
	Sampling	—	UJNID	5.20E-06	1.32E-03	5.08E-03	0.5
	—	—	**CNID**	**5.20E-06**	**1.32E-03**	**5.08E-03**	**0.5**

(no other variation listed, since there were no events)

Table C-4. Industry uncertainty distributions LOOP frequencies (/rsy) during shutdown periods.

LOOP category	Source of variation	P-value for differences	Dist. type (Note a)	Industry gamma uncertainty distribution			
				5th	Mean	95th	Shape (α)

a. UJNID: Updated Jeffreys noninformative distribution. CNID: Constrained noninformative distribution. EB: Empirical Bayes distribution.

Table C-5. Industry uncertainty distributions for LOOP frequencies (/ry) (operations and shutdown).

LOOP category	Source of variation	P-value for differences	Dist. type (Note a)	Industry gamma uncertainty distribution			
				5th	Mean	95th	Shape (α)
Grid-related (1986-2003) -- 14 events in 1886.9 ry							
	Sampling	—	UJNID	4.69E-03	7.68E-03	1.13E-02	14.5
	—	—	CNID	3.02E-05	7.68E-03	2.95E-02	0.5
	Year	**<0.00005**	EB	3.63E-13	7.51E-03	4.30E-02	0.12
	Plant	0.6276	—	—	—	—	—
	Site	**0.0052**	EB	2.92E-08	7.55E-03	3.79E-02	0.22
	NERC subregion	**<0.00005**	EB	2.93E-06	7.18E-03	3.12E-02	0.35
	NERC region	**0.0001**	EB	1.78E-05	7.19E-03	2.85E-02	0.46
	Interconnection	0.4070	—	—	—	—	—
	Coast	1.0000	—	—	—	—	—
	1032 design group	**0.0125**	EB	2.29E-03	8.75E-03	1.86E-02	2.9
Extreme-weather-related (1986-2003) -- 3 events in 1886.9 ry							
	Sampling	—	UJNID	5.74E-04	1.85E-03	3.73E-03	3.5
	—	—	CNID	7.29E-06	1.85E-03	7.13E-03	0.5
	Year	0.0682	EB	1.43E-09	1.58E-03	8.15E-03	0.2
	Plant	0.7442	—	—	—	—	—
	Site	**0.0062**	EB	1.41E-32	1.63E-03	8.13E-03	0.04
	NERC subregion	**0.0236**	EB	1.30E-09	1.83E-03	9.50E-03	0.2
	NERC region	**0.0006**	EB	7.25E-10	2.54E-03	1.34E-02	0.18
	Interconnection	0.8248	—	—	—	—	—
	Coast	0.5580	—	—	—	—	—
	1032 design group	0.3080	—	—	—	—	—

a. UJNID: Updated Jeffreys noninformative distribution. CNID: Constrained noninformative distribution. EB: Empirical Bayes distribution.

C.1.3.1. Differences with respect to year. Statistically significant year differences were shown in only two instances: grid LOOPs during operation, and severe-weather-related LOOPs during shutdown. The grid results carry over to the overall results in Table C-5. The grid event that makes grid-related frequencies differ by year is the August 14, 2003 grid blackout, while the severe-weather-related year differences are associated with storms that affected more

than one plant. The EB distributions for these events are not used in the overall study because either they have very small shape (α) parameters representing extremely skewed distributions, or other variation sources were more significant. Also, the dependence found in both of these classes of events weakens the validity of the function that was maximized to estimate the EB distribution parameters.

C.1.3.2. Differences with respect to plant. Between-plant variation was identified in switchyard LOOPs and in severe-weather-related LOOPs during shutdown. The EB distribution for switchyard LOOP frequencies was not used in the study, however, because the p-value for site differences was more significant.

The severe-weather-related distribution was also discounted, due to dependence in the events and the high skewness of the fitted EB distribution. Also, other choices were available for the severe-weather-related data.

C.1.3.3. Differences with respect to site. Where plant differences were seen, site differences were also seen. This is a natural consequence of almost half of the sites currently operating being single-unit plants. The EB distribution for switchyard-related LOOPS while shutdown was used in the study to model the industry variation for this category of LOOPs.

Site differences were also seen in plant-centered LOOPs during shutdowns. They are the only significant sources of variation identified for this grouping of LOOPs, and were used to describe the industry-level LOOP frequency.

Site differences are also shown in the extreme-weather-related events, for which two of three events occurred at the same site. The data here were too sparse to estimate the parameters for an EB distribution.

The same situation occurs for the three grid-related events for which the plants were shutdown.

Note that the distributions identified as EB distributions in the main report (Table 3-3) have different mean values and bounds than the distributions listed here. The UJNID (or, equivalently, the CNID) mean is retained, along with the EB shape parameter. For Table 3-3, the scale parameter was recomputed so that the shape to scale ratio equals the mean, then the median and 5^{th} and 95^{th} percentiles of the resulting gamma distribution were computed and tabulated.

C.1.3.4. Differences with respect to NERC subregion (grid). The subregions are local grouping of the sites. Three of the 17 subregions with commercial nuclear power plants have just one site, and eight have three or fewer sites. On the other hand, the Mid-America Interconnected Network (MAIN) located in Illinois, Missouri, and Wisconsin has ten sites and 17 plants, and the “VACAR” subregion in Virginia and the Carolinas has 9 sites and 16 plants.

Site-level variations carry over into subregion variations for the grid-, severe-weather-, and extreme-weather-related categories during operations (see the second half of Table C-3). These evaluations are affected by the strong dependencies in the data. The corresponding EB distributions have very low shape (α) parameters, characteristic of outliers and heavily skewed distributions. Because all the extreme-weather-related events occurred during operations, and a majority of the grid events, these findings also carry over in the total rates in Table C-5.

C.1.3.5. Differences with respect to NERC region (reliability council). The ten NERC regions vary from having as little as three plants at two sites, to having 30 plants at 18 sites. Between-region differences were identified in many of the same data sets as the ones showing subregion differences (e.g., grid-, severe-weather-, and extreme-weather-related events during operations).

Switchyard LOOPs during shutdown are an exception; differences were observed between the regions but were not statistically significant for the subregions. Nine of 38 events occurred in the Northeast Power Coordinating Council (NPCC), which consists of the New York State subregion and the rest of the New England states. The nine events were divided 5 and 4 between the two subregions. Among the subregions, there were three others with five events, and none with more, so statistically significant subregion differences were not observed.

C.1.3.6. Differences with respect to interconnection. The interconnection geographical regions divide the United States into three areas, with physical isolation between the power distribution systems. The major division is along the Rocky Mountains, separating the western region of the U.S. from the east. The other division separates Texas from the remainder of the states east of the Rockies.

Because there are many fewer nuclear plants in the western region and in Texas, compared with the rest of the country, interconnection differences are not likely to be observed. None were.

C.1.3.7. Differences with respect to coast. The coast/inland classification separates plants within approximately 100 miles from the Atlantic and Gulf coasts from the other plants. The LOOP frequencies differed significantly between coastal and more inland plants only in the shutdown, severe-weather-related category. The data were too sparse to see any difference in operations. The LER data do not indicate which plants shut down in anticipation of a storm or other weather event.

Table C-4 shows an evaluation of the coastal and inland plants separately for severe-weather-related LOOPs. The data show that the occurrence rate is significantly higher for the coastal group. Among the coastal plants, variations are seen in year, plant, and site. However, with highly-skewed EB distributions in each case, these results are influenced by the dependency in the data. The seven events occurred at Brunswick (one 1993 salt spray event affecting the site), Crystal River 3 (two events in March of 1993), and Pilgrim (3 separate events). The clustering of the events around particular years (1993), plants, and sites is obvious.

C.1.3.8. Differences with respect to 1032 design classes (NUREG-1032 plant electrical design). Although no differences show in Tables C-3 through C-5, differences were seen in the full 1986-2003 data set for plant-centered LOOP trips (p-value 0.0078). The twelve events were split 3/9/0 among the classes I1 / I2 / I3, respectively, while the reactor critical years (rcry) were divided 243.6/ 596.8 / 668.5. The I3 occurrence rate was lower. However, only one of the twelve events occurred more recently than 1992. Thus, the design class pattern has not shown itself in the more recent data.

C.1.4 Frequency Trend Results

Figures 3-1 through 3-5 show yearly trends in the frequencies during operation for the five categories of LOOP events. Figure 3-6 provides a composite, based on all the LOOP trip events. Table C-6 shows the slope estimates, their estimated standard deviations, and the p-values associated with tests of goodness of fit and tests of the significance of the slopes for the analyses.

Plant-centered and switchyard-centered frequencies during operation showed decreasing trends, while both weather-related categories showed no significant trends. For the grid events, and for the overall data, the trend-fitting methods were complicated by lack of fit to the assumptions of the Poisson regression model.

