NUREG/CR-6890, Vol. 1
INL/EXT-05-00501, Vol. 1

Reevaluation of Station Blackout Risk at Nuclear Power Plants

Analysis of Loss of Offsite Power Events: 1986-2004

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U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, DC 20555-0001

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Manuscript Completed: November 2005
Published: December 2005

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ABSTRACT

This report is an update of previous reports analyzing loss of offsite power (LOOP) events and the associated station blackout (SBO) core damage risk at U.S. commercial nuclear power plants. LOOP data for 1986–2004 were collected and analyzed. Frequency and duration estimates for critical and shutdown operations were generated for four categories of LOOPs: plant centered, switchyard centered, grid related, and weather related. Overall, LOOP frequencies during critical operation have decreased significantly in recent years, while durations have increased. Various additional topics of interest are also addressed, including comparisons with results from other studies, seasonal impacts on LOOP frequencies, and consequential LOOPs. Finally, additional engineering analyses of the LOOP data were performed. To obtain SBO results, updated LOOP frequencies and offsite power nonrecovery curves were input into standardized plant analysis risk (SPAR) models covering the 103 operating commercial nuclear power plants. Core damage frequency results indicating contributions from SBO and other LOOP-initiated scenarios are presented for each of the 103 plants, along with plant class and industry averages. In addition, a comprehensive review of emergency diesel generator performance was performed to obtain current estimates for the SPAR models. Overall, SPAR results indicate that core damage frequencies for LOOP and SBO are lower than previous estimates. Improvements in emergency diesel generator performance contribute to this risk reduction.

Abstract

FOREWORD

The availability of alternating current (ac) electrical power is essential for the safe operation and accident recovery of commercial nuclear power plants (NPPs). Offsite power sources normally supply this essential power from the electrical grid to which the plant is connected. If the plant loses offsite power, highly reliable emergency diesel generators provide onsite ac electrical power. A total loss of ac power at an NPP as a result of complete failure of both offsite and onsite ac power sources, which rarely occurs, is referred to as a "station blackout" (SBO).

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 associated with 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, and these inputs must reflect current industry performance in order for plant risk models to accurately estimate the risk associated with LOOP-initiated scenarios.

One extremely important subset of LOOP-initiated scenarios involves SBO situations, in which the affected plant must achieve safe shutdown by relying on components that do not require ac power, such as turbine- or diesel-driven pumps. Thus, the reliability of such components, direct current (dc) battery depletion times, and characteristics of offsite power restoration are important contributors to SBO risk.

Based on concerns about SBO risk and associated reliability of emergency diesel generators, the U.S. Nuclear Regulatory Commission (NRC) established Task Action Plan (TAP) A-44 in 1980. Then, in 1988, the NRC issued the SBO rule and the associated Regulatory Guide (RG) 1.155, entitled "Station Blackout." The SBO rule requires that NPPs must have the capability to withstand an SBO and maintain core cooling for a specified duration. As a result, NPPs were required to enhance procedures and training for restoring both offsite and onsite ac power sources. Also, in order to meet the requirements of the SBO rule, some licensees chose to make NPP modifications, such as adding additional emergency ac power sources. The NRC and its licensees also increased their emphasis on establishing and maintaining high reliability of onsite emergency power sources.

On August 14, 2003, a widespread loss of the Nation's electrical power grid (blackout) resulted in LOOPs at nine U.S. commercial NPPs. As a result, the NRC initiated a comprehensive program to review grid stability and offsite power issues as they relate to NPPs. That program included updating and reevaluating LOOP frequencies and durations, as well as the associated SBO risk, to provide risk insights to guide agency actions. This report, published in three volumes, presents the results of those evaluations.

Volume 1 constitutes an update of two reports that the NRC previously published to document analyses of LOOP events at U.S. commercial NPPs. The first report, NUREG-1032, "Evaluation of Station Blackout Accidents at Nuclear Power Plants," covered events that occurred in 1968–1985 and incorporated many of the actions performed as part of TAP A-44. The second, 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 the impact that deregulation might have on LOOP frequencies and/or durations and, therefore, on nuclear plant safety.

The analyses documented in Volume 1 provide frequency estimates for NPPs at power and shutdown operations under four categories: plant-centered, switchyard-centered, grid-related, and weather-related LOOPs. For power operation, grid-related LOOPs contribute 52 percent to the total frequency of 0.036 per reactor critical year (rcry), while switchyard-centered LOOPs contribute 29 percent, weather-related LOOPs contribute 13 percent, and plant-centered LOOPs contribute 6 percent. By contrast, for shutdown operation, switchyard-centered LOOPs contribute 51 percent to the total frequency of 0.20 per reactor shutdown year, while plant-centered LOOPs contribute 26 percent.

Overall, LOOP frequencies during power operation decreased significantly over the 37 years from 1968 through 2004. The overall trend shows a statistically significant decrease through 1996, and then stabilized from 1997 through 2002. This decrease in the frequency of LOOP events is largely attributable to a decrease in the number of plant-centered and switchyard-centered events beginning in the mid-1990s. In fact, only one plant-centered event occurred during the period from 1997 through 2004. Nonetheless, the number of LOOP events in 2003 and 2004 was much higher than in previous years. Specifically, 12 LOOP events occurred in 2003, and 5 occurred in 2004.

The analyses documented in Volume 1 also indicate that, on average, LOOP events lasted longer in 1997–2004 than in 1986–1996. However, the LOOP duration data for 1986–1996 exhibited a statistically significant increasing trend over time. By contrast, no statistically significant trend exists for 1997–2004.

Volume 2 presents the current core damage risk associated with SBO scenarios at all 103 operating U.S. commercial NPPs. The results indicate an industry average SBO core damage frequency (point estimate) of about 3×10^{-6} rcry, which Volume 2 compares with historical estimates that show a decreasing trend from a high of approximately 2×10^{-5}/rcry during the period from 1980 through the present. This historical decrease in SBO core damage frequency is the result of many factors, including plant modifications in response to the SBO rule, as well as improved plant risk modeling and component performance.

Volume 2 also documents several sensitivity studies, showing that SBO core damage frequency is sensitive to emergency diesel generator performance, as expected. Degraded diesel performance and/or large increases in diesel unavailability can significantly increase SBO risk. In addition, SBO risk is significantly higher during the "summer" period (May–September), compared with the annual average result, because the LOOP frequency is significantly higher at that time, as discussed in Volume 1.

Using data from 1997 through 2004, the NRC's SBO reevaluation reveals that SBO risk was low when evaluated on an average annual basis. However, when we focus on grid-related LOOP events, the SBO risk has increased. Our current results show that the grid contributes 53 percent to the SBO core damage frequency. Severe and extreme weather events, which are generally related to grid events, contribute another 28 percent. Therefore, the increasing number of grid-related LOOP events in 2003 and 2004 is a cause for concern. Additionally, if we consider only data from the "summer" period, the SBO risk increases by approximately a factor of two.

Volume 3 lists review comments received on draft versions of Volumes 1 and 2. This final report benefited greatly from the resolution of those comments.

Overall, this study succeeded in updating the LOOP frequencies and nonrecovery probabilities, as well as evaluating the risk of SBO core damage frequency for U.S. commercial NPPs. The NRC staff has already begun to apply these results and insights, and they will continue to guide agency actions related to grid stability and offsite power issues at the Nation's NPPs.

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EXECUTIVE SUMMARY

This report, *Reevaluation of Station Blackout Risk at Nuclear Power Plants*, consists of three volumes. Volume 1 reevaluates loss of offsite power (LOOP) events from 1986 through 2004 and presents updated LOOP frequencies and associated offsite power recovery curves. Volume 2 addresses the associated station blackout (SBO) core damage risk for the 103 operating commercial nuclear power plants in the U.S. Volume 3 documents the comments received on the draft volumes and their resolution. This executive summary addresses only the LOOP-related work; the executive summary for the SBO core damage risk work is in Volume 2.

Alternating current (ac) power is essential for safe operations and accident recovery at commercial nuclear power plants. This ac power is normally supplied by offsite sources via the electrical grid. Thus, LOOP (also referred to as LOSP) and subsequent restoration of offsite power are important inputs to plant probabilistic risk assessments (PRAs). Data on LOOP and/or offsite power restoration have been analyzed in several reports, including:

- NUREG-1032, *Evaluation of Station Blackout Accidents at Nuclear Power Plants*, which evaluated LOOP data from U.S. commercial nuclear reactors from 1968 through 1985.
- NUREG/CR-5496, *Evaluation of Loss of Offsite Power Events at Nuclear Power Plants: 1980–1996*.
- NUREG/CR-5750, *Rates of Initiating Events at U.S. Nuclear Power Plants: 1987–1995*, which covered a wide variety of initiating events including LOOP.
- NUREG-1784, *Operating Experience Assessment—Effects of Grid Events on Nuclear Power Plant Performance*, which focuses on a subset of LOOP events and the effects of deregulation of the electrical industry on such events.
- EPRI reports, the latest of which is *Losses of Off-Site Power at U.S. Nuclear Power Plants–Through 2003*.

This volume analyzes data from 1986 through 2004, beginning where NUREG-1032 ended. It is patterned after NUREG/CR-5496 but extends coverage from 1997 though 2004 (NUREG/CR-5496 data end in 1996). These additional data are important because deregulation of the electrical industry, and resultant changes to electrical grid operation, began around 1997. Therefore, LOOPs before deregulation (up through 1996) and after the start of deregulation (1997 and on) were analyzed separately.

This study is a statistical and engineering analysis of LOOP frequencies and durations at commercial nuclear reactors in the U.S. 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 four LOOP event categories: plant centered, switchyard centered, grid related, and weather related. In addition, these frequencies were subdivided into results for critical and shutdown operation. Table ES-1 summarizes these results (plant-specific LOOP frequencies are presented in Appendix D). For critical operation, grid-related LOOPs contribute 52% to the total frequency of 3.6E−2 per reactor critical year (/rcry), while switchyard-centered LOOPs contribute 29%. The remaining two categories of LOOPs have frequency contributions of 13% (weather related) and 6% (plant centered). For shutdown operation, switchyard-centered LOOPs contribute 51% to the total frequency of 2.0E−1 per reactor shutdown year (/rsy), while plant-centered LOOPs contribute 26%.

Table ES-1. Plant-level LOOP frequencies.

Mode	LOOP Category	Plant-Level LOOP Frequency				
		Data Period	Events	Reactor Critical or Shutdown Years	Mean Frequency[a]	Frequency Units[b]
Critical operation	Plant centered	1997–2004	1	724.3	2.07E−03	/rcry
	Switchyard centered	1997–2004	7	724.3	1.04E−02	/rcry
	Grid related	1997–2004	13	724.3	1.86E−02	/rcry
	Weather related	1997–2004	3	724.3	4.83E−03	/rcry
	All	1997–2004	—	—	3.59E−02	/rcry
Shutdown operation	Plant centered	1986–2004	19	383.2	5.09E−02	/rsy
	Switchyard centered	1986–2004	38	383.2	1.00E−01	/rsy
	Grid related	1986–2004	3	383.2	9.13E−03	/rsy
	Weather related	1986–2004	13	383.2	3.52E−02	/rsy
	All	1986–2004	—	—	1.96E−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 ES−2 compares this study's results with those from previous studies. For critical operation, the overall LOOP frequency has decreased from 1.2E−1/rcry (NUREG-1032) to 5.8E−2/rcry (NUREG/CR-5496) to the current estimate of 3.6E−2/rcry. In addition, the relative contributions of the four categories of LOOPs have changed significantly. However, the shutdown operation overall LOOP frequency has remained essentially constant at approximately 2.0E−1/rsy.

The August 14, 2003, grid disturbance that resulted in LOOPs at nine plants is included in the frequency estimates in this report. No other event of this magnitude has occurred from 1968 through 2004. 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 in the near future, 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 2.5E−2/rcry rather than 3.6E−2/rcry.) However, if such events continue to occur, then the frequency presented in this report may be an underestimation.