The grid events were dominated by the grid blackout that occurred on 8/14/2003. With these events in year 2003 included in the modeling, the "deviance" goodness-of-fit measure rejected the hypothesis that the data could be Poisson in each year with a log trend line describing the yearly mean (p-value 0.03). On the other hand, with the year 2003 excluded, the trend model

Table C-6. Summary of LOOP frequency trend tests (critical operation).

LOOP Category	Slope of log of frequency	Standard error of slope	Pearson's chi-square p-value for goodness of fit	Deviance chi-square p-value for goodness of fit	P-value for slope
Plant-centered trip	-0.204	0.072	0.1184	0.1824	0.0045
Switchyard-centered trip	-0.129	0.041	0.5724	0.3110	0.0015
Grid-related trip	(note a)	(note a)	0.3464	0.9896	(note a)
Severe-weather-related trip	0.061	0.102	0.1660	0.5933	0.5493
Extreme-weather-related trip	-0.036	0.113	0.0573	0.6421	0.7485
Overall (all trip events, per rcry)	-0.0575	0.0302	0.4172	(note b)	0.0568

a. The model was a constant model, omitting year 2003. No slope was estimated.
b. The deviance was forced to equal the degrees of freedom (16 years) in order to allow the procedure to estimate the variation in the data. Automatically, the p-value is in the middle of its range, showing adequate fit.

sees just a LOOP event in 1989. In this case, there is insufficient variation in the data, and the Poisson regression model is an overfit (the goodness-of-fit p-values were 0.91 for the Pearson chi-square measure, and 0.996 for the deviance). Therefore, a constant Poisson model (that did not permit any trend) was fit for the grid data for 1986-2002. The data from 2003 was omitted, thus treating it as an outlier.

For the overall data, including 2003, both the Pearson chi-square and the deviance goodness-of-fit measures showed extra-Poisson variation. For purely Poisson data that behave according to the model, a "scale" parameter associated with the model is identically one. The SAS Procedure GENMOD option, "DSCALE," was used in order to allow the procedure to estimate this scale parameter (1.70) and thereby consider the extra variation. The option has no effect on the fitted curve, but widens the bounds and increases the p-value for the significance of the trend, thus making it less significant. The p-value changed from 0.0012 to 0.0567. Thus, overall, a decrease in the frequency of LOOP-related trips is not conclusive. The 8/14/2003 grid event and its associated uncertainty weaken the ability to assess the overall trend.

C.2 Analysis of LOOP Durations

In subsections below, differences in the potential bus recovery time are considered first from the standpoint of overall groupings of the data, and then from the standpoint of variation within levels of selected attributes of the data.

The fitting of distributions for the data was a major goal of the current analysis. The Weibull distribution fits are noted in the main text (Table 4-1). The lognormal distribution fits are briefly described here, for comparison. Both are plotted in the main text (Figures 4-1 through 4-5).

The data were checked for trends, to see if recoveries were becoming faster or slower, but no trends were found. The analysis is discussed in Section C.2.4.

Although all three time variables were analyzed, results are presented here for the time of primary interest, namely the potential bus restoration time.

C.2.1 Differences in the Five LOOP Categories

Table C-7 provides details for the statistical tests for differences in the site-average potential bus restoration times among the five LOOP categories. For these assessments and the analysis of Section C.2.2, the one missing time (out of 115) was assumed equal to one minute.

Table C-7. Overall tests of differences in groups of LOOP potential bus restoration times.

Grouping variable	Time period	Plant Mode	LOOP category (Note a)	Number of groups	No. of durations	Kruskal-Wallis p-value	K-S p-value (Note b)
LOOP category	1986-2003	All	All	5	115	**0.0013**	**HS**
		All	P vs. S	2	92	**0.0066**	**0.0425**
		Operational	All	5	49	**0.0255**	**S**
		Shutdown	All	4 (note c)	66	0.2225	NS
		Operational	P vs. S	2	37	0.093	0.2203
		Shutdown	P vs. S	2	55	0.0714	0.3228
	1997-2003	Operational	All	4	13	0.0815	No test
		Shutdown	All	4	16	0.0635	No test
		Operational	P vs. S	1 (note d)	5	—	—
		Shutdown	P vs. S	2	12	0.1645	0.5758
Plant mode	1986-2003	All	All	2	115	**0.011**	**0.0323**
	1986-1996		All	2	86	**0.0038**	**0.0179**
	1997-2003		All	2	29	0.93	0.9936
	1986-2003	All	Plant-cent.	2	30	0.6027	0.9296
			Switchyard	2	62	0.092	0.2162
			Grid	2	10	0.5688	0.6119
			Weather	2	11	0.8368	0.9188
			Extreme w.	1	2	—	—
Time (note e)	1986-2003	All	All	2	115	**0.0456**	0.2190
		Operational	All	2	49	0.7857	1.0000
		Shutdown	All	2	66	**0.0239**	0.1164
	1986-2003	All	Plant-cent.	2	30	0.7577	0.8996
			Switchyard	2	62	0.8098	0.9332
			Grid	2	10	0.2963	0.8186
			Weather	2	11	0.3030	0.5440
			Extreme w.	2	2	—	—

a. P. vs. S: plant-centered durations compared with switchyard-centered. In the bottom sections of the table, “Plant-cent.” refers to plant-centered, “Switchyard” refers to switchyard-centered, “Grid” refers to grid-related, “Weather,” to severe-weather-related, and “Extreme w.,” to extreme-weather-related.
b. K-S test: Kolmogorov-Smirnov test. NS, not significant, HS, highly significant (p-value less than 0.01), S, statistically significant (p-value less than 0.05). In these three cases, the actual p-value was not quantified. “No test” means that the actual p-value was not quantified and the number of observations is insufficient to draw conclusions from the asymptotic KS test. The SAS procedure quantifies the p-value only when the number of groups is two.
c. There are no extreme-weather-related events among the shutdown data.
d. There can be no statistical test with only one group. Also, more than one observation per group is required.
e. These test compare durations in the 1986-1996 period with those in the 1997-2003 period.

Data from 1986-2003 were used for the study because no time trends were observed in the data (see Section C.2.4). The bottom section of Table C-7 confirms the choice to use the entire study period, since breaking the period into two pieces (approximately before and after deregulation of the electrical distribution system) makes a difference only when considering the shutdown data or all the data grouped together. The idea of grouping all the data together is strongly rejected as shown in the data in the first part of the table. As intended in the defining of the LOOP categories, there are significant differences in the durations.

The second row in the table shows an overall difference in the plant and switchyard-centered restoration durations. The switchyard events tend to require a longer recovery time. The mean for the recovery time is 0.5 h for plant-centered events, and 1.3 h for switch-yard centered.

Splitting the weather events into two categories was motivated by the recovery times themselves; the two site-level times classified as extreme-weather-related are the two longest times in the data.

The center section of Table C-7 addresses differences in plant mode. The potential restoration times are significantly longer during operations than during shutdowns. However, the difference appears primarily in the 1986-1996 data. Furthermore, the difference is not statistically significant after the data are broken into groupings based on LOOP category. The LOOP category differences are believed to be the most meaningful, both from the viewpoint of the actual recovery times, and of their use in risk assessments.

In the bottom part of the table, there are restoration time differences in the 1986-1996 period and compared with 1997-2003. The 29 newer events took somewhat longer for potential recovery of power to the bus, on average, than the 86 older events (with p-value 0.0456). The averages are, respectively, 3.3 h and 2.7 h. The differences are seen primarily in the shutdown data. As with the plant mode differences, the LOOP category evaluations took priority over the period differences. For each separate LOOP category, the data provided insufficient evidence to reject the null hypothesis that the times could be the same.

Therefore, the plant mode and time differences were subsumed by the LOOP category differences, and the entire site-level data set was used in the restoration time analysis. Overall, the average duration in each category is as indicated in Table 4-2 of the main report, with plant-centered being the shortest, then switchyard-centered, then grid-related, then severe-weather-related, and finally extreme-weather-related.

C.2.2 Differences for Other Groupings of the Data

Table C-8 provides a summary of potential restoration time variation from other possible data attributes for each LOOP category. The attributes considered are site, NERC subregion, NERC region, interconnection, whether the plant is near the coast, the cause category associated with the event, and the NUREG-1032 design group. Plant is not considered because the data are combined at a site level. Year is not considered because of the analysis in the bottom part of Table C-7, and because a separate trend analysis was performed.

P-values that are less than 0.05 are highlighted in the table. The instances of statistically significant differences are all in the switchyard-related category, which is the category having the most data (62 observations, compared with 30 plant-centered, 11 severe-weather-related, 10 grid, and 2 extreme-weather-related).