LOOP duration data were also analyzed. Probabilities of exceedance versus duration are summarized in Table ES−3 for each of the four LOOP categories. As an example, there is a 0.28 probability, given a plant-centered LOOP, that the duration will be longer than 1 h. But given a grid-related LOOP, the corresponding probability is 0.61. Table ES−3 also gives the summary statistics such as the mean and median durations. The mean duration of a plant-centered LOOP is 1.7 h, and the mean duration for grid-related LOOPs is 2.4 h. The corresponding curves are presented in Figure ES−1. Statistical analyses indicated that the critical operation and shutdown operation LOOP data were similar for each LOOP category, so the duration information in Table ES−3 and Figure ES−1 is applicable to both types of operation.

Table ES−2. LOOP frequency comparison with previous reports.

Mode	LOOP Category	This Report (1986–2004) Mean Frequency	Frequency Units[a]	NUREG/CR-5750 (1987–1995) Mean Frequency	NUREG/CR-5496 (1980–1996) Mean Frequency	NUREG-1032 (1968–1985) Mean Frequency
Critical operation	Plant centered	2.07E−03	/rcry	Categories not distinguished	4.4E−02	8.7E−02
	Switchyard centered	1.04E−02	/rcry		Included in plant centered	Included in plant centered
	Grid related	1.86E−02	/rcry		2.9E−03	1.8E−02
	Weather related	4.83E−03	/rcry		1.2E−02	1.1E−02
	All	3.59E−02	/rcry	4.6E−02	5.8E−02	1.2E−01
Shutdown operation	Plant centered	5.09E−02	/rsy	Shutdown not covered	1.8E−01	Shutdown not covered
	Switchyard centered	1.00E−01	/rsy		Included in plant centered	
	Grid related	9.13E−03	/rsy		3.3E−03	
	Weather related	3.52E−02	/rsy		1.2E−02	
	All	1.96E−01	/rsy		1.9E−01	

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

Table ES−3. LOOP probability of exceedance versus duration curve fits and summary statistics.

Duration (h)	LOOP Category (Critical or Shutdown Operation) Plant Centered	Switchyard Centered	Grid Related	Weather Related	Composite[a]
0.00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
0.25	6.87E−01	7.86E−01	9.43E−01	8.64E−01	8.72E−01
0.50	4.79E−01	5.95E−01	8.25E−01	7.73E−01	7.31E−01
1.00	2.77E−01	3.78E−01	6.11E−01	6.56E−01	5.30E−01
1.50	1.83E−01	2.63E−01	4.61E−01	5.78E−01	4.03E−01
2.00	1.29E−01	1.94E−01	3.56E−01	5.20E−01	3.18E−01
2.50	9.64E−02	1.49E−01	2.81E−01	4.75E−01	2.58E−01
3.00	7.44E−02	1.18E−01	2.27E−01	4.39E−01	2.15E−01
4.00	4.77E−02	7.86E−02	1.54E−01	3.82E−01	1.57E−01
5.00	3.28E−02	5.57E−02	1.09E−01	3.40E−01	1.20E−01
6.00	2.37E−02	4.11E−02	8.05E−02	3.07E−01	9.63E−02
7.00	1.78E−02	3.14E−02	6.10E−02	2.80E−01	7.95E−02
8.00	1.37E−02	2.46E−02	4.73E−02	2.58E−01	6.72E−02
9.00	1.08E−02	1.97E−02	3.73E−02	2.39E−01	5.79E−02
10.00	8.67E−03	1.60E−02	3.00E−02	2.23E−01	5.07E−02
11.00	7.07E−03	1.32E−02	2.44E−02	2.09E−01	4.50E−02
12.00	5.85E−03	1.10E−02	2.00E−02	1.97E−01	4.04E−02

Table ES-3 (continued).

Duration (h)	LOOP Category (Critical or Shutdown Operation) Plant Centered	Switchyard Centered	Grid Related	Weather Related	Composite[a]
13.00	4.89E−03	9.31E−03	1.67E−02	1.86E−01	3.66E−02
14.00	4.13E−03	7.93E−03	1.40E−02	1.76E−01	3.34E−02
15.00	3.52E−03	6.81E−03	1.18E−02	1.67E−01	3.08E−02
16.00	3.03E−03	5.89E−03	1.01E−02	1.59E−01	2.85E−02
17.00	2.62E−03	5.13E−03	8.66E−03	1.52E−01	2.65E−02
18.00	2.28E−03	4.50E−03	7.47E−03	1.45E−01	2.48E−02
19.00	2.00E−03	3.96E−03	6.49E−03	1.39E−01	2.33E−02
20.00	1.76E−03	3.51E−03	5.66E−03	1.33E−01	2.20E−02
21.00	1.56E−03	3.12E−03	4.96E−03	1.28E−01	2.08E−02
22.00	1.38E−03	2.79E−03	4.37E−03	1.23E−01	1.97E−02
23.00	1.24E−03	2.50E−03	3.86E−03	1.19E−01	1.88E−02
24.00	1.11E−03	2.25E−03	3.42E−03	1.14E−01	1.79E−02

Lognormal Fits	Plant Centered	Switchyard Centered	Grid Related	Weather Related
p value	>0.25	>0.25	>0.25	>0.25
Mu (μ)	−0.760	−0.391	0.300	0.793
Sigma (σ)	1.287	1.256	1.064	1.982
Curve Fit 95% (h)	3.88	5.34	7.77	57.60
Curve Fit Mean (h)	1.07	1.49	2.38	15.77
Actual Data Mean (h)	1.74	1.41	2.43	14.21
Curve Fit Median (h)	0.47	0.68	1.35	2.21
Actual Data Median (h)	0.30	0.67	1.56	1.28
Curve Fit 5% (h)	0.06	0.09	0.23	0.08

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

LOOP duration results were also compared with those of previous reports. As shown in Table ES−4, LOOP durations have increased compared with results from NUREG-1032 (1968–1985), but are similar to those from NUREG/CR-5496 (1980–1996). For plant-centered and switchyard-centered LOOPs, the average duration is 1.5 h (1986–2004), compared with the NUREG-1032 result of 0.45 h (1968–1985). For grid-related LOOPs, the mean durations are 2.4 and 1.2 h, respectively. Finally, for weather related LOOPs, the mean duration for 1986–2004 is 14 h, compared with 4.6 h for 1968–1985.

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−1) multiplied by their respective frequencies. Results for all four LOOP categories can be added to obtain a single composite curve. The composite curves from the present study, NUREG/CR-5496, and NUREG-1032 are presented in Figure ES-2 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-2, the composite curve based on the current

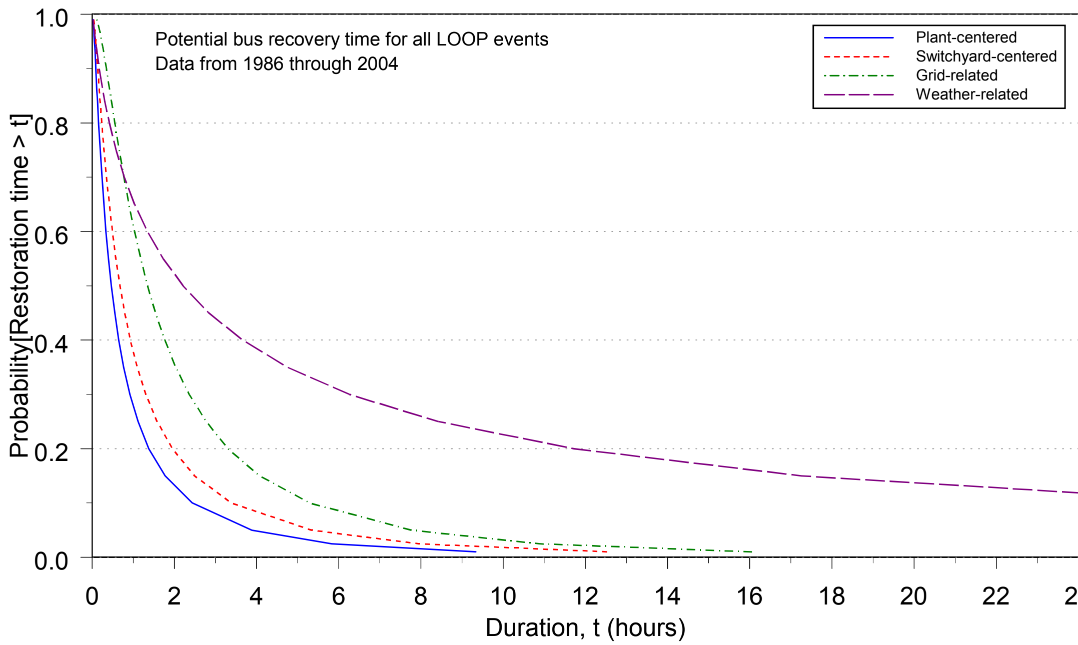


Figure ES−1. Probability of exceedance versus duration curves.

Table ES−4. LOOP duration comparison with previous studies. [a]

LOOP Category	Summary Statistic	Present Study 1986–2004	NUREG/CR-5496 1980–1996	NUREG-1032 1968–1985
Plant Centered (including switchyard centered)	Median Duration (h) (Actual Data)	0.50	0.33	0.26
	Mean Duration (h) (Actual Data)	1.52	1.22	0.45
	Type of Fit	Lognormal	Lognormal	Weibull
Grid Related	Median Duration (h) (Actual Data)	1.56	2.38	0.55
	Mean Duration (h) (Actual Data)	2.43	2.64	1.24
	Type of Fit	Lognormal	Lognormal	Weibull
Weather Related (Severe and Extreme)	Median Duration (h) (Actual Data)	1.28	1.18	4.50
	Mean Duration (h) (Actual Data)	14.2	11.8	4.64
	Type of Fit	Lognormal	Lognormal	Weibull

a. LOOP events during both critical and shutdown operation are included in these statistics.

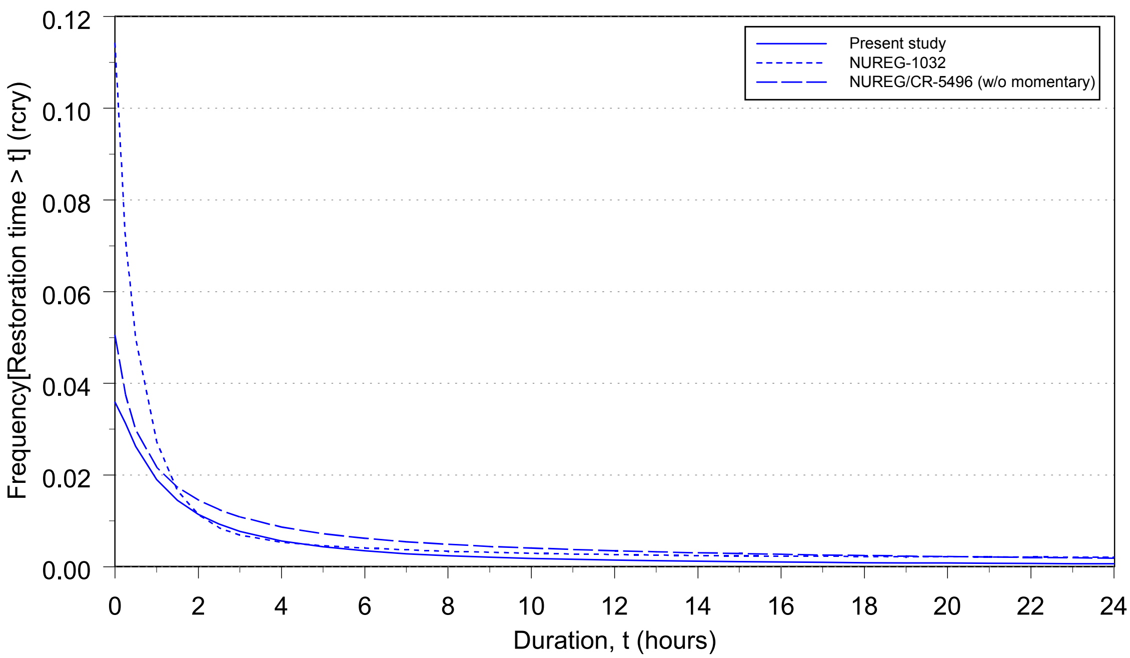


Figure ES-2. Frequency of exceedance versus duration curve comparison for critical operation.

study (representative of the period 1997–2004) lies below the NUREG/CR-5496 curve (1980–1996) and significantly below the NUREG-1032 curve (1968–1985) up to approximately 2 h. Beyond 5 h, the current study results again lie below those of the other two reports. Therefore, the increased LOOP durations (compared with 1968–1985) are mitigated by the reduction in LOOP frequency.