For switchyard-centered LOOPs, the most significant difference is in NERC reliability councils. Switchyard-centered events occurred in eight of the ten. The empirical estimates of percentiles and mean (using SAS procedure Univariate) are listed below. The council acronyms

Table C-8. Tests of differences in groupings of LOOP potential bus restoration times, by category.

	Plant-centered			Switchyard-centered			Grid-related		
Grouping variable	No. of levels / No of durations	Kruskal-Wallis p-value	K-S p-value (Note a)	No. of levels / No of durations	Kruskal-Wallis p-value	K-S p-value (Note a)	No. of levels / No of durations	Kruskal-Wallis p-value	K-S p-value (Note a)
Site	20 / 30	0.5818	No test	39 / 62	0.4371	HS	9 / 10	0.4211	No test
NERC subregion	9 / 30	0.7317	No test	13 / 62	0.0511	**HS**	5 / 10	0.2295	No test
NERC region	8 / 30	0.6343	No test	8 / 62	**0.0047**	**HS**	4 / 10	0.2780	No test
Interconnection	1 / 30	—	—	2 / 62	0.4646	0.3920	1 / 10	—	—
Coast	2 / 30	0.7853	0.4970	2 / 62	**0.0102**	0.0587	2 / 10	0.3051	0.6119
Cause (Note b)	3 / 30	0.7264	No test	3 / 62	0.1794	NS	3 / 10	0.1030	No test
1032 design group	3 / 30	0.2774	No test	3 / 62	0.2643	NS	3 / 10	0.3949	No test

	Severe-weather-related			Extreme-weather-related		
Grouping variable	No. of levels / No of durations	Kruskal-Wallis p-value	K-S p-value (Note a)	No. of levels / No of durations	Kruskal-Wallis p-value	K-S p-value (Note a)
Site	7 / 11	0.6013	No test	2 / 2	—	—
NERC subregion	6 / 11	0.5231	No test	2 / 2	—	—
NERC region	5 / 11	0.4148	No test	2 / 2	—	—
Interconnection	1 / 11	—	—	1 / 2	—	—
Coast	2 / 11	0.6803	0.8432	2 / 2	—	—
Cause (Note b)	1 / 11	—	—	1 / 2	—	—
1032 design group	2 / 11	0.5804	0.9668	2 / 2	—	—

a. K-S test: Kolmogorov-Smirnov test. NS, not significant, HS, highly significant (p-value less than 0.01), S, statistically significant (p-value less than 0.05). In these three cases, the actual p-value was not quantified. "No test" means that the actual p-value was not quantified and the number of observations is insufficient to draw conclusions from the asymptotic KS test. The SAS procedure quantifies the p-value only when the number of groups is two.
b. Cause: human, equipment, external, or other.

are defined in Appendix A. The data show a variety of restoration times, with the means ranging from approximately 0.2 h to over 2 h.

NERC Council	No. of obs.	Minimum	5th	25th	50th	Mean	75th	95th	Maximum
ECAR	4	0.067	0.067	0.146	0.763	2.015	3.883	6.467	6.467
FRCC	5	0.033	0.033	0.033	0.183	0.317	0.317	1.017	1.017
MAAC	6	0.4	0.4	0.517	1.083	1.675	1.967	5	5
MAIN	12	0.017	0.017	0.267	0.883	2.260	2.983	12.02	12.02
MAPP	5	0.067	0.067	0.233	0.633	0.677	0.633	1.817	1.817
NPCC	14	0.017	0.017	0.017	0.175	0.223	0.417	0.617	0.617
SERC	12	0.133	0.133	0.525	1.55	1.788	2.175	7.567	7.567
WECC	4	0.483	0.483	0.5	0.575	1.596	2.692	4.75	4.75

With regard to coast, the data show the inland plants taking the longer potential bus restoration time.

Plant location	No. of obs.	Minimum	5th	25th	50th	Mean	75th	95th	Maximum
Inland	36	0.017	0.033	0.267	0.742	1.701	1.892	6.467	12.02
Coast	26	0.017	0.017	0.033	0.317	0.766	0.667	2.333	7.567

C.2.3 Exceedance Distributions

For each LOOP category, smooth distributions were fit to the potential bus restoration times (measured in hours). The Diablo Canyon 1 May 15, 2000 event with a potential recovery time exceeding 30 hours was removed as an outlier prior to the distribution fitting process for plant-centered data. The Weibull distribution data are in Table 4-2 of the main report. The lognormal distribution data are in Table C-9.

Table C-9. Lognormal exceedance distribution fits and comparison with Weibull.

	Lognormal								Weibull
LOOP category	Mu (Note a)	Sigma (Note a)	Curve fit 5th	Curve fit median	Actual data mean	Curve fit mean	Curve fit 95th	Shapiro-Wilk p-value	Chi-squared p-value
Plant-centered	-1.98	1.75	0.008	0.138	0.509	0.636	2.45	**0.0162**	0.306
Switchyard-centered	-8.33	1.72	0.026	0.435	1.31	1.89	7.30	**0.0164**	0.760
Grid-related	1.98	1.55	0.095	1.22	2.72	4.05	15.6	0.7348	0.892
Severe-weather-related	-7.00	2.77	0.005	0.497	4.71	23.0	47.3	0.0844	0.667
Extreme-weather-related	4.03	1.22	7.64	56.1	77.9	117	411	1.0000	0.969

a. Mu and Sigma are the mean and standard deviation of the underlying normal distribution.

Table C-9 shows that the lognormal fitted mean values are greater than the actual data means for each category. Comparing these results with Table 4-2 shows that the fitted Weibull means are much closer to the data than the lognormal means.

Table C-9 also shows goodness of fit test p-values for both distributions. The Shapiro-Wilk test rejects the hypothesis that the logarithms of the potential bus restoration times are normally distributed for plant-centered and switchyard-centered LOOPs. The tests for Weibull fit, on the other hand, show statistics within the expected range for the Weibull hypothesis. Therefore, the Weibull distributions were selected for this report.

Neither of the distributions fit the data from the extreme-weather-related category well. With only two data points, the curve fits can only match; there are no degrees of freedom left over to assess the goodness of fit. Furthermore, the fit is not good because, no matter how the distribution curves are estimated, the rule that the potential bus restoration times always be greater than or equal to the switchyard recovery times, and always less than or equal to the actual bus restoration times, is violated. When any family of parametric curves is fit for all three of the recovery times, the curves intersect. They do not stay uniformly in order from shorter times to longer times. The problem exists because the three times are huge and are virtually the same for one of the events, but differ for the other event.

C.2.4 Trend Results

All of the trend tests for the potential bus recovery times showed no statistically significant trends. Selected statistics related to the tests are Table C-10. The goodness of fit for the plant-centered data was not adequate, as shown by the Shapiro-Wilk test rejection of the hypothesis that the residuals are normally distributed.

Table C-10. Summary of potential bus restoration time trend tests.

LOOP Category	Slope of log of frequency	Standard error of slope	P-value for normality of residuals	P-value for homogeneity of variances	P-value for slope
Plant-centered	6.48E-05	9.32E-05	**0.0232**	0.2527	0.4930
Switchyard-centered	7.88E-05	5.83E-05	0.1049	0.3327	0.1814
Grid-related	1.54E-04	9.31E-05	0.6849	0.3256	0.1368
Severe-weather-related	3.67E-04	2.03E-04	0.7512	0.3645	0.1042
Extreme-weather-related	(Note a)	—	—	—	—

a. There was no trend for extreme-weather-related potential bus restoration times (only two observations).

C.3 Analysis of LOOP-Related Probabilities

The LOOP-related probability that was studied from a statistical viewpoint in the most detail is the probability of multiple units being affected in a LOOP event. Among the 127 LOOP unit-level events considered in this study (spanning 1986-2003, and either associated with a trip or occurring when the unit was shut down), there were ten occurrences involving multiple units on the same day. These events are listed in chronological order in Table 6-2 in the main report. Nine involved two units, while one (on 8/14/2004) involved all three units at the site. The remaining 106 events were single-unit events: 52 at single-unit sites, 43 at two-unit sites, and 11 at three-unit sites. When a LOOP occurs at a multiple-unit site, the probability of a LOOP at the other unit or units is higher, as evidenced by the experience summarized in Table 6-2.

Table C-11 summarizes the site-level LOOP experience with respect to site size. For this multiple-unit study, site size was assessed at the start of the study period. Two sites that were three-unit sites at that time (San Onofre and Millstone) are regarded as two-unit sites in the main body of this report (San Onofre 1 was decommissioned in 1992, and Millstone 1 was decommissioned in 1998).

Table C-11. LOOP site event counts tabulated by site size.