In addition to LOOP frequency and duration analyses, this volume addresses special topics of interest such as seasonal effects on frequencies, consequential LOOPs (events in which a reactor trip results in a 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 more than twice as high as the annual average. However, no significant seasonal effects were identified for shutdown operation.

Consequential LOOPs (LOOPs occurring because of a plant trip from other causes) were also reviewed to determine conditional probabilities of consequential LOOPs occurring, given a reactor trip. The review identified that this conditional probability has increased in recent years, from 3.0E−3 (1986–1996) to 5.3E−3 (1997–2004). In addition, this conditional probability is greater (9.1E−3) 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 6.0E−2 (plant-centered LOOPs) to a high of 8.2E−1 (grid-related LOOPs).

In summary, this volume updates estimates for LOOP frequencies for both critical and shutdown operation. In addition, LOOP duration information is presented as probability of exceedance versus duration curves. Both types of information are needed for PRA models of U.S. commercial nuclear power plants to accurately assess 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 nonsummer months).

ACKNOWLEDGMENTS

The authors acknowledge the support of Jeffrey Einerson, who prepared many of the figures for Volume 1. Corwin Atwood reviewed several drafts of Volume 1 and provided many helpful comments. For Volume 2, John Schroeder and Robert Buell updated the standardized plant analysis risk (SPAR) models used to estimate the core damage risk from loss of offsite power initiators and subsequent station blackout events. In addition, Ted Wood and Kellie Kvarfordt provided software support for the SAPHIRE code. Finally, the many comments received through the formal review process (outlined in Volume 3) led to significant improvements.

The authors express their appreciation to the following NRC staff who helped to guide this study from its start: Patrick O'Reilly, Donald Dube, Gary DeMoss, John Lane, and William Raughley (Office of Nuclear Regulatory Research) and George Morris, James Lazevnick, Gareth Parry, and Martin Stutzke (Office of Nuclear Reactor Regulation). The authors also thank Patrick Baranowsky, Nilesh Chokshi, and Michael Cheok for their support and efforts in completing this report.

Finally, the authors greatly appreciate the assistance of Myrtle Siefken, Debra Iverson, Mary Schlegel, Penny Simon, and Debbie Southwick in editing and producing this 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
INL	Idaho National Laboratory
LER	licensee event report
LOOP	loss of offsite power
LOOP-IE	loss of offsite power initiating event
LOOP-IE-C	loss of offsite power initiating event consequential
LOOP-IE-I	loss of offsite power initiating event initial
LOOP-IE-NC	loss of offsite power initiating event not consequential
LOOP-NT	loss of offsite power no trip
LOSP	loss of offsite power
MAAC	Mid-Atlantic Area Council
MAIN	Mid-America Interconnected Network
MAPP	Mid-Continent Area Power Pool
NERC	North American Electric Reliability Council
NPCC	Northeastern Power Coordinating Council
NPP	commercial nuclear power plant
PRA	probabilistic risk assessment
rcry	reactor critical year
rcy	reactor calendar year
rsy	reactor shutdown year
SBO	station blackout
SERC	Southeastern Electric Reliability Council
SPAR	standardized plant analysis risk
SPP	Southwest Power Pool
WECC	Western Electricity Coordinating Council

REEVALUATION OF STATION BLACKOUT RISK AT NUCLEAR POWER PLANTS

Analysis of Loss of Offsite Power Events: 1986–2004

1. INTRODUCTION

The availability of alternating current (ac) power is essential for safe operation and accident recovery at commercial nuclear power plants. Normally, ac power is supplied by offsite sources via the electrical grid. Loss of this offsite power can have a major negative impact on a power plant's ability to achieve and maintain safe shutdown conditions. Risk analyses performed for U.S. commercial nuclear power plants indicate that the loss of all ac power contributes over 70% of the overall risk at some plants. Clearly, loss of offsite power (LOOP, also referred to as LOSP) and subsequent restoration of offsite power are important inputs to plant probabilistic risk assessments (PRAs). These inputs must reflect current industry performance in order for PRAs to accurately estimate the risk from LOOP initiated scenarios. This volume presents the results of a LOOP study that is part of a larger Nuclear Regulatory Commission (NRC) effort to characterize the risk from LOOP initiated scenarios, including station blackout (SBO), that was undertaken following the widespread grid disturbance on August 14, 2003, which caused LOOPs at nine commercial nuclear power plants in the U.S. Results of this LOOP study—frequencies and durations for four different categories and associated insights—are inputs to the actual risk evaluations addressed in the SBO study (Volume 2 of this report).

Several studies have analyzed data on LOOP and/or offsite power restoration [1–4]; this study extends the analysis to 2004. 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. Electric Power Research Institute (EPRI) reports covering LOOP events have been issued periodically; the latest EPRI report covers LOOP events from 1994–2003 [4]. And NUREG-1784, *Operating Experience Assessment—Effects of Grid Events on Nuclear Power Plant Performance* [5], focuses on a subset of LOOP events (1985–2001) 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.

This study covers 1986–2004; i.e., the data begin where NUREG-1032 ended and extend past 1996, where NUREG/CR-5496 ended, to 2004. Including data for 1997–2004 is important because deregulation of the electrical industry, considered to start around 1997, changed operation of the electrical grid. Therefore, special attention is given in this analysis to LOOP before deregulation (up through 1996) and after the start of deregulation (1997 and later). The statistical and engineering analysis of LOOP frequencies and durations includes both critical (at power) and shutdown operations at the nuclear plants. Partial LOOP events, in which not all offsite power lines to the plant are lost or not all offsite power to safety buses is lost, are not included.

This volume is patterned after NUREG/CR-5496. Thus Section 2 addresses definitions, the categorization of types of LOOP events, and the data collection process. 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, Section 9 lists the references and Section 10 is the glossary. In addition, appendixes cover details of the LOOP event database, statistical methods, analysis results, and plant-specific LOOP frequency information.

2. LOOP CATEGORIZATION AND DATA COLLECTION

LOOP is 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 nonessential buses may also be de-energized as a result of LOOP. The impacts of a LOOP 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, challenging 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 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 via portions of safety systems that can function for a limited period of time without 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.

2.1 LOOP Categorization

In this study, the analysis of LOOP events is at the plant level, in contrast to the site level (for sites with more than one plant) or regional level. Thus, if a single weather event causes both plants at a site to experience a LOOP, then that weather event causes two plant-level LOOP events. At a regional level, if one electrical grid disturbance event impacts more than one site and results in, for example, five plant LOOP events, then that single grid disturbance contributes five plant-level LOOP events. This report uses three categorization schemes to classify LOOP events. The first, presented in Figure 2-1, classifies LOOP events according to whether the plant was shut down or operating when the LOOP occurred and the consequences of the LOOP. The three main categories of LOOPs are those that occur (1) while a plant is shut down (LOOP-SD), (2) during critical operation and involve a plant trip (LOOP-IE), and (3) during critical operation but the plant is able to continue critical operation without a plant trip (LOOP-NT). LOOP-IE events are further subdivided, following the initiating event nomenclature in NUREG/CR-5750, 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 is placed into one of the LOOP categories: LOOP-SD, LOOP-NT, LOOP-IE-I, LOOP-IE-C, or LOOP-IE-NC. This classification scheme helps determine which LOOP events should be included when determining LOOP frequency estimates, as explained in Section 3 of this report.

The second categorization scheme focuses on the cause of the LOOP, as illustrated in Figure 2-2. LOOP events can be subdivided into four types by cause or location: plant centered, switchyard centered, grid related, and 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. Weather-related events have the potential to affect areas larger than one site but typically impact a single site. In such events, restoration of offsite power often requires a longer time because of either the extent of the damage caused by the weather or the continuing effects of the weather hampering restoration efforts. Note that some weather-related events are included in the plant-centered and switchyard-centered categories. Refer to the Glossary for more information concerning category definitions. 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

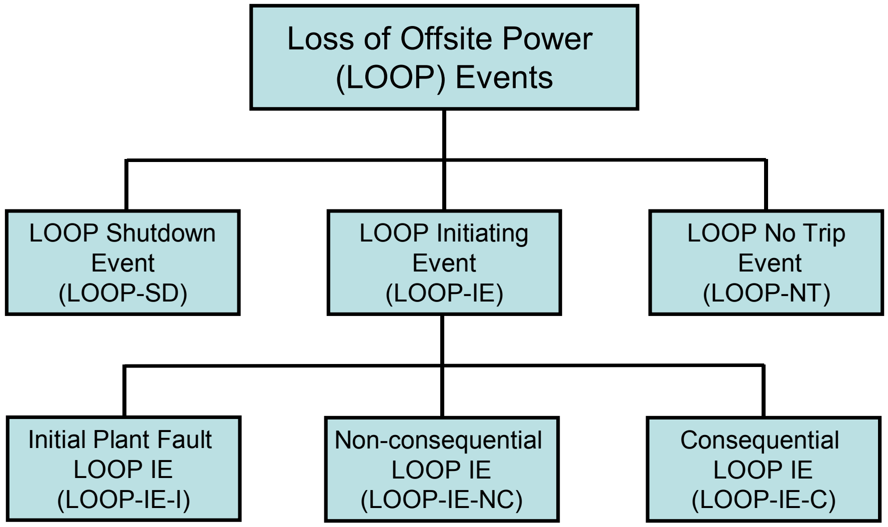


Figure 2-1. LOOP classification according to whether the plant was shut down or operating when the LOOP occurred and the consequences of the LOOP.

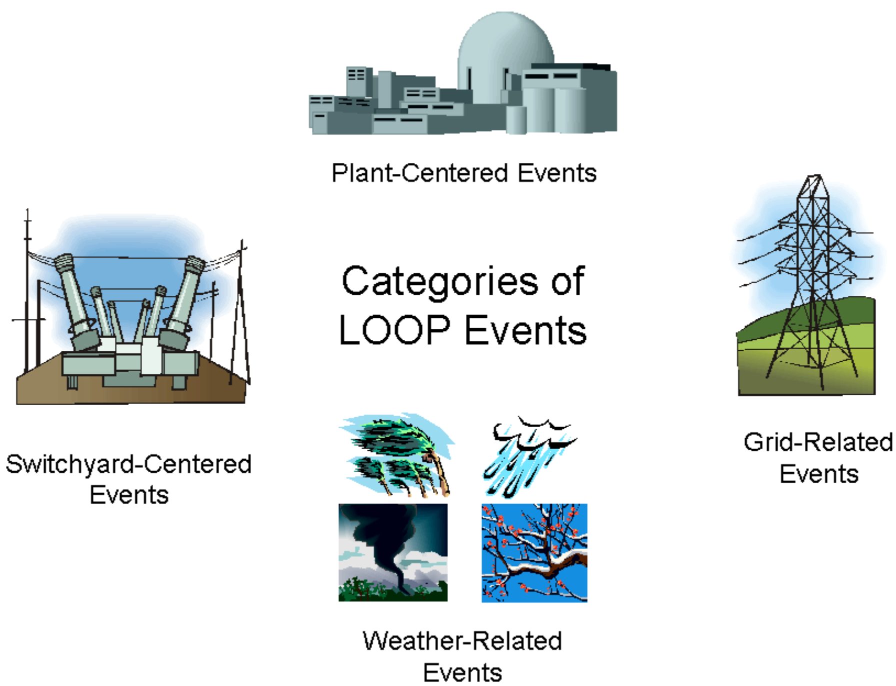


Figure 2-2. LOOP categories by cause of the LOOP.

switchyard to the safety buses). This event categorization scheme is used because offsite power restoration times and frequencies may vary among these categories.

In NUREG/CR-5496, the switchyard-centered events were included in the plant-centered category. The present report considers 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 may be different if switchyard-centered LOOPs are separated from other plant-centered LOOPs.