	1-unit sites	2-unit sites	3-unit sites	Totals
Number of site-level events	52	52	12	116
Number of sites	33	31	6	70
Number of sites with no events	10	9	2	21
Number of single-unit events	52	43	11	106
Number of sites represented among 1-unit events	23	18	4	45
Number of 2-unit events	—	9	0	9
Number of sites represented among 2-unit events	—	8	0	8
Number of 3-unit events	—	—	1	1
Number of sites represented among 3-unit events	—	—	1	1

In the first two rows of Table C-11, the percentage of events at each size of site corresponds closely with the percentage of sites in each of the three site size categories. There are no statistically significant differences in the LOOP site-level occurrence rate for the three sizes of sites (the chi-squared exact p-value is 0.8342). Thus, overall, we accept the hypothesis that the number of units at a site has no influence on whether a site experiences a LOOP event.

Among the 31 two-unit sites, 9 had no events, 8 had at least one two-unit event, and (by subtraction) 14 had events with at most one unit affected. A similar distribution exists among three-unit sites: 2 of 6 had no events, one had an event affecting all three units, and (by subtraction), 3 had events with at most one unit affected. Each site-level LOOP event affected either one unit or all units at the site; there were no 2-unit events at 3-unit sites. Comparing two and three-unit sites, the distribution of the number of sites having no events, the number of sites having events never affecting more than one plant, and the number of sites having events that sometimes affect more than one plant can be combined (chi-square p-value 0.8916).

The pooled data show that, with 64 of the site events at multiple-unit sites, 10 affected multiple units. After a Jeffreys prior update, these data correspond to an overall probability of 0.162 for more than one unit being affected by a LOOP at a multiple-unit site.

The events were considered as a function of LOOP category. The hypothesis tests discussed above, showing that two and three-unit sites can be combined, give the same statistical conclusions when LOOP category subsets of the data are considered. However, highly statistically significant differences exist between LOOP categories (p-value 0.0001). An empirical Bayes distribution was fitted to the data. The fitted beta distribution has parameters (alpha, beta) equal to (0.5684; 1.0034). The overall distribution, and the means and bounds from the updated distribution for each category, is shown in Table C-12 below. The higher probabilities associated with grid-, severe-weather-, and extreme-weather-related events are not surprising.

Table C-12. Probability that more than one unit at a site is affected given a LOOP at the site.

LOOP Category	# of site events at multiple-unit sites	# of site events at multiple-unit sites affecting more than one unit	5th percentile	Mean	95th percentile
All	64	10	5.12E-03	3.62E-01	9.13E-01
Plant-centered	16	0	4.31E-05	3.23E-02	1.31E-01
Switchyard-centered	39	4	4.34E-02	1.13E-01	2.04E-01
Grid-related	4	3	2.51E-01	6.40E-01	9.44E-01
Severe-weather-related	4	2	1.36E-01	4.61E-01	8.06E-01
Extreme-weather-related	1	1	3.60E-02	6.10E-01	9.98E-01

The bounds for the LOOP categories reflect the increased variation associated with estimating the parameters.

A study of the variation in the multi-unit data also shows that the events are more likely when the plant is at power (p-value 0.034), and are more likely for plants in certain reliability councils (p-value 0.031). Among the councils, for example, the estimated probability is over three times higher for MAAC, with three of the 10 events, than for MAIN which had no multiple-unit events among 15 LOOPs at multiple-unit sites. Two of the multi-unit events were associated with the August 14, 2003 power blackout, but neither of these was in the MAIN or MAAC regions. The MAIN region had mostly switch-yard centered events.

Within each LOOP category, variation in the probability of multiple-unit events was considered. The switchyard category is the only one with sufficient data to show any patterns. Reliability council differences were seen in the four switchyard events. Two multi-unit events among 4 total switchyard-centered events at sites with multiple units occurred for MAAC. The ECAR event was one of two switchyard-centered LOOPs at such sites, and the SERC event was one of 10 switchyard-centered LOOPs at such sites. The other councils had no multiple-unit switchyard events, but NPCC had 7 opportunities and MAIN had 10 opportunities for multiple-unit events.

One other finding of the multiple-unit study is that all ten of the multiple-unit events had loss of power to the switchyard. All events for which the switchyard restoration time was zero were single-unit events.

Appendix D

Plant-Specific LOOP Frequencies

Appendix D

Plant-Specific LOOP Frequencies

Plant-specific loss of offsite power (LOOP) frequencies are presented in this appendix for the 103 operating U.S. commercial nuclear power plants. Frequencies are presented for each of the five categories of LOOPs and their sum for both critical operation (Table D-1.) and shutdown operation (Table D-2.). The five categories of LOOPs are plant centered, switchyard centered, grid related, severe weather related, and extreme weather related.

The plant-specific LOOP frequencies were estimated by performing Bayesian updates on each of the individual LOOP categories using the industry frequencies (Table 3 in the main report) as priors and plant-specific data over the period 1997 – 2003. Industry priors were used rather than the regional priors (Table 4 in the main report) because the regional priors for grid-related LOOPs are heavily influenced by the single grid blackout event on August 14, 2003. Also, plant-specific data over 1997 – 2003 were used because trends were noted in several of the LOOP categories for critical operation. Using data over this period results in plant-specific LOOP frequency estimates representative of the year 2000 (the midpoint of the period 1997 – 2003).

The Bayesian updates are performed for each of the LOOP categories using the following equation for the posterior mean:

$$\text{Posterior mean} = (\alpha + n)/(\beta + T),$$

where

where	α	=	prior gamma distribution shape parameter (Table 3 in the main report)
	β	=	prior gamma distribution scale parameter (Table 3 in the main report)
	n	=	number of LOOP events at the plant in question (1997 – 2003)
	T	=	number of reactor critical years or reactor shutdown years (1997 – 2003).

The posterior distribution is gamma for each of the LOOP categories. The shape parameter of this distribution is "α+ n" and the scale parameter is "β+ T". For the combined or overall LOOP frequency (the sum of the five LOOP category frequencies), the mean is just the sum of the individual means as indicated in Tables D-1. and D-2.. To obtain a distribution for this combined LOOP frequency, simulation should be performed.

LOOPs are rare events and a single occurrence at a plant can significantly affect the plant-specific frequencies presented in this appendix. Also, plant performance (for LOOPs that are caused by plant activities) can vary with time. If a plant experiences several LOOPs caused by its own activities, then actions are taken to improve its performance. Therefore, the plant-specific LOOP frequencies presented in this report should be used with care. As additional years of data are collected, it is suggested that the most recent seven years of plant-specific data be used in Bayesian updates to obtain the most current LOOP frequency estimates.

Table D-1. Plant-specific LOOP frequencies for critical operation.

	Plant-Specific Mean Frequencies for Critical Operation (/rcry) (1997 - 2003 Data)						LOOP-IEs During Critical Operation (1997 - 2003)					1997 - 2003		
Plant	**Plant Centered**	**Switchyard Centered**	**Grid Related**	**Severe Weather Related**	**Extreme Weather Related**	**Combined**	**Plant Centered**	**Switchyard Centered**	**Grid Related**	**Severe Weather Related**	**Extreme Weather Related**	**rcry**	**rsy**	**rcy**
Arkansas 1	2.31E-03	7.86E-03	1.38E-02	2.87E-03	2.32E-03	2.91E-02						6.40	0.60	7.00
Arkansas 2	2.31E-03	7.88E-03	1.38E-02	2.87E-03	2.32E-03	2.92E-02						6.22	0.78	7.00
Beaver Valley 1	2.32E-03	7.99E-03	1.41E-02	2.89E-03	2.32E-03	2.97E-02						5.41	1.59	7.00
Beaver Valley 2	2.32E-03	7.95E-03	1.40E-02	2.88E-03	2.32E-03	2.95E-02						5.69	1.31	7.00
Braidwood 1	2.31E-03	7.85E-03	1.37E-02	2.87E-03	2.32E-03	2.91E-02						6.49	0.51	7.00
Braidwood 2	2.31E-03	7.84E-03	1.37E-02	2.87E-03	2.32E-03	2.90E-02						6.58	0.42	7.00
Browns Ferry 2	2.31E-03	7.84E-03	1.37E-02	2.87E-03	2.32E-03	2.90E-02						6.58	0.42	7.00
Browns Ferry 3	2.31E-03	7.82E-03	1.36E-02	2.87E-03	2.32E-03	2.89E-02						6.73	0.27	7.00
Brunswick 1	2.31E-03	7.83E-03	1.37E-02	2.87E-03	2.32E-03	2.90E-02						6.69	0.31	7.00
Brunswick 2	2.31E-03	7.84E-03	1.37E-02	2.87E-03	2.32E-03	2.90E-02						6.57	0.43	7.00
Byron 1	2.31E-03	7.87E-03	1.38E-02	2.87E-03	2.32E-03	2.91E-02						6.35	0.65	7.00
Byron 2	2.31E-03	7.83E-03	1.37E-02	2.87E-03	2.32E-03	2.90E-02						6.67	0.33	7.00
Callaway	2.31E-03	7.85E-03	1.37E-02	2.87E-03	2.32E-03	2.91E-02						6.49	0.51	7.00
Calvert Cliffs 1	2.31E-03	7.88E-03	1.38E-02	2.87E-03	2.32E-03	2.92E-02						6.25	0.75	7.00
Calvert Cliffs 2	2.31E-03	7.88E-03	1.38E-02	2.87E-03	2.32E-03	2.92E-02						6.26	0.74	7.00
Catawba 1	2.31E-03	7.86E-03	1.37E-02	2.87E-03	2.32E-03	2.91E-02						6.43	0.57	7.00
Catawba 2	2.31E-03	7.87E-03	1.38E-02	2.87E-03	2.32E-03	2.92E-02						6.34	0.66	7.00
Clinton 1	2.33E-03	8.12E-03	1.46E-02	2.90E-03	2.32E-03	3.02E-02						4.39	2.61	7.00
Columbia 2	2.32E-03	7.93E-03	1.40E-02	2.88E-03	2.32E-03	2.94E-02						5.81	1.19	7.00
Comanche Peak 1	2.31E-03	7.85E-03	1.37E-02	2.87E-03	2.32E-03	2.91E-02						6.52	0.48	7.00
Comanche Peak 2	2.31E-03	7.86E-03	1.37E-02	2.87E-03	2.32E-03	2.91E-02						6.43	0.57	7.00
Cook 1	2.35E-03	8.29E-03	1.51E-02	2.93E-03	2.32E-03	3.10E-02						3.12	3.88	7.00
Cook 2	2.34E-03	8.21E-03	1.49E-02	2.92E-03	2.32E-03	3.07E-02						3.68	3.32	7.00
Cooper	2.32E-03	7.93E-03	1.40E-02	2.88E-03	2.32E-03	2.94E-02						5.86	1.14	7.00
Crystal River 3	2.32E-03	7.97E-03	1.41E-02	2.88E-03	2.32E-03	2.96E-02						5.55	1.45	7.00
Davis-Besse	2.33E-03	8.07E-03	1.44E-02	2.90E-03	6.96E-03	3.47E-02					1	4.73	2.27	7.00
Diablo Canyon 1	6.93E-03	7.86E-03	1.38E-02	2.87E-03	2.32E-03	3.37E-02	1					6.40	0.60	7.00
Diablo Canyon 2	2.31E-03	7.85E-03	1.37E-02	2.87E-03	2.32E-03	2.91E-02						6.48	0.52	7.00
Dresden 2	2.31E-03	7.84E-03	1.37E-02	2.87E-03	2.32E-03	2.90E-02						6.54	0.46	7.00
Dresden 3	2.31E-03	7.87E-03	1.38E-02	2.87E-03	2.32E-03	2.92E-02						6.33	0.67	7.00

Table D-1. Plant-specific LOOP frequencies for critical operation. (continued)

	Plant-Specific Mean Frequencies for Critical Operation (/rcry) (1997 - 2003 Data)						LOOP-IEs During Critical Operation (1997 - 2003)					1997 - 2003		
Plant	**Plant Centered**	**Switchyard Centered**	**Grid Related**	**Severe Weather Related**	**Extreme Weather Related**	**Combined**	**Plant Centered**	**Switchyard Centered**	**Grid Related**	**Severe Weather Related**	**Extreme Weather Related**	**rcry**	**rsy**	**rcy**
Duane Arnold	2.31E-03	7.87E-03	1.38E-02	2.87E-03	2.32E-03	2.92E-02						6.30	0.70	7.00
Farley 1	2.31E-03	7.90E-03	1.39E-02	2.88E-03	2.32E-03	2.93E-02						6.10	0.90	7.00
Farley 2	2.31E-03	7.87E-03	1.38E-02	2.87E-03	2.32E-03	2.91E-02						6.36	0.64	7.00
Fermi 2	2.31E-03	7.90E-03	4.16E-02	2.88E-03	2.32E-03	5.70E-02			1			6.10	0.90	7.00
FitzPatrick	2.31E-03	7.85E-03	4.12E-02	2.87E-03	2.32E-03	5.65E-02			1			6.48	0.52	7.00
Fort Calhoun	2.31E-03	7.88E-03	1.38E-02	2.87E-03	2.32E-03	2.92E-02						6.26	0.74	7.00
Ginna	2.31E-03	7.85E-03	4.11E-02	2.87E-03	2.32E-03	5.65E-02			1			6.51	0.49	7.00
Grand Gulf	2.31E-03	7.84E-03	1.37E-02	2.87E-03	2.32E-03	2.90E-02						6.55	0.45	7.00
Harris	2.31E-03	7.88E-03	1.38E-02	2.87E-03	2.32E-03	2.92E-02						6.26	0.74	7.00
Hatch 1	2.31E-03	7.85E-03	1.37E-02	2.87E-03	2.32E-03	2.91E-02						6.46	0.54	7.00
Hatch 2	2.31E-03	7.87E-03	1.38E-02	2.87E-03	2.32E-03	2.91E-02						6.35	0.65	7.00
Hope Creek	2.31E-03	7.88E-03	1.38E-02	2.87E-03	2.32E-03	2.92E-02						6.25	0.75	7.00
Indian Point 2	2.33E-03	2.43E-02	4.34E-02	2.90E-03	2.32E-03	7.52E-02		1	1			4.64	2.36	7.00
Indian Point 3	2.31E-03	7.89E-03	4.15E-02	2.87E-03	2.32E-03	5.69E-02			1			6.19	0.81	7.00
Kewaunee	2.31E-03	7.91E-03	1.39E-02	2.88E-03	2.32E-03	2.93E-02						6.01	0.99	7.00
La Salle 1	2.32E-03	8.01E-03	1.42E-02	2.89E-03	2.32E-03	2.98E-02						5.21	1.79	7.00
La Salle 2	2.33E-03	8.11E-03	1.45E-02	2.90E-03	2.32E-03	3.02E-02						4.47	2.53	7.00
Limerick 1	2.31E-03	7.83E-03	1.37E-02	2.87E-03	2.32E-03	2.90E-02						6.67	0.33	7.00
Limerick 2	2.31E-03	7.83E-03	1.37E-02	2.87E-03	2.32E-03	2.90E-02						6.67	0.33	7.00
McGuire 1	2.31E-03	7.87E-03	1.38E-02	2.87E-03	2.32E-03	2.92E-02						6.32	0.68	7.00
McGuire 2	2.31E-03	7.87E-03	1.38E-02	2.87E-03	2.32E-03	2.92E-02						6.33	0.67	7.00
Millstone 2	2.33E-03	8.15E-03	1.47E-02	2.91E-03	2.32E-03	3.04E-02						4.12	2.88	7.00
Millstone 3	2.32E-03	8.03E-03	1.43E-02	2.89E-03	2.32E-03	2.99E-02						5.02	1.98	7.00
Monticello	2.31E-03	7.90E-03	1.39E-02	2.88E-03	2.32E-03	2.93E-02						6.10	0.90	7.00
Nine Mile Pt. 1	2.32E-03	7.94E-03	4.20E-02	2.88E-03	2.32E-03	5.75E-02			1			5.77	1.23	7.00
Nine Mile Pt. 2	2.31E-03	7.88E-03	4.14E-02	2.87E-03	2.32E-03	5.68E-02			1			6.27	0.73	7.00
North Anna 1	2.31E-03	7.85E-03	1.37E-02	2.87E-03	2.32E-03	2.91E-02						6.51	0.49	7.00
North Anna 2	2.31E-03	7.88E-03	1.38E-02	2.87E-03	2.32E-03	2.92E-02						6.22	0.78	7.00
Oconee 1	2.32E-03	7.95E-03	1.40E-02	2.88E-03	2.32E-03	2.95E-02						5.65	1.35	7.00
Oconee 2	2.31E-03	7.88E-03	1.38E-02	2.87E-03	2.32E-03	2.92E-02						6.26	0.74	7.00
Oconee 3	2.31E-03	7.91E-03	1.39E-02	2.88E-03	2.32E-03	2.93E-02						5.99	1.01	7.00

Table D-1. Plant-specific LOOP frequencies for critical operation. (continued)