In NUREG-1032, four categories were used: plant centered, grid related, severe weather related, and extreme weather related. Similar to NUREG/CR-5496, the plant-centered LOOPs included the switchyard-centered LOOPs. However, NUREG-1032 subdivided the weather category into severe weather and extreme weather. Extreme weather events were defined as tornadoes or hurricanes that typically resulted in long times to restore offsite power to the plants. Over the time period covered by NUREG-1032, 1968–1985, no such extreme weather events occurred. However, since 1985, three weather LOOPs resulted in offsite power restoration times longer than 24 h. The present study includes both severe weather and extreme weather events in the single weather-related LOOP category.

The final categorization scheme used 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 2 min. Sustained LOOP events require 2 min or more to restore offsite power to at least one safety bus. Selecting 2 min as the demarcation between momentary and sustained LOOPs is arbitrary but consistent 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.

2.2 Data Collection

Collection and interpretation of LOOP data involved a three-step process: review of data from NUREG/CR-5496 (1986–1996), addition of data for 1997–2004, and review of data by licensees and NRC site inspectors. 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- and plant-centered events. In addition, offsite power restoration times were expanded to include three values (given sufficient information related to the event): switchyard restoration time, potential bus recovery 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. That effort was aided by additional information obtained from a recent 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 1997–2004. 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 LOOP database generated in the first two steps, and as part of the Temporary Instruction 2515/156, “Offsite Power System Operational Readiness” [6], NRC 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.

Loop Categorization and Data Collection

3. LOOP FREQUENCIES

Results of the statistical analyses of the LOOP occurrence data are presented in this section. Section 3.1 addresses LOOP frequency results, Section 3.2 addresses seasonal differences in the results, Section 3.3 covers time period differences, Section 3.4 looks at regional differences in frequencies, Section 3.5 discusses plant-specific LOOP frequency estimates, and Section 3.6 compares current results with those from previous studies. Appendix A lists the LOOP events included in the frequency calculations. Appendixes B and C present the details of the statistical analyses of the LOOP data. Finally, Appendix D lists plant-specific frequency estimates.

3.1 Industry-wide LOOP Frequencies

LOOP frequencies were determined for each of the four LOOP event categories: plant centered, switchyard centered, grid related, and weather related. In addition, these frequencies are subdivided into results for critical and shutdown operation. Results are summarized in Table 3-1. Frequencies in the table are plant-level, industry average results. 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 Appendixes B and C determined 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. Plant-level LOOP frequencies.

		Plant-Level LOOP Frequency				
Mode	LOOP Category	Data Period	Events	Reactor Critical or Shutdown Years	Mean Frequency[a]	Frequency Units[b]
Critical operation	Plant centered[c]	1997–2004	1	724.3	2.07E−03	/rcry
	Switchyard centered[c]	1997–2004	7	724.3	1.04E−02	/rcry
	Grid related	1997–2004	13	724.3	1.86E−02	/rcry
	Weather related	1997–2004	3	724.3	4.83E−03	/rcry
	All	1997–2004	—	—	3.59E−02	/rcry
Shutdown operation	Plant centered[d]	1986–2004	19	383.2	5.09E−02	/rsy
	Switchyard centered[d]	1986–2004	38	383.2	1.00E−01	/rsy
	Grid related	1986–2004	3	383.2	9.13E−03	/rsy
	Weather related	1986–2004	13	383.2	3.52E−02	/rsy
	All	1986–2004	—	—	1.96E−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).

c. For risk studies that combine plant-centered and switchyard-centered LOOPs, the mean frequencies should be added, resulting in 1.25E−2/rcry for the combined category.

d. For risk studies that combine plant-centered and switchyard-centered LOOPs, the mean frequencies should be added, resulting in 1.51E−1/rsy for the combined category.

Trend plots for all four LOOP event categories and all LOOPs combined during critical operation are presented in Figure 3-1 through Figure 3-5. These figures show trends over two periods, 1986–1996 and 1997–2004. For plant-centered and switchyard-centered LOOPs, industry performance has improved considerably since 1986–1996. The corresponding trend analyses indicate p-values close to 0.05, which is a typical statistical measure indicating existence of a significant trend. Therefore, the baseline period for determining industry frequencies representative of current performance is 1997–2004. 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 and 2004, as indicated in Figure 3-3. The 2003 and (perhaps 2004) data are considered potential outliers. (Future industry performance will indicate whether 2003 and 2004 are actually outliers or are the start of an increasing trend as indicated in the figure.) Again, the baseline period for grid-related LOOPs is 1997–2004, to capture this more recent industry performance. Finally, for weather-related LOOPs, Figure 3-4 indicates no significant trend over the entire period covered, 1986–2004. However, the period 1986–1996 shows no events during 1986–1992, but several during 1993–1996. The resulting analysis indicates an increasing trend that is close to being significant (a p-value of 0.1). Therefore, the baseline period used is 1997–2004 in order to capture the more recent events. Figure 3-5 presents the trend plot for all LOOPs combined. There is a downward trend that is close to being significant (p-value of 0.052) in the combined LOOPs during critical operation over the period 1986–1996. There is no significant trend over the period 1997–2002. 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). Over the entire 1997–2004 period, an increasing trend is shown, resulting from 2003 and 2004 data.

The industry mean frequency of LOOP events during critical operation (including momentary LOOPs) is 3.6E−2/reactor critical year, or 3.6E−2/rcry. This frequency is the sum of four contributions: 2.1E−3/rcry for plant-centered LOOPs (5.8%), 1.0E−2/rcry for switchyard-centered LOOPs (28.8%), 1.9E−2/rcry for grid-related LOOPs (51.9%), and 4.8E−3/rcry for weather-related LOOPs (13.5%).

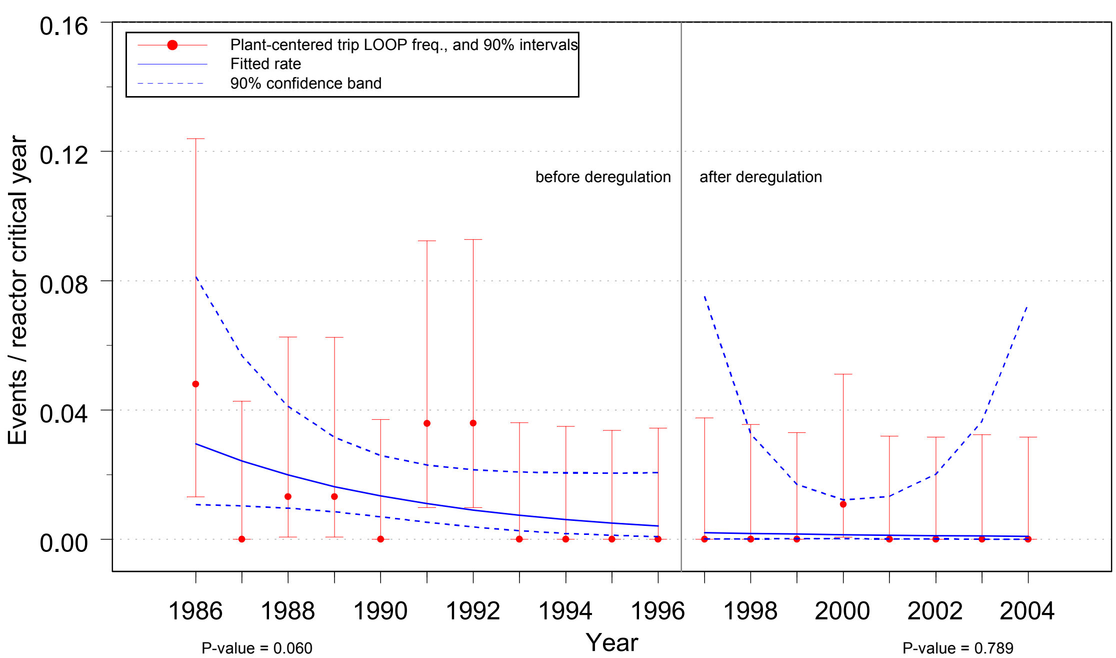


Figure 3-1. Plant-centered LOOPs: trend plot of industry performance during critical operation.

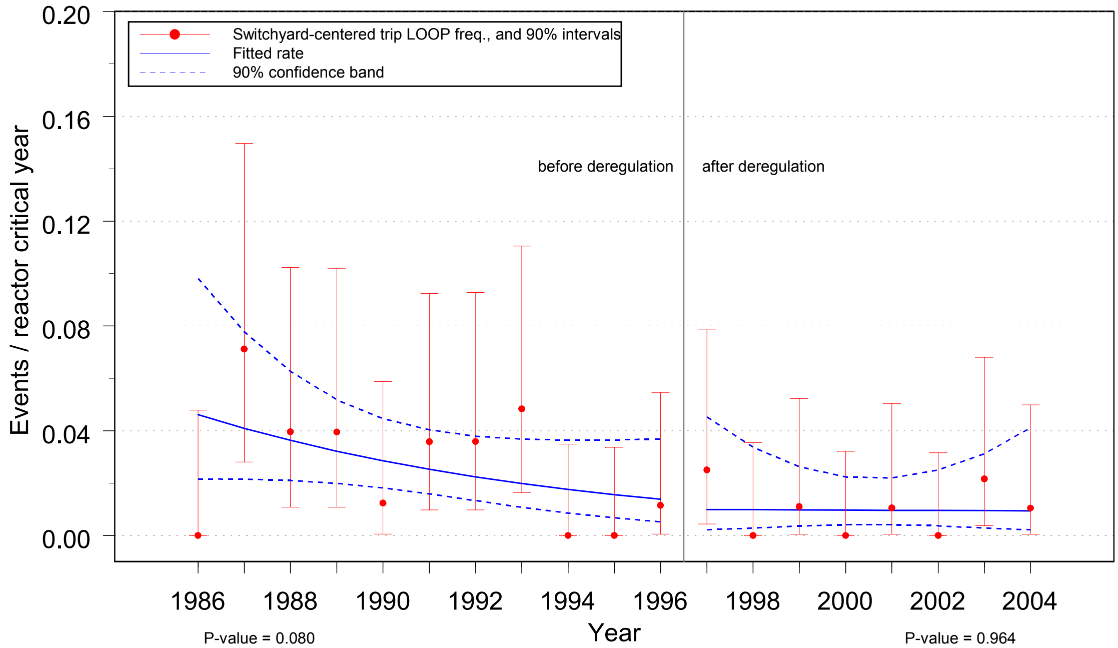
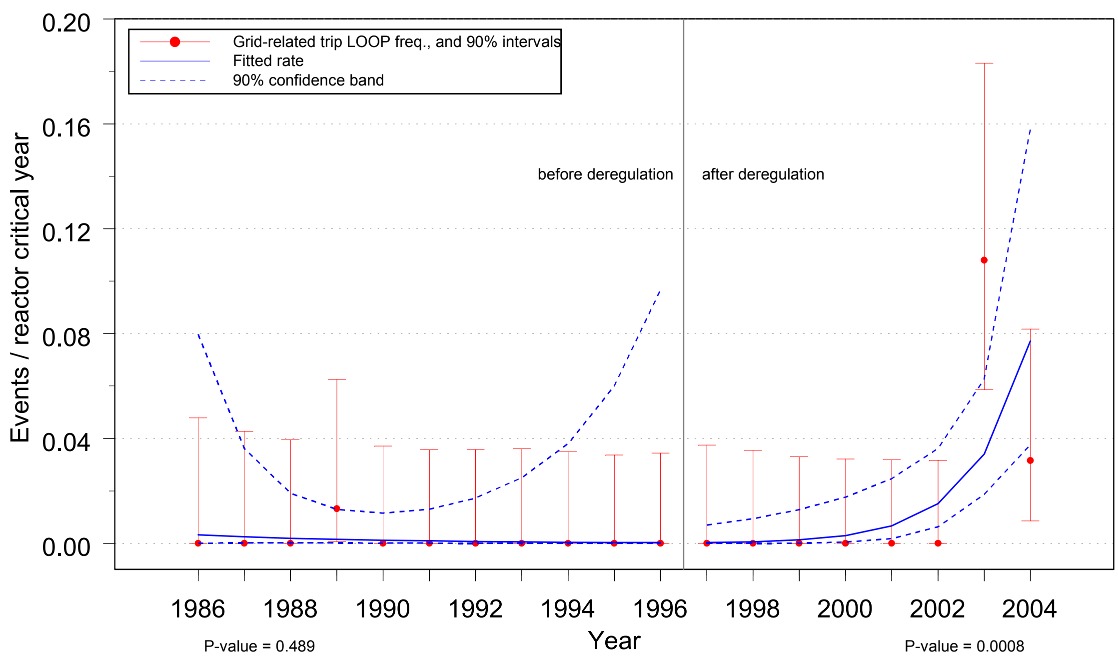


Figure 3-2. Switchyard-centered LOOPs: trend plot of industry performance during critical operation.