	Plant-Specific Mean Frequencies for Critical Operation (/rcry) (1997 - 2003 Data)						LOOP-IEs During Critical Operation (1997 - 2003)					1997 - 2003		
Plant	**Plant Centered**	**Switchyard Centered**	**Grid Related**	**Severe Weather Related**	**Extreme Weather Related**	**Combined**	**Plant Centered**	**Switchyard Centered**	**Grid Related**	**Severe Weather Related**	**Extreme Weather Related**	**rcry**	**rsy**	**rcy**
Oyster Creek	2.31E-03	2.35E-02	1.37E-02	2.87E-03	2.32E-03	4.48E-02		1				6.49	0.51	7.00
Palisades	2.32E-03	7.96E-03	1.41E-02	2.88E-03	2.32E-03	2.95E-02						5.64	1.36	7.00
Palo Verde 1	2.31E-03	7.84E-03	1.37E-02	2.87E-03	2.32E-03	2.90E-02						6.56	0.44	7.00
Palo Verde 2	2.31E-03	7.87E-03	1.38E-02	2.87E-03	2.32E-03	2.92E-02						6.28	0.72	7.00
Palo Verde 3	2.31E-03	7.85E-03	1.37E-02	2.87E-03	2.32E-03	2.91E-02						6.45	0.55	7.00
Peach Bottom 2	2.31E-03	7.82E-03	4.09E-02	2.87E-03	2.32E-03	5.62E-02			1			6.72	0.28	7.00
Peach Bottom 3	2.31E-03	7.83E-03	4.10E-02	2.87E-03	2.32E-03	5.63E-02			1			6.65	0.35	7.00
Perry	2.31E-03	7.87E-03	4.14E-02	2.87E-03	2.32E-03	5.68E-02			1			6.29	0.71	7.00
Pilgrim	2.31E-03	7.86E-03	1.38E-02	2.87E-03	2.32E-03	2.91E-02						6.42	0.58	7.00
Point Beach 1	2.32E-03	7.99E-03	1.42E-02	2.89E-03	2.32E-03	2.97E-02						5.39	1.61	7.00
Point Beach 2	2.32E-03	7.99E-03	1.41E-02	2.89E-03	2.32E-03	2.97E-02						5.40	1.60	7.00
Prairie Island 1	2.31E-03	7.87E-03	1.38E-02	2.87E-03	2.32E-03	2.92E-02						6.30	0.70	7.00
Prairie Island 2	2.31E-03	7.88E-03	1.38E-02	2.87E-03	2.32E-03	2.92E-02						6.25	0.75	7.00
Quad Cities 1	2.31E-03	7.90E-03	1.39E-02	2.88E-03	2.32E-03	2.93E-02						6.08	0.92	7.00
Quad Cities 2	2.32E-03	2.38E-02	1.40E-02	2.88E-03	2.32E-03	4.54E-02		1				5.71	1.29	7.00
River Bend	2.31E-03	7.87E-03	1.38E-02	2.87E-03	2.32E-03	2.92E-02						6.32	0.68	7.00
Robinson 2	2.31E-03	7.83E-03	1.37E-02	2.87E-03	2.32E-03	2.90E-02						6.61	0.39	7.00
Salem 1	2.32E-03	2.40E-02	1.42E-02	2.89E-03	2.32E-03	4.57E-02		1				5.28	1.72	7.00
Salem 2	2.32E-03	7.95E-03	1.40E-02	2.88E-03	2.32E-03	2.95E-02						5.68	1.32	7.00
San Onofre 2	2.31E-03	7.89E-03	1.38E-02	2.87E-03	2.32E-03	2.92E-02						6.20	0.80	7.00
San Onofre 3	2.31E-03	7.90E-03	1.39E-02	2.88E-03	2.32E-03	2.93E-02						6.05	0.95	7.00
Seabrook	2.31E-03	7.90E-03	1.39E-02	8.63E-03	2.32E-03	3.50E-02				1		6.07	0.93	7.00
Sequoyah 1	2.31E-03	7.88E-03	1.38E-02	2.87E-03	2.32E-03	2.92E-02						6.24	0.76	7.00
Sequoyah 2	2.31E-03	7.85E-03	1.37E-02	2.87E-03	2.32E-03	2.91E-02						6.52	0.48	7.00
South Texas 1	2.31E-03	7.89E-03	1.38E-02	2.87E-03	2.32E-03	2.92E-02						6.18	0.82	7.00
South Texas 2	2.31E-03	7.87E-03	1.38E-02	2.87E-03	2.32E-03	2.92E-02						6.30	0.70	7.00
St. Lucie 1	2.31E-03	7.85E-03	1.37E-02	2.87E-03	2.32E-03	2.91E-02						6.49	0.51	7.00
St. Lucie 2	2.31E-03	7.85E-03	1.37E-02	2.87E-03	2.32E-03	2.91E-02						6.46	0.54	7.00
Summer	2.31E-03	7.89E-03	1.39E-02	2.87E-03	2.32E-03	2.93E-02						6.13	0.87	7.00

Table D-1. Plant-specific LOOP frequencies for critical operation. (continued)

	Plant-Specific Mean Frequencies for Critical Operation (/rcry) (1997 - 2003 Data)						**LOOP-IEs During Critical Operation (1997 - 2003)**					**1997 - 2003**		
Plant	**Plant Centered**	**Switchyard Centered**	**Grid Related**	**Severe Weather Related**	**Extreme Weather Related**	**Combined**	**Plant Centered**	**Switchyard Centered**	**Grid Related**	**Severe Weather Related**	**Extreme Weather Related**	**rcry**	**rsy**	**rcy**
Surry 1	2.31E-03	7.88E-03	1.38E-02	2.87E-03	2.32E-03	2.92E-02						6.23	0.77	7.00
Surry 2	2.31E-03	7.86E-03	1.38E-02	2.87E-03	2.32E-03	2.91E-02						6.38	0.62	7.00
Susquehanna 1	2.31E-03	7.85E-03	1.37E-02	2.87E-03	2.32E-03	2.91E-02						6.45	0.55	7.00
Susquehanna 2	2.31E-03	7.87E-03	1.38E-02	2.87E-03	2.32E-03	2.92E-02						6.34	0.66	7.00
Three Mile Isl 1	2.31E-03	2.36E-02	1.37E-02	2.87E-03	2.32E-03	4.48E-02		1				6.46	0.54	7.00
Turkey Point 3	2.31E-03	7.85E-03	1.37E-02	2.87E-03	2.32E-03	2.91E-02						6.51	0.49	7.00
Turkey Point 4	2.31E-03	7.83E-03	1.37E-02	2.87E-03	2.32E-03	2.90E-02						6.62	0.38	7.00
Vermont Yankee	2.31E-03	7.85E-03	1.37E-02	2.87E-03	2.32E-03	2.91E-02						6.49	0.51	7.00
Vogtle 1	2.31E-03	7.85E-03	1.37E-02	2.87E-03	2.32E-03	2.91E-02						6.46	0.54	7.00
Vogtle 2	2.31E-03	7.85E-03	1.37E-02	2.87E-03	2.32E-03	2.91E-02						6.49	0.51	7.00
Waterford 3	2.31E-03	7.89E-03	1.39E-02	2.87E-03	2.32E-03	2.93E-02						6.15	0.85	7.00
Watts Bar 1	2.31E-03	7.86E-03	1.38E-02	2.87E-03	2.32E-03	2.91E-02						6.38	0.62	7.00
Wolf Creek	2.31E-03	7.86E-03	1.38E-02	2.87E-03	2.32E-03	2.91E-02						6.40	0.60	7.00
Total							1	5	10	1	1	628.91	92.09	721.00
Max	6.93E-03	2.43E-02	4.34E-02	8.63E-03	6.96E-03	7.52E-02								
95%	2.33E-03	8.28E-03	4.14E-02	2.90E-03	2.32E-03	5.68E-02								
Mean	2.36E-03	8.67E-03	1.66E-02	2.93E-03	2.37E-03	3.29E-02								
50%	2.31E-03	7.87E-03	1.38E-02	2.87E-03	2.32E-03	2.92E-02								
5%	2.31E-03	7.83E-03	1.37E-02	2.87E-03	2.32E-03	2.90E-02								

Key: rcry – reactor critical year, rsy – reactor shutdown year, rcy – reactor calendar year

Table D-2. Plant-specific LOOP frequencies for shutdown operation.