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

Figure 3-3. Grid-related LOOPs: trend plot of industry performance during critical operation.

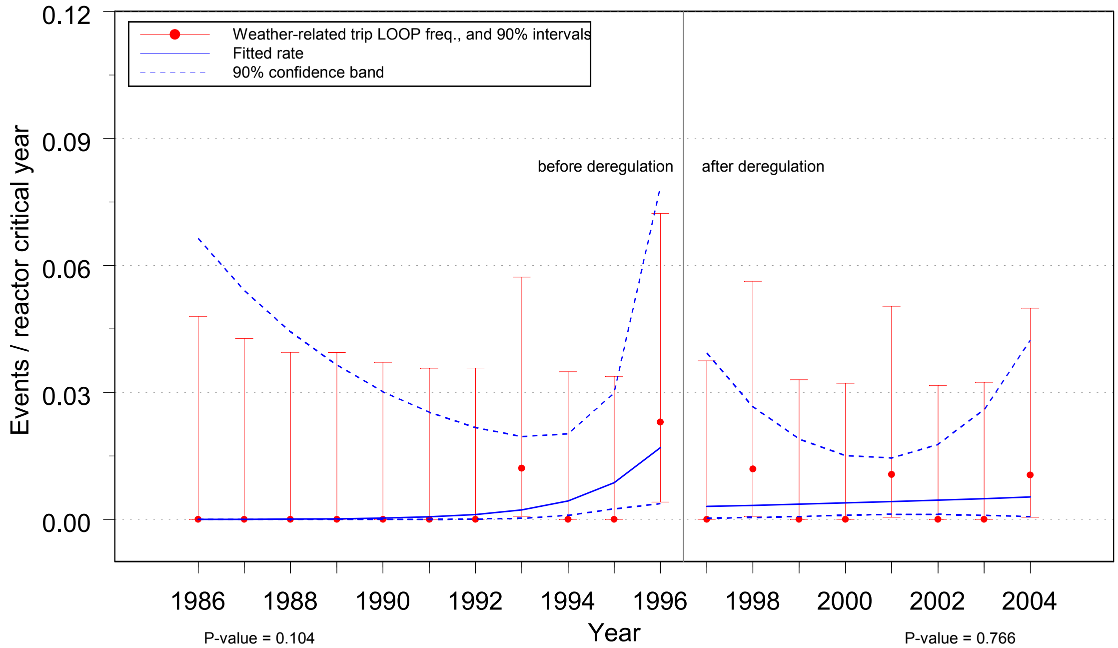
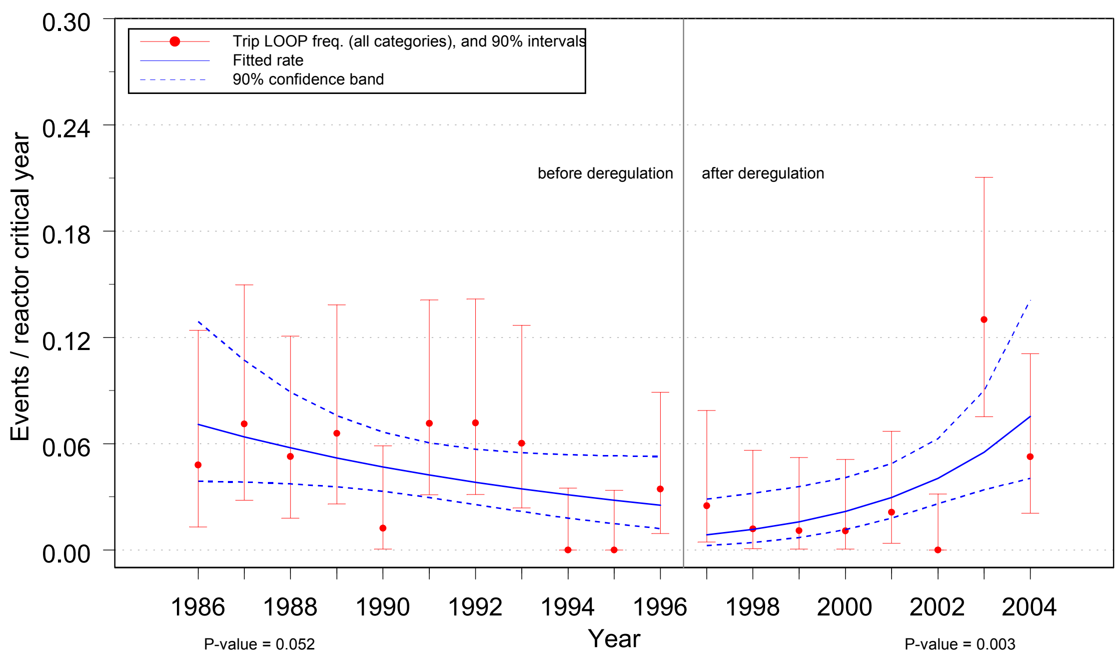


Figure 3-4. Weather-related LOOPs: trend plot of industry performance during critical operation.



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

Figure 3-5. All LOOPs combined: trend plot of industry performance during critical operation.

Similar results were obtained for shutdown operation; these results are also presented in Table 3-1. The industry mean frequency of LOOP events during shutdown (including momentary LOOPs) is 2.0E−1/reactor shutdown year, or 2.0E−1/rsy. This frequency is the sum of four contributions: 5.1E−2/rsy for plant-centered LOOPs (26.0%), 1.0E−1/rsy for switchyard-centered LOOPs (51.3%), 9.1E−3/rsy for grid-related LOOPs (4.7%), and 3.5E−2/rsy for weather-related LOOPs (18.0%). All of these LOOP frequencies for shutdown operation were obtained using the entire data period, 1986–2004. No significant trends in industry performance exist over this period.

Poisson distribution predictions of the number of LOOPs expected over the seven-year period 1997–2004 using the frequencies listed in Table 3-1 were compared with 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 1997–2004, the U.S. commercial nuclear power plants were in critical operation 87.4% of the calendar time. Therefore, this overall weighted LOOP frequency is

(0.0359/rcry)(0.874rcry/rcy) + (0.196/rsy)(0.126rsy/rcy) = 0.0561/rcy,

where

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

(0.0561/rcy)(8rcy) = 0.449.

Table 3-2. Comparison of Poisson distribution predictions with actual LOOPs for 1997–2004.

Poisson Model. Mean = (0.0359*0.874+0.196*0.126)(8 years) = 0.449/rcy

Number of Events	Probability	Prediction for 103 plants	Actual (1997–2004)	Chi-Square Statistic
0	0.6383	65.7	70	0.276
1	0.2866	29.5	27	0.215
2	0.0643	6.6	4	1.041
3	0.0096	1.0	2	1.025
4	0.0011	0.1	0	0.111
Totals	0.448	46.2	41	2.668
		P-value of Chi-Square Test		0.615

Notes:

1. The 0.615 chi-square test p-value indicates that the hypothesis of the Poisson model fitting actual LOOP data for 1997–2004 should not be rejected.

2. The Zion 1 LOOP was not included in the above analysis because it was permanently shut down early in the 1997–2004 period and is not included in the 103 plants.

3. The total number of LOOPs, 41, does not match the totals in Table 3-1 because that table includes shutdown LOOPs over 1986–2004, rather than 1997–2004.

Table 3-2. (continued).

Actual Experience			
Plant Name	Date	Mode	LOOP Category
Braidwood Unit 1	9/6/1998	Shutdown	Weather Related
Browns Ferry Unit 3	3/5/1997	Shutdown	Switchyard Centered
Brunswick Unit 1	3/3/2000	Shutdown	Switchyard Centered
Brunswick Unit 1	8/14/2004	Power Ops	Weather Related
Clinton Unit 1	1/6/1999	Shutdown	Switchyard Centered
Davis-Besse	6/24/1998	Power Ops	Weather Related
Davis-Besse	4/22/2000	Shutdown	Plant Centered
Davis-Besse	8/14/2003	Shutdown	Grid Related
Diablo Canyon Unit 1	5/15/2000	Power Ops	Plant Centered
Dresden Unit 3	5/5/2004	Power Ops	Switchyard Centered
Farley Unit 1	4/9/2000	Shutdown	Switchyard Centered
Fermi Unit 2	8/14/2003	Power Ops	Grid Related
FitzPatrick	8/14/2003	Power Ops	Grid Related
Fort Calhoun	5/20/1998	Shutdown	Switchyard Centered
Fort Calhoun	10/26/1999	Shutdown	Plant Centered
Ginna	8/14/2003	Power Ops	Grid Related
Grand Gulf	4/24/2003	Power Ops	Switchyard Centered
Indian Point Unit 2	9/1/1998	Shutdown	Plant Centered
Indian Point Unit 2	8/31/1999	Decay Heat	Switchyard Centered
Indian Point Unit 2	8/14/2003	Power Ops	Grid Related
Indian Point Unit 3	6/16/1997	Shutdown	Grid Related
Indian Point Unit 3	8/14/2003	Power Ops	Grid Related
Nine Mile Pt. Unit 1	8/14/2003	Power Ops	Grid Related
Nine Mile Pt. Unit 2	8/14/2003	Power Ops	Grid Related
Oyster Creek	8/1/1997	Power Ops	Switchyard Centered
Palisades	12/22/1998	Shutdown	Plant Centered
Palisades	3/25/2003	Shutdown	Plant Centered
Palo Verde Unit 1	6/14/2004	Power Ops	Grid Related
Palo Verde Unit 2	6/14/2004	Power Ops	Grid Related
Palo Verde Unit 3	6/14/2004	Power Ops	Grid Related
Peach Bottom Unit 2	9/15/2003	Power Ops	Grid Related
Peach Bottom Unit 3	9/15/2003	Power Ops	Grid Related
Perry	8/14/2003	Power Ops	Grid Related
Pilgrim	4/1/1997	Shutdown	Weather Related
Quad Cities Unit 2	8/2/2001	Power Ops	Switchyard Centered
Salem Unit 1	7/29/2003	Power Ops	Switchyard Centered
Seabrook	3/5/2001	Power Ops	Weather Related
St. Lucie Unit 1	9/25/2004	Shutdown	Weather Related
St. Lucie Unit 2	9/25/2004	Shutdown	Weather Related
Three Mile Isl Unit 1	6/21/1997	Power Ops	Switchyard Centered
Turkey Point Unit 4	10/21/2000	Shutdown	Switchyard Centered
Zion Unit 1	3/11/1997	Shutdown	Switchyard Centered

Given a Poisson process and 103 plants, 66 plants should experience no LOOPs over an eight-year period. The actual industry experience is 70 plants with no LOOPs over 1997–2004. Also, approximately 29 plants should experience one LOOP. Actual industry experience is 27 plants with one LOOP. Six to seven plants should experience two LOOPs, while the actual industry experience indicates four plants experienced two LOOPs. Finally, about one plant should experience three LOOPs, and the actual industry experience is two plants. Overall, the 103 plants are predicted to experience 46 LOOPs over an eight-year period, while the actual industry experience was 41 LOOPs. Results in Table 3-2 indicate that the assumption of a Poisson process for LOOPs is reasonable, even with several dependent events.