Plant	Plant-Specific Mean Frequencies for Shutdown Operation (/rsy) (1997 - 2003 Data)						LOOPs During Shutdown Operation (1997 - 2003)					1997 - 2003		
	Plant Centered	Switchyard Centered	Grid Related	Severe Weather Related	Extreme Weather Related	Combined	Plant Centered	Switchyard Centered	Grid Related	Severe Weather Related	Extreme Weather Related	rcry	rsy	rcy
Arkansas 1	4.86E-02	9.09E-02	9.16E-03	2.44E-02	1.32E-03	1.74E-01						6.40	0.60	7.00
Arkansas 2	4.78E-02	8.80E-02	9.13E-03	2.42E-02	1.32E-03	1.70E-01						6.22	0.78	7.00
Beaver Valley 1	4.43E-02	7.70E-02	8.99E-03	2.32E-02	1.31E-03	1.55E-01						5.41	1.59	7.00
Beaver Valley 2	4.55E-02	8.05E-02	9.04E-03	2.36E-02	1.32E-03	1.60E-01						5.69	1.31	7.00
Braidwood 1	4.90E-02	9.23E-02	9.17E-03	7.34E-02	1.32E-03	2.25E-01				1		6.49	0.51	7.00
Braidwood 2	4.95E-02	9.39E-02	9.19E-03	2.46E-02	1.32E-03	1.78E-01						6.58	0.42	7.00
Browns Ferry 2	4.95E-02	9.40E-02	9.19E-03	2.46E-02	1.32E-03	1.79E-01						6.58	0.42	7.00
Browns Ferry 3	5.02E-02	2.90E-01	9.21E-03	2.48E-02	1.32E-03	3.75E-01		1				6.73	0.27	7.00
Brunswick 1	5.00E-02	2.88E-01	9.21E-03	2.47E-02	1.32E-03	3.73E-01		1				6.69	0.31	7.00
Brunswick 2	4.94E-02	9.37E-02	9.19E-03	2.46E-02	1.32E-03	1.78E-01						6.57	0.43	7.00
Byron 1	4.83E-02	9.00E-02	9.15E-03	2.43E-02	1.32E-03	1.73E-01						6.35	0.65	7.00
Byron 2	4.99E-02	9.56E-02	9.20E-03	2.47E-02	1.32E-03	1.81E-01						6.67	0.33	7.00
Callaway	4.90E-02	9.24E-02	9.17E-03	2.45E-02	1.32E-03	1.76E-01						6.49	0.51	7.00
Calvert Cliffs 1	4.79E-02	8.84E-02	9.13E-03	2.42E-02	1.32E-03	1.71E-01						6.25	0.75	7.00
Calvert Cliffs 2	4.79E-02	8.86E-02	9.13E-03	2.42E-02	1.32E-03	1.71E-01						6.26	0.74	7.00
Catawba 1	4.87E-02	9.14E-02	9.16E-03	2.44E-02	1.32E-03	1.75E-01						6.43	0.57	7.00
Catawba 2	4.83E-02	8.99E-02	9.15E-03	2.43E-02	1.32E-03	1.73E-01						6.34	0.66	7.00
Clinton 1	4.07E-02	2.00E-01	8.83E-03	2.22E-02	1.31E-03	2.73E-01		1				4.39	2.61	7.00
Columbia 2	4.60E-02	8.21E-02	9.06E-03	2.37E-02	1.32E-03	1.62E-01						5.81	1.19	7.00
Comanche Peak 1	4.91E-02	9.28E-02	9.18E-03	2.45E-02	1.32E-03	1.77E-01						6.52	0.48	7.00
Comanche Peak 2	4.87E-02	9.14E-02	9.16E-03	2.44E-02	1.32E-03	1.75E-01						6.43	0.57	7.00
Cook 1	3.68E-02	5.69E-02	8.64E-03	2.10E-02	1.31E-03	1.25E-01						3.12	3.88	7.00
Cook 2	3.84E-02	6.08E-02	8.72E-03	2.15E-02	1.31E-03	1.31E-01						3.68	3.32	7.00
Cooper	4.62E-02	8.28E-02	9.07E-03	2.37E-02	1.32E-03	1.63E-01						5.86	1.14	7.00
Crystal River 3	4.49E-02	7.88E-02	9.02E-03	2.34E-02	1.31E-03	1.57E-01						5.55	1.45	7.00
Davis-Besse	1.25E-01	6.97E-02	2.67E-02	2.25E-02	1.31E-03	2.46E-01	1		1			4.73	2.27	7.00
Diablo Canyon 1	4.86E-02	9.09E-02	9.16E-03	2.44E-02	1.32E-03	1.74E-01						6.40	0.60	7.00
Diablo Canyon 2	4.90E-02	9.22E-02	9.17E-03	2.45E-02	1.32E-03	1.76E-01						6.48	0.52	7.00
Dresden 2	4.93E-02	9.33E-02	9.18E-03	2.45E-02	1.32E-03	1.78E-01						6.54	0.46	7.00
Dresden 3	4.83E-02	8.97E-02	9.15E-03	2.43E-02	1.32E-03	1.73E-01						6.33	0.67	7.00

Table D-2. Plant-specific LOOP frequencies for shutdown operation. (continued)

	Plant-Specific Mean Frequencies for Shutdown Operation (/rsy) (1997 - 2003 Data)						LOOPs During Shutdown Operation (1997 - 2003)					1997 - 2003		
Plant	**Plant Centered**	**Switchyard Centered**	**Grid Related**	**Severe Weather Related**	**Extreme Weather Related**	**Combined**	**Plant Centered**	**Switchyard Centered**	**Grid Related**	**Severe Weather Related**	**Extreme Weather Related**	**rcry**	**rsy**	**rcy**
Duane Arnold	4.81E-02	8.92E-02	9.14E-03	2.42E-02	1.32E-03	1.72E-01						6.30	0.70	7.00
Farley 1	4.72E-02	2.59E-01	9.11E-03	2.40E-02	1.32E-03	3.40E-01		1				6.10	0.90	7.00
Farley 2	4.84E-02	9.03E-02	9.15E-03	2.43E-02	1.32E-03	1.73E-01						6.36	0.64	7.00
Fermi 2	4.72E-02	8.62E-02	9.11E-03	2.40E-02	1.32E-03	1.68E-01						6.10	0.90	7.00
FitzPatrick	4.90E-02	9.23E-02	9.17E-03	2.45E-02	1.32E-03	1.76E-01						6.48	0.52	7.00
Fort Calhoun	1.44E-01	2.66E-01	9.14E-03	2.42E-02	1.32E-03	4.45E-01	1	1				6.26	0.74	7.00
Ginna	4.91E-02	9.28E-02	9.18E-03	2.45E-02	1.32E-03	1.77E-01						6.51	0.49	7.00
Grand Gulf	4.93E-02	9.34E-02	9.18E-03	2.45E-02	1.32E-03	1.78E-01						6.55	0.45	7.00
Harris	4.80E-02	8.87E-02	9.14E-03	2.42E-02	1.32E-03	1.71E-01						6.26	0.74	7.00
Hatch 1	4.89E-02	9.19E-02	9.17E-03	2.44E-02	1.32E-03	1.76E-01						6.46	0.54	7.00
Hatch 2	4.83E-02	9.00E-02	9.15E-03	2.43E-02	1.32E-03	1.73E-01						6.35	0.65	7.00
Hope Creek	4.79E-02	8.85E-02	9.13E-03	2.42E-02	1.32E-03	1.71E-01						6.25	0.75	7.00
Indian Point 2	1.24E-01	6.88E-02	8.87E-03	2.24E-02	1.31E-03	2.26E-01	1					4.64	2.36	7.00
Indian Point 3	4.76E-02	8.76E-02	2.74E-02	2.41E-02	1.32E-03	1.88E-01			1			6.19	0.81	7.00
Kewaunee	4.68E-02	8.48E-02	9.09E-03	2.39E-02	1.32E-03	1.66E-01						6.01	0.99	7.00
La Salle 1	4.35E-02	7.47E-02	8.96E-03	2.30E-02	1.31E-03	1.52E-01						5.21	1.79	7.00
La Salle 2	4.09E-02	6.73E-02	8.85E-03	2.23E-02	1.31E-03	1.41E-01						4.47	2.53	7.00
Limerick 1	4.99E-02	9.55E-02	9.20E-03	2.47E-02	1.32E-03	1.81E-01						6.67	0.33	7.00
Limerick 2	4.99E-02	9.55E-02	9.20E-03	2.47E-02	1.32E-03	1.81E-01						6.67	0.33	7.00
McGuire 1	4.82E-02	8.96E-02	9.14E-03	2.43E-02	1.32E-03	1.73E-01						6.32	0.68	7.00
McGuire 2	4.83E-02	8.98E-02	9.15E-03	2.43E-02	1.32E-03	1.73E-01						6.33	0.67	7.00
Millstone 2	3.98E-02	6.42E-02	8.79E-03	2.19E-02	1.31E-03	1.36E-01						4.12	2.88	7.00
Millstone 3	4.28E-02	7.27E-02	8.93E-03	2.28E-02	1.31E-03	1.49E-01						5.02	1.98	7.00
Monticello	4.72E-02	8.62E-02	9.11E-03	2.40E-02	1.32E-03	1.68E-01						6.10	0.90	7.00
Nine Mile Pt. 1	4.58E-02	8.15E-02	9.05E-03	2.36E-02	1.32E-03	1.61E-01						5.77	1.23	7.00
Nine Mile Pt. 2	4.80E-02	8.88E-02	9.14E-03	2.42E-02	1.32E-03	1.71E-01						6.27	0.73	7.00
North Anna 1	4.91E-02	9.28E-02	9.18E-03	2.45E-02	1.32E-03	1.77E-01						6.51	0.49	7.00
North Anna 2	4.78E-02	8.81E-02	9.13E-03	2.42E-02	1.32E-03	1.70E-01						6.22	0.78	7.00
Oconee 1	4.53E-02	8.00E-02	9.03E-03	2.35E-02	1.32E-03	1.59E-01						5.65	1.35	7.00
Oconee 2	4.79E-02	8.86E-02	9.13E-03	2.42E-02	1.32E-03	1.71E-01						6.26	0.74	7.00
Oconee 3	4.67E-02	8.46E-02	9.09E-03	2.39E-02	1.32E-03	1.66E-01						5.99	1.01	7.00