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 (α) and scale (β) parameters for the gamma distributions. For categories with limited data (nine 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 10 or more 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 Appendixes B and C for more information.) The 13 grid events during critical operation (Table 3-1) include eight resulting from a single grid disturbance on August 14, 2003, and three resulting from a single grid disturbance on June 14, 2004. 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 13 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 3.6E−2/rcry has a lower bound (5%) of 4.6E−3/rcry and an upper bound (95%) of 9.2E−2/rcry. The error factor for this gamma distribution is 3.2. For shutdown operation, the overall mean frequency of 2.0E−1/rsy has a lower bound of 4.5E−2/rsy, an upper bound of 4.3E−1/rsy, and an error factor of 2.5.

3.2 LOOP Industry Frequencies by Season

Table 3-4 presents the LOOP data (from Table 3-1) and resultant industry frequencies broken down by season. As in NUREG-1784, the summer period is defined as May–September and nonsummer as October–April. For critical operation, the summer overall LOOP frequency is 7.7E−2/rcry, while the nonsummer frequency is 9.7E−3/rcry. This large difference results from all four LOOP categories having higher summer frequencies compared with nonsummer frequencies. The switchyard-centered and grid-related LOOP categories exhibit the largest differences. Large contributors to the seasonal difference for grid-related LOOPs are the August 14, 2003, and June 14, 2004, grid disturbances. However, even if the August 14, 2003, event is removed from the data, there still is a seasonal difference for this category. Additional discussion concerning this seasonal variation in LOOP frequency is presented in Section 6.2. In contrast, the shutdown overall LOOP frequency does not vary much between seasons.

Table 3-3. Plant-level LOOP frequency distributions.

		Plant-Level LOOP Frequency Distribution[a]							
Mode	LOOP Category	5%	Median (50%)	Mean	95%	Error Factor	Gamma Shape Parameter (α)	Gamma Scale Parameter (β, years)	Source[b]
Critical operation (1997–2004)	Plant centered[c]	8.14E−06	9.42E−04	2.07E−03	7.96E−03	8.44	0.50	241.43	CNID
	Switchyard centered[c]	4.07E−05	4.71E−03	1.04E−02	3.98E−02	8.44	0.50	48.29	CNID
	Grid related	7.33E−05	8.48E−03	1.86E−02	7.16E−02	8.44	0.50	26.83	CNID
	Weather related	1.90E−05	2.20E−03	4.83E−03	1.86E−02	8.44	0.50	103.47	CNID
	All	4.57E−03	2.87E−02	3.59E−02	9.19E−02	3.21	1.58	44.02	Simulation
Shutdown operation (1986–2004)	Plant centered[d]	8.42E−05	2.00E−02	5.09E−02	2.06E−01	10.31	0.43	8.45	EB (site)
	Switchyard centered[d]	7.66E−03	7.41E−02	1.00E−01	2.83E−01	3.82	1.19	11.84	EB (site)
	Grid related	3.59E−05	4.16E−03	9.13E−03	3.51E−02	8.44	0.50	54.74	CNID
	Weather related	1.39E−04	1.60E−02	3.52E−02	1.35E−01	8.44	0.50	14.19	CNID
	All	4.48E−02	1.70E−01	1.96E−01	4.33E−01	2.54	2.50	12.77	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 4 categories simulated and fit to gamma

c. For risk studies that combine the plant-centered and switchyard-centered LOOPs, the gamma distribution has α = 0.50 and β = 40.10. The mean of this distribution is 1.25E−2/rcry.

d. For risk studies that combine the plant-centered and switchyard-centered LOOPs, the gamma distribution has α = 0.995 and β = 6.589. The mean of this distribution is 1.51E−1/rsy.

Table 3-4. Plant-level LOOP frequency seasonal variation.

Mode	LOOP Category	Summer (May–September) Events	Summer Reactor Critical or Shutdown Years[a]	Summer Mean Frequency[b]	Summer Frequency Units[c]	Nonsummer (October–April) Events	Nonsummer Reactor Critical or Shutdown Years[a]	Nonsummer Mean Frequency[b]	Nonsummer Frequency Units[c]
Critical operation (1997–2004)	Plant centered	1	312.2	4.80E−03	/rcry	0	412.1	1.21E−03	/rcry
	Switchyard centered	6	312.2	2.08E−02	/rcry	1	412.1	3.64E−03	/rcry
	Grid related	13	312.2	4.32E−02	/rcry	0	412.1	1.21E−03	/rcry
	Weather related	2	312.2	8.01E−03	/rcry	1	412.1	3.64E−03	/rcry
	All	22	—	7.68E−02	/rcry	2	—	9.70E−03	/rcry
Shutdown operation (1986–2004)	Plant centered	7	135.3	5.54E−02	/rsy	12	247.9	5.04E−02	/rsy
	Switchyard centered	12	135.3	9.24E−02	/rsy	26	247.9	1.07E−01	/rsy
	Grid related	3	135.3	2.59E−02	/rsy	0	247.9	2.02E−03	/rsy
	Weather related	5	135.3	4.07E−02	/rsy	8	247.9	3.43E−02	/rsy
	All	27	—	2.14E−01	/rsy	46	—	1.94E−01	/rsy

a. The critical and shutdown years for summer and nonsummer were obtained from a monthly breakdown of actual plant performance.

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

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

3.3 LOOP Frequency Comparison (1986–1996 versus 1997–2004)

For comparison purposes, LOOP frequencies were calculated by subdividing the entire data set into two periods: 1986–1996 and 1997–2004. Table 3-5 presents the results. For critical operation, the plant-centered and switchyard-centered LOOP frequencies dropped considerably from the older period to the more recent period. The plant-centered LOOP frequency dropped from 1.3E−2/rcry to 2.1E−3/rcry, and the switchyard-centered frequency dropped from 2.7E−2/rcry to 1.0E−2/rcry. However, the grid-related LOOP frequency increased from 1.7E−3/rcry to 1.9E−2/rcry, mainly because of the August 14, 2003, and June 14, 2004, grid disturbances. Weather-related LOOPs increased slightly, from 4.0E−3/rcry to 4.8E−3/rcry. These results support the decisions discussed in Section 3.1, where the recommended LOOP frequencies for critical operation were based on the 1997–2004 period. Finally, the overall LOOP frequency for critical operation dropped from 4.6E−2/rcry to 3.6E−2/rcry. See Appendix C for statistical analyses of the two data periods.

Table 3-5 also lists the frequency comparison for shutdown operation LOOPs. The overall LOOP frequency for both periods is approximately 2.0E−1/rsy. There are some differences in LOOP category frequencies, but none of them are statistically significant. For the recommended LOOP frequencies in Table 3-1, the entire data period 1986–2004 was used for each of the LOOP categories for shutdown operation. Again, refer to Appendix C for statistical analysis results.

3.4 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 noncoastal, and various grid-related geographical breakdowns. Appendix A presents the plant assignments with respect to each of the subgroups. Appendixes B and C present the details of the statistical analysis effort. No significant differences exist in frequencies for the various subgroups analyzed for the plant-centered and switchyard-centered LOOPs. However, differences were identified for the weather-related (for shutdown operation) and grid-related LOOPs (for critical operation), as indicated in Table 3-6.

For weather-related LOOPs, a significant subgroup in terms of distinguishing frequencies is coastal versus noncoastal (Figure 3-6). However, this significance is evident only in the shutdown operation data. (There are too few events during critical operation to distinguish coastal versus noncoastal.) Table 3-6 presents the subgroup frequencies for weather-related LOOPs during shutdown operation. For the coastal plants (including plants near the coast), the frequency for weather-related LOOPs during shutdown operation is 6.8E−2/rsy, compared with 1.0E−2/rsy for noncoastal 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.

Grid-related LOOP analysis by region included three different subdivisions (Figure 3-7 through Figure 3-9): North American Electric Reliability Council (NERC) interconnections (three regions), NERC reliability councils (10 regions), and NERC subregions (18 subregions with one not containing any commercial nuclear power plants). Empirical Bayes analyses identified the NERC reliability councils and NERC subregions 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 the August 14, 2003, grid disturbance event causing LOOPs at nine plants (eight of which

Table 3-5. Plant-level LOOP frequency comparison: 1986–1996 versus 1997–2004.

		1986–1996				1997–2004			
Mode	LOOP Category	Events	Reactor Critical or Shutdown Years	Mean Frequency[a]	Frequency Units[b]	Events	Reactor Critical or Shutdown Years	Mean Frequency[a]	Frequency Units[b]
Critical operation	Plant centered	11	877.2	1.31E−02	/rcry	1	724.3	2.07E−03	/rcry
	Switchyard centered	23	877.2	2.68E−02	/rcry	7	724.3	1.04E−02	/rcry
	Grid related	1	877.2	1.71E−03	/rcry	13	724.3	1.86E−02	/rcry
	Weather related	3	877.2	3.99E−03	/rcry	3	724.3	4.83E−03	/rcry
	All	—	—	4.56E−02	/rcry	—	—	3.59E−02	/rcry
Shutdown operation	Plant centered	14	278.5	5.21E−02	/rsy	5	104.7	5.25E−02	/rsy
	Switchyard centered	31	278.5	1.13E−01	/rsy	7	104.7	7.16E−02	/rsy
	Grid related	1	278.5	5.39E−03	/rsy	2	104.7	2.39E−02	/rsy
	Weather related	9	278.5	3.41E−02	/rsy	4	104.7	4.30E−02	/rsy
	All	—	—	2.05E−01	/rsy	—	—	1.91E−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 3-6. Plant-level LOOP frequency regional differences.

Mode	LOOP Category	Subgroup (NERC reliability council or Region)	LOOP Frequency				
			Data Period	Events	Reactor Critical or Shutdown Years	Mean Frequency[a]	Frequency Units[b]
Critical operation	Plant centered	Entire country	1997–2004	1	724.3	2.07E−03	/rcry
	Switchyard centered	Entire country	1997–2004	7	724.3	1.04E−02	/rcry
	Grid related	ECAR	1997–2004	2	48.3	3.33E−02	/rcry
		ERCOT	1997–2004	0	29.2	8.92E−03	/rcry
		FRCC	1997–2004	0	36.2	7.93E−03	/rcry
		MAAC	1997–2004	2	94.1	2.07E−02	/rcry
		MAIN	1997–2004	0	102.0	3.88E−03	/rcry
		MAPP	1997–2004	0	42.8	7.18E−03	/rcry
		NPCC	1997–2004	6	74.4	6.42E−02	/rcry
		SERC	1997–2004	0	218.4	2.04E−03	/rcry
		SPP	1997–2004	0	21.9	1.03E−02	/rcry
		WECC	1997–2004	3	57.0	4.18E−02	/rcry
	Weather related	Entire country	1992–2004	3	724.3	4.83E−03	/rcry
Shutdown operation	Plant centered	Entire country	1986–2004	19	383.2	5.09E−02	/rsy
	Switchyard centered	Entire country	1986–2004	38	383.2	1.00E−01	/rsy
	Grid related	Entire country	1986–2004	3	383.2	9.13E−03	/rsy
	Weather related	Coastal	1986–2004	11	155.6	6.77E−02	/rsy
	—	Noncoastal	1986–2004	2	227.7	1.03E−02	/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 α and β obtained from the industry results in Table 3-3). For example, for grid related, the subgroup result for critical operation is mean = (α + events)/(β + critical years). (For the constrained noninformative gamma prior, $\alpha = 0.5$ and $\beta = 26.83$.)

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

Figure 3-6. Coastal (dot with yellow center) versus noncoastal (red dot) regions. (Map based on http://www.nei.org/documents/U.S._Nuclear_Plants_Country_Wide-Map.pdf.)