Table D-2. Plant-specific LOOP frequencies for shutdown operation. (continued)

Plant	Plant-Specific Mean Frequencies for Shutdown Operation (/rsy) (1997 - 2003 Data)						LOOPs During Shutdown Operation (1997 - 2003)					1997 - 2003		
	Plant Centered	Switchyard Centered	Grid Related	Severe Weather Related	Extreme Weather Related	Combined	Plant Centered	Switchyard Centered	Grid Related	Severe Weather Related	Extreme Weather Related	rcry	rsy	rcy
Oyster Creek	4.90E-02	9.24E-02	9.17E-03	2.45E-02	1.32E-03	1.76E-01						6.49	0.51	7.00
Palisades	2.26E-01	7.98E-02	9.03E-03	2.35E-02	1.32E-03	3.40E-01	2					5.64	1.36	7.00
Palo Verde 1	4.93E-02	9.35E-02	9.18E-03	2.46E-02	1.32E-03	1.78E-01						6.56	0.44	7.00
Palo Verde 2	4.81E-02	8.90E-02	9.14E-03	2.42E-02	1.32E-03	1.72E-01						6.28	0.72	7.00
Palo Verde 3	4.88E-02	9.17E-02	9.17E-03	2.44E-02	1.32E-03	1.75E-01						6.45	0.55	7.00
Peach Bottom 2	5.01E-02	9.64E-02	9.21E-03	2.47E-02	1.32E-03	1.82E-01						6.72	0.28	7.00
Peach Bottom 3	4.98E-02	9.52E-02	9.20E-03	2.47E-02	1.32E-03	1.80E-01						6.65	0.35	7.00
Perry	4.81E-02	8.91E-02	9.14E-03	2.42E-02	1.32E-03	1.72E-01						6.29	0.71	7.00
Pilgrim	4.87E-02	9.12E-02	9.16E-03	7.32E-02	1.32E-03	2.23E-01				1		6.42	0.58	7.00
Point Beach 1	4.43E-02	7.68E-02	8.99E-03	2.32E-02	1.31E-03	1.55E-01						5.39	1.61	7.00
Point Beach 2	4.43E-02	7.70E-02	8.99E-03	2.32E-02	1.31E-03	1.55E-01						5.40	1.60	7.00
Prairie Island 1	4.81E-02	8.93E-02	9.14E-03	2.43E-02	1.32E-03	1.72E-01						6.30	0.70	7.00
Prairie Island 2	4.79E-02	8.84E-02	9.13E-03	2.42E-02	1.32E-03	1.71E-01						6.25	0.75	7.00
Quad Cities 1	4.71E-02	8.58E-02	9.10E-03	2.40E-02	1.32E-03	1.67E-01						6.08	0.92	7.00
Quad Cities 2	4.55E-02	8.08E-02	9.04E-03	2.36E-02	1.32E-03	1.60E-01						5.71	1.29	7.00
River Bend	4.82E-02	8.96E-02	9.15E-03	2.43E-02	1.32E-03	1.73E-01						6.32	0.68	7.00
Robinson 2	4.96E-02	9.45E-02	9.19E-03	2.46E-02	1.32E-03	1.79E-01						6.61	0.39	7.00
Salem 1	4.38E-02	7.55E-02	8.97E-03	2.31E-02	1.31E-03	1.53E-01						5.28	1.72	7.00
Salem 2	4.54E-02	8.03E-02	9.04E-03	2.35E-02	1.32E-03	1.60E-01						5.68	1.32	7.00
San Onofre 2	4.77E-02	8.77E-02	9.13E-03	2.41E-02	1.32E-03	1.70E-01						6.20	0.80	7.00
San Onofre 3	4.70E-02	8.55E-02	9.10E-03	2.40E-02	1.32E-03	1.67E-01						6.05	0.95	7.00
Seabrook	4.71E-02	8.57E-02	9.10E-03	2.40E-02	1.32E-03	1.67E-01						6.07	0.93	7.00
Sequoyah 1	4.78E-02	8.83E-02	9.13E-03	2.42E-02	1.32E-03	1.71E-01						6.24	0.76	7.00
Sequoyah 2	4.92E-02	9.29E-02	9.18E-03	2.45E-02	1.32E-03	1.77E-01						6.52	0.48	7.00
South Texas 1	4.76E-02	8.73E-02	9.12E-03	2.41E-02	1.32E-03	1.69E-01						6.18	0.82	7.00
South Texas 2	4.81E-02	8.92E-02	9.14E-03	2.42E-02	1.32E-03	1.72E-01						6.30	0.70	7.00
St. Lucie 1	4.90E-02	9.24E-02	9.17E-03	2.45E-02	1.32E-03	1.76E-01						6.49	0.51	7.00
St. Lucie 2	4.89E-02	9.18E-02	9.17E-03	2.44E-02	1.32E-03	1.76E-01						6.46	0.54	7.00
Summer	4.74E-02	8.67E-02	9.11E-03	2.41E-02	1.32E-03	1.69E-01						6.13	0.87	7.00

Table D-2. Plant-specific LOOP frequencies for shutdown operation. (continued)

	Plant-Specific Mean Frequencies for Shutdown Operation (/rsy) (1997 - 2003 Data)						**LOOPs During Shutdown Operation (1997 - 2003)**					**1997 - 2003**		
Plant	**Plant Centered**	**Switchyard Centered**	**Grid Related**	**Severe Weather Related**	**Extreme Weather Related**	**Combined**	**Plant Centered**	**Switchyard Centered**	**Grid Related**	**Severe Weather Related**	**Extreme Weather Related**	**rcry**	**rsy**	**rcy**
Surry 1	4.78E-02	8.81E-02	9.13E-03	2.42E-02	1.32E-03	1.71E-01						6.23	0.77	7.00
Surry 2	4.85E-02	9.05E-02	9.15E-03	2.43E-02	1.32E-03	1.74E-01						6.38	0.62	7.00
Susquehanna 1	4.88E-02	9.17E-02	9.17E-03	2.44E-02	1.32E-03	1.75E-01						6.45	0.55	7.00
Susquehanna 2	4.83E-02	8.98E-02	9.15E-03	2.43E-02	1.32E-03	1.73E-01						6.34	0.66	7.00
Three Mile Isl 1	4.89E-02	9.18E-02	9.17E-03	2.44E-02	1.32E-03	1.76E-01						6.46	0.54	7.00
Turkey Point 3	4.91E-02	9.28E-02	9.18E-03	2.45E-02	1.32E-03	1.77E-01						6.51	0.49	7.00
Turkey Point 4	4.96E-02	2.84E-01	9.19E-03	2.46E-02	1.32E-03	3.69E-01		1				6.62	0.38	7.00
Vermont Yankee	4.90E-02	9.23E-02	9.17E-03	2.45E-02	1.32E-03	1.76E-01						6.49	0.51	7.00
Vogtle 1	4.89E-02	9.19E-02	9.17E-03	2.44E-02	1.32E-03	1.76E-01						6.46	0.54	7.00
Vogtle 2	4.90E-02	9.23E-02	9.17E-03	2.45E-02	1.32E-03	1.76E-01						6.49	0.51	7.00
Waterford 3	4.74E-02	8.69E-02	9.12E-03	2.41E-02	1.32E-03	1.69E-01						6.15	0.85	7.00
Watts Bar 1	4.85E-02	9.06E-02	9.16E-03	2.43E-02	1.32E-03	1.74E-01						6.38	0.62	7.00
Wolf Creek	4.86E-02	9.08E-02	9.16E-03	2.44E-02	1.32E-03	1.74E-01						6.40	0.60	7.00
Total							5	6	2	2	0	628.91	92.09	721.00
Max	2.26E-01	2.90E-01	2.74E-02	7.34E-02	1.32E-03	4.45E-01								
95%	5.01E-02	1.89E-01	9.20E-03	2.47E-02	1.32E-03	3.33E-01								
Mean	5.17E-02	9.74E-02	9.46E-03	2.50E-02	1.32E-03	1.85E-01								
50%	4.83E-02	8.97E-02	9.15E-03	2.43E-02	1.32E-03	1.73E-01								
5%	4.29E-02	7.00E-02	8.88E-03	2.24E-02	1.31E-03	1.52E-01								

Key: rcry – reactor critical year, rsy – reactor shutdown year, rcy – reactor calendar year