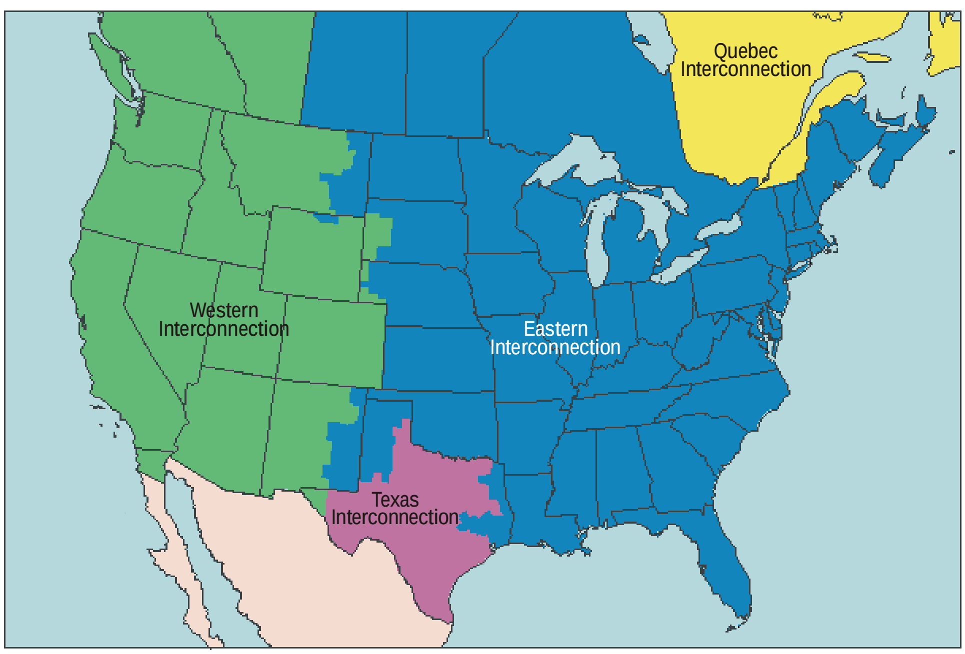


Figure 3-7. NERC reliability council interconnection regions. (Map based on http://www.nerc.com/regional/NERC_interconnections_color.jpg.)

Loop Frequencies

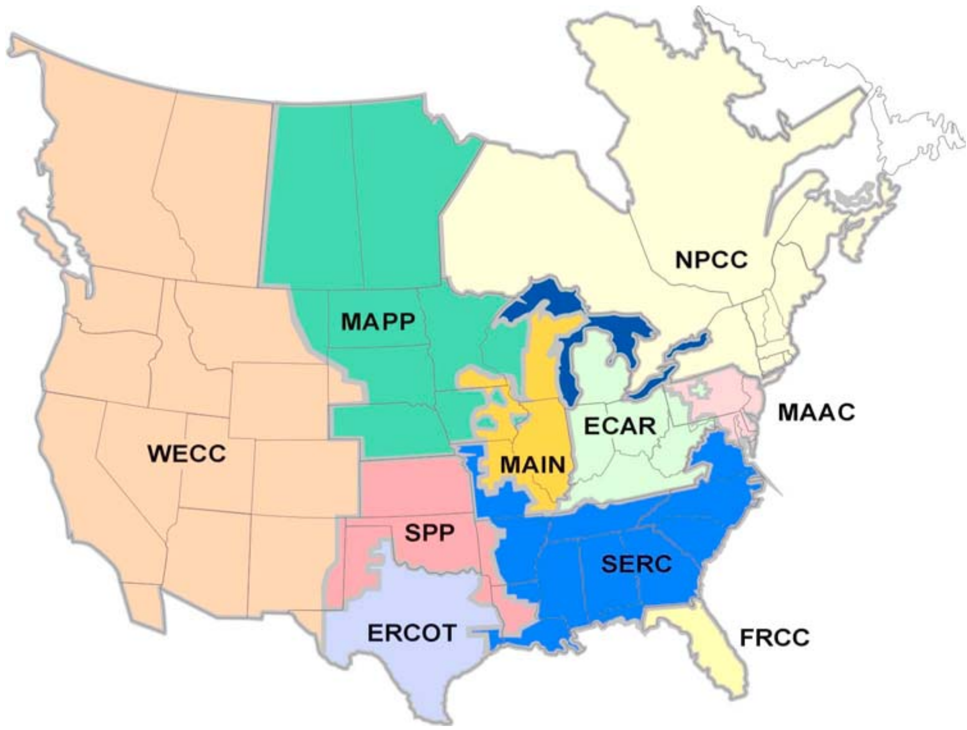


Figure 3-8. NERC reliability council regions. (Map based on http://www.nerc.com/regional/nercmapcolor.jpg.)

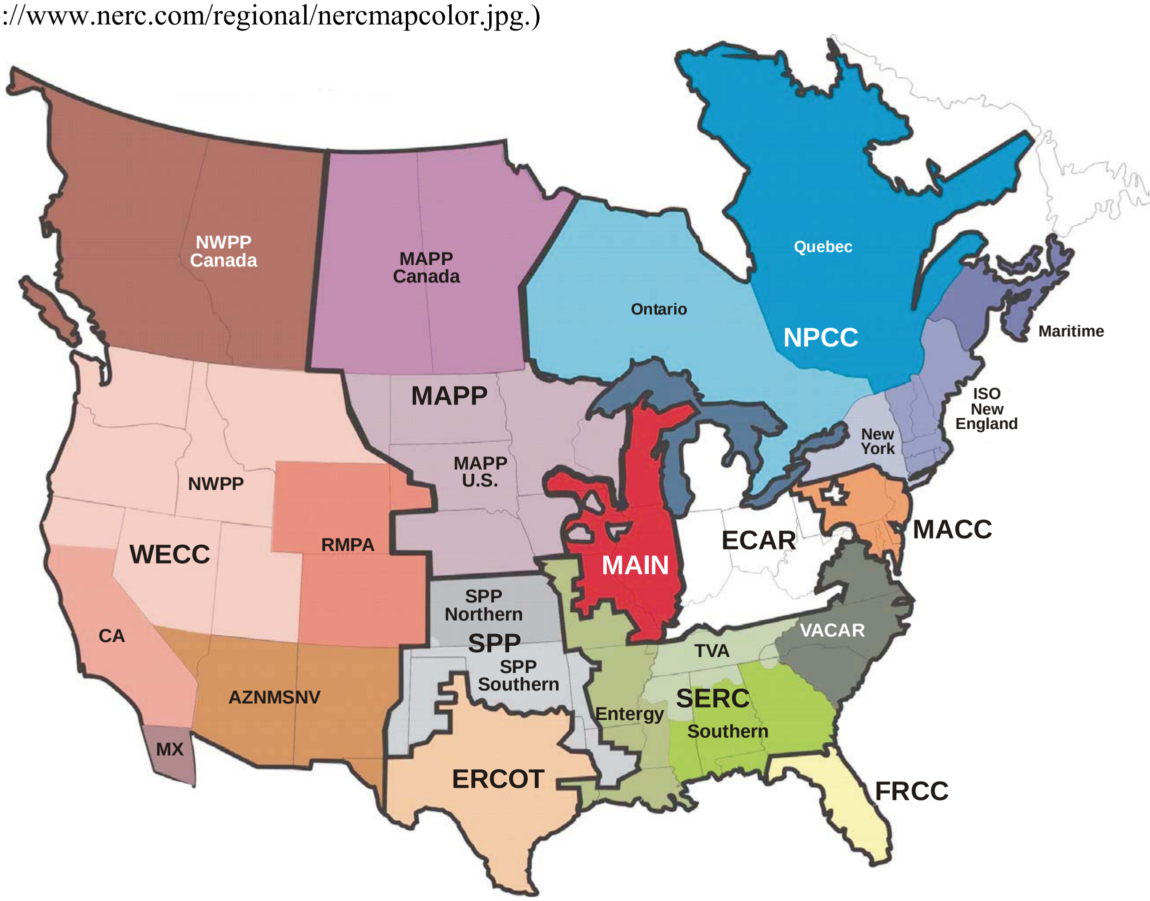


Figure 3-9. NERC subregions. (Map based on http://www.nerc.com/regional/nercmapsubregions.jpg.)

were in critical operation). The total number of grid-related events during 1997–2004 for critical operation is only 13, so this event clearly dominates. Regional results are presented in Table 3-6 for the NERC reliability councils. Grid-related frequencies for these councils range from a low of 2.0E−3/rcry for the Southeastern Electric Reliability Council (SERC) to a high of 6.4E−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.

Grid-related frequencies are not presented for the NERC subregions, which are a finer breakdown of 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.

3.5 Plant-Specific LOOP 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 3.6E−2/rcry, and for shutdown operation is 2.0E−1/rsy.

Another approach is to use the regional information in Table 3-6. (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 a plant, such as Indian Point 2, that lies within the NPCC reliability council. For critical operation, only the grid-related LOOPs exhibited a significant regional dependence, and the NPCC regional grid-related LOOP frequency is the highest of the NERC councils. The industry frequencies (Table 3-1) for plant-centered, switchyard-centered, and weather-related LOOPs are applicable to the plant. For grid-related LOOPs, the NPCC reliability council regional frequency is 6.4E−2/rcry (Table 3-6). Therefore, the overall LOOP frequency for critical operation is

2.1E−3/rcry + 1.0E−2/rcry + 6.4E−2/rcry + 4.8E−3/rcry = 8.2E−2/rcry.

This compares with the industry value of 3.6E−2/rcry. The 95% of the industry distribution is 9.2E−2/rcry (Table 3-3), so the highest regional estimate of 8.2E−2/rcry lies within the uncertainty bounds of the overall industry value.

Similarly, because Indian Point 2 is in the coastal region for weather-related LOOPs, the overall LOOP frequency for shutdown operation at Indian Point 2 is

5.1E−2/rsy + 1.0E−1/rsy + 9.1E−3/rsy + 6.8E−2/rsy = 2.3E−1/rsy.

This compares with the industry value of 2.0E−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 1997–2004 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 1997–2004 period for critical operation (5.55 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 1997–2004.) The Bayesian update for plant-centered LOOPs results in a posterior mean frequency of

(0.5 + 0)/(241.43rcry + 5.55rcry) = 2.0E−3/rcry.

Similar Bayesian updates for the other categories result in 2.8E−2/rcry for switchyard-related LOOPs, 4.6E−2/rcry for grid-related LOOPs, and 4.6E−3/rcry for weather-related LOOPs. The overall LOOP frequency for critical operation at Indian Point 2 is then 8.1E−2/rcry. This compares with the industry value of 3.6E−2/rcry and the regional approach value of 8.2E−2/rcry.

For shutdown operation, Indian Point 2 experienced one plant-centered LOOP during 1997–2004 (2.45 rsy) and no LOOPs for the other three categories. Similar Bayesian updates for each of the four LOOP categories results in an overall LOOP frequency for shutdown operation of 2.5E−1/rsy. This compares with the industry value of 2.0E−1/rsy and regional approach value of 2.3E−1/rsy.

The results for all three approaches are summarized in Table 3-7. For plant-specific analyses based on current plant performance, the third approach discussed above may be most appropriate. 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.

Table 3-7. Summary of plant-specific LOOP estimates for Indian Point 2.

		1997–2004 LOOP Data		Plant-Level LOOP Mean Frequency Estimates			
Mode	LOOP Category	Events	Reactor Critical or Shutdown Years	Industry Frequency Approach	Regional Frequency Approach	Plant-Specific Frequency Approach	Frequency Units[a]
Critical operation	Plant centered	0	5.55	2.07E−03	2.07E−03	2.02E−03	/rcry
	Switchyard centered	1	5.55	1.04E−02	1.04E−02	2.79E−02	/rcry
	Grid related	1	5.55	1.86E−02	6.42E−02	4.63E−02	/rcry
	Weather related	0	5.55	4.83E−03	4.83E−03	4.59E−03	/rcry
	All	—	—	3.59E−02	8.15E−02	8.08E−02	/rcry
Shutdown operation	Plant centered	1	2.45	5.09E−02	5.09E−02	1.31E−01	/rsy
	Switchyard centered	0	2.45	1.00E−01	1.00E−01	8.32E−02	/rsy
	Grid related	0	2.45	9.13E−03	9.13E−03	8.74E−03	/rsy
	Weather related	0	2.45	3.52E−02	6.77E−02	3.00E−02	/rsy
	All	—	—	1.96E−01	2.28E−01	2.53E−01	/rsy

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

3.6 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 3-8. 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 1.2E−2/rcry (this report). This trend is also evident 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 2.9E−3/rcry. However, the present report estimate for 1997–2004 is 1.9E−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 weather-related LOOPs indicate a recent drop in the frequency estimate, from 1.1E−2/rcry to 4.8E−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 nearly the same for both reports—1.9E−1/rsy for NUREG/CR-5496 and 2.0E−1/rsy for the present report. However, the recent data analysis indicates improvement in the combined plant-centered and switchyard-centered category but worsening in the grid-related and weather-related categories.

Table 3-8. Plant-level LOOP frequency comparison with previous studies.

		This Report				
Mode	LOOP Category	Mean Frequency	Frequency Units[a]	NUREG/CR-5750[b] Mean Frequency	NUREG/CR-5496[c] Mean Frequency	NUREG-1032[d] Mean Frequency
Critical operation	Plant centered	2.07E−03	/rcry	Categories not distinguished	4.4E−02	8.7E−02
	Switchyard centered	1.04E−02	/rcry	Categories not distinguished	Included in plant-centered category	Included in plant-centered category
	Grid related	1.86E−02	/rcry	Categories not distinguished	2.9E−03	1.8E−02
	Weather related	4.83E−03	/rcry	Categories not distinguished	1.2E−02	1.1E−02
	All	3.59E−02	/rcry	4.6E−02	5.8E−02	1.2E−01
Shutdown operation	Plant centered	5.09E−02	/rsy	Shutdown not covered	1.8E−01	Shutdown not covered
	Switchyard centered	1.00E−01	/rsy	Shutdown not covered	Included in plant-centered category	Shutdown not covered
	Grid related	9.13E−03	/rsy	Shutdown not covered	3.3E−03	Shutdown not covered
	Weather related	3.52E−02	/rsy	Shutdown not covered	1.2E−02	Shutdown not covered
	All	1.96E−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 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 weather-related LOOP frequency includes the contribution from extreme-weather-related LOOPs (2.0E−3) for the SS3 group as indicated in ORNL/NRC/LTR-89/11.

4. LOOP DURATIONS

4.1 Probability of Exceedance versus Duration Analysis

For risk analyses, it is important to know the probability that a LOOP, if one occurs, will last longer than a selected duration. The analysis described in this section provides that information. Each plant-level LOOP has three associated durations that indicate actual or potential times to restore offsite power to the switchyard or a safety bus. These durations are switchyard restoration time, potential bus recovery time, and actual bus restoration time. Potential bus recovery time is the duration from the start of the LOOP to when offsite power could have been recovered to a safety bus. 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 higher priorities related to the LOOP event. Potential bus recovery 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). For purposes of risk analysis, the potential bus recovery times are most appropriate. Section 6.7 presents more details concerning the estimation of the potential bus recovery time, and Appendix A lists LOOP events and their associated durations.

The probability of exceedance versus LOOP duration analysis involves examining 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 2 h to recover offsite power, given that the LOOP was plant centered? Similar to the approach used in NUREG-1032 and NUREG/CR-5496, this 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 weather-related event resulted in a LOOP at both plants at a two-plant site, then this was considered a single piece of information for weather-related LOOP durations. In this example, the restoration times (switchyard, potential bus, and actual bus) for this weather-related event are averages of the two individual plant entries. Two events 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 recovery times were 102 min for both units. At the Nine Mile Point 1 and Fitzpatrick site (considered one site in this report), the potential bus recovery times were 110 and 174 min, respectively. Other sites (with only one plant) had potential bus recovery times ranging from 54 to 657 min. Therefore, the differences in potential recovery 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. Appendix A presents LOOP duration data aggregated at the site level.

For risk analyses, the probability of not recovering offsite power to a safety bus at various times following initiation of the LOOP is needed. Curves of probability of exceedance versus duration summarize this information. These curves are generated by first fitting the potential bus recovery times for a given LOOP category to a density function (e.g., lognormal). 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.

Probability of exceedance versus duration curves were generated for each of the four LOOP categories: plant centered, switchyard centered, grid related, and weather related. No significant differences exist between the critical operation and shutdown operation data within the distinct LOOP categories, so curves were generated combining both types of data. In addition, no significant differences exist within each LOOP category between the 1986–1996 and 1997–2004 data periods, so the entire 1986–2004 period is applicable. (See Section 4.2 for a discussion of trends in LOOP durations over the period 1986–2004. Combining the individual LOOP category data, a statistically significant increasing trend in durations exists over the period 1986–1996.) Both lognormal and Weibull curve fits were generated. In almost all cases, the lognormal curve fit the data better. Therefore, this study chose to use the lognormal curves. Details of the statistical analyses are presented in Appendixes B and C.

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

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

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

where

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

The definitions of the lognormal μ and σ parameters in Equations 1 and 2 are those found in Microsoft® Excel and the curve fitting software described in Appendix B.

Results of the lognormal curve fits to the potential bus recovery times are summarized in Table 4-1. The corresponding probability of exceedance versus duration curves are presented in Figure 4-1 through Figure 4-6. Figure 4-1 through Figure 4-4 present the probability of exceedance curves for the four LOOP event categories. The lognormal curve fits are shown, along with the 5% and 95% uncertainty ranges. Uncertainty parameters associated with the lognormal curve fit parameters are presented in Table 4-2. Details of the uncertainty analysis are presented in Appendixes B and C. Also shown in these figures are the actual data, to show how well the lognormal curves fit the data. All four figures indicate that the lognormal curves fit the actual data well. However, even with such good fits, Table 4-1 indicates that it can be difficult to match both the median and mean for a given LOOP category. The switchyard-centered and grid-related curve fits match both median and mean fairly well. However, the plant-centered curve mean is 1.1 h, while the actual data mean is 1.7 h. In addition, the weather-related curve median is 2.2 h, while the actual data median is 1.3 h.

Figure 4-5 presents all four probabilities of exceedance curves in one graph for comparison purposes. The plant-centered and switchyard-centered LOOPs result in the lowest probabilities of exceedance versus duration. Grid-related LOOPs have higher probabilities of exceedance up to 14 h. Finally, the weather-related LOOPs result in the highest probabilities of exceedance except for the first hour.

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

	LOOP Category (Critical or Shutdown Operation)					Critical Operation		Shutdown Operation	
Duration (h)	Plant Centered	Switchyard Centered	Grid Related	Weather Related	Combined Plant and Switchyard Centered[a]	Composite[b]	Actual Data	Composite[b]	Actual Data
0.00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
0.25	6.87E−01	7.86E−01	9.43E−01	8.64E−01	7.53E−01	8.72E−01	8.52E−01	7.82E−01	7.31E−01
0.50	4.79E−01	5.95E−01	8.25E−01	7.73E−01	5.56E−01	7.31E−01	6.48E−01	6.08E−01	4.63E−01
1.00	2.77E−01	3.78E−01	6.11E−01	6.56E−01	3.44E−01	5.30E−01	4.63E−01	4.13E−01	2.99E−01
1.50	1.83E−01	2.63E−01	4.61E−01	5.78E−01	2.36E−01	4.03E−01	3.89E−01	3.08E−01	2.09E−01
2.00	1.29E−01	1.94E−01	3.56E−01	5.20E−01	1.73E−01	3.18E−01	2.22E−01	2.44E−01	1.79E−01
2.50	9.64E−02	1.49E−01	2.81E−01	4.75E−01	1.32E−01	2.58E−01	1.85E−01	2.00E−01	1.64E−01
3.00	7.44E−02	1.18E−01	2.27E−01	4.39E−01	1.04E−01	2.15E−01	1.48E−01	1.69E−01	1.49E−01
4.00	4.77E−02	7.86E−02	1.54E−01	3.82E−01	6.87E−02	1.57E−01	1.30E−01	1.29E−01	1.34E−01
5.00	3.28E−02	5.57E−02	1.09E−01	3.40E−01	4.85E−02	1.20E−01	9.30E−02	1.04E−01	9.00E−02
6.00	2.37E−02	4.11E−02	8.05E−02	3.07E−01	3.57E−02	9.63E−02	5.60E−02	8.64E−02	9.00E−02
7.00	1.78E−02	3.14E−02	6.10E−02	2.80E−01	2.72E−02	7.95E−02	5.60E−02	7.42E−02	9.00E−02
8.00	1.37E−02	2.46E−02	4.73E−02	2.58E−01	2.13E−02	6.72E−02	3.70E−02	6.49E−02	9.00E−02
9.00	1.08E−02	1.97E−02	3.73E−02	2.39E−01	1.70E−02	5.79E−02	3.70E−02	5.78E−02	7.50E−02
10.00	8.67E−03	1.60E−02	3.00E−02	2.23E−01	1.38E−02	5.07E−02	3.70E−02	5.21E−02	7.50E−02
11.00	7.07E−03	1.32E−02	2.44E−02	2.09E−01	1.14E−02	4.50E−02	3.70E−02	4.75E−02	6.00E−02
12.00	5.85E−03	1.10E−02	2.00E−02	1.97E−01	9.51E−03	4.04E−02	3.70E−02	4.36E−02	4.50E−02
13.00	4.89E−03	9.31E−03	1.67E−02	1.86E−01	8.03E−03	3.66E−02	3.70E−02	4.03E−02	4.50E−02
14.00	4.13E−03	7.93E−03	1.40E−02	1.76E−01	6.84E−03	3.34E−02	3.70E−02	3.75E−02	4.50E−02
15.00	3.52E−03	6.81E−03	1.18E−02	1.67E−01	5.87E−03	3.08E−02	3.70E−02	3.51E−02	4.50E−02
16.00	3.03E−03	5.89E−03	1.01E−02	1.59E−01	5.08E−03	2.85E−02	3.70E−02	3.30E−02	4.50E−02
17.00	2.62E−03	5.13E−03	8.66E−03	1.52E−01	4.43E−03	2.65E−02	3.70E−02	3.11E−02	3.00E−02
18.00	2.28E−03	4.50E−03	7.47E−03	1.45E−01	3.88E−03	2.48E−02	3.70E−02	2.94E−02	3.00E−02

Table 4-1. (continued)

	LOOP Category (Critical or Shutdown Operation)					Critical Operation		Shutdown Operation	
Duration (h)	Plant Centered	Switchyard Centered	Grid Related	Weather Related	Combined Plant and Switchyard Centered[a]	Composite[b]	Actual Data	Composite[b]	Actual Data
19.00	2.00E−03	3.96E−03	6.49E−03	1.39E−01	3.42E−03	2.33E−02	3.70E−02	2.79E−02	3.00E−02
20.00	1.76E−03	3.51E−03	5.66E−03	1.33E−01	3.03E−03	2.20E−02	3.70E−02	2.66E−02	1.50E−02
21.00	1.56E−03	3.12E−03	4.96E−03	1.28E−01	2.69E−03	2.08E−02	3.70E−02	2.53E−02	1.50E−02
22.00	1.38E−03	2.79E−03	4.37E−03	1.23E−01	2.41E−03	1.97E−02	3.70E−02	2.42E−02	1.50E−02
23.00	1.24E−03	2.50E−03	3.86E−03	1.19E−01	2.16E−03	1.88E−02	3.70E−02	2.32E−02	1.50E−02
24.00	1.11E−03	2.25E−03	3.42E−03	1.14E−01	1.94E−03	1.79E−02	1.90E−02	2.22E−02	1.50E−02

Lognormal Fits[c]

	Plant Centered	Switchyard Centered	Grid Related	Weather Related	Combined Plant and Switchyard Centered[a]
p-value	>0.25	>0.25	>0.25	>0.25	>0.25
Mu (μ)	−0.760	−0.391	0.300	0.793	−0.512
Sigma (σ)	1.287	1.256	1.064	1.982	1.278
Curve Fit 95% (h)	3.88	5.34	7.77	57.60	4.90
Curve Fit Mean (h)	1.07	1.49	2.38	15.77	1.36
Actual Data Mean (h)	1.74	1.41	2.43	14.21	1.52
Curve Fit Median (h)	0.47	0.68	1.35	2.21	0.60
Actual Data Median (h)	0.30	0.67	1.56	1.28	0.50
Curve Fit 5% (h)	0.06	0.09	0.23	0.08	0.07
Error Factor (95%/median)	8.31	7.89	5.76	26.07	8.19

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

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

c. The LaCrosse and two Pilgrim events were excluded from these analyses. See Appendix A, Table A-1 for more information.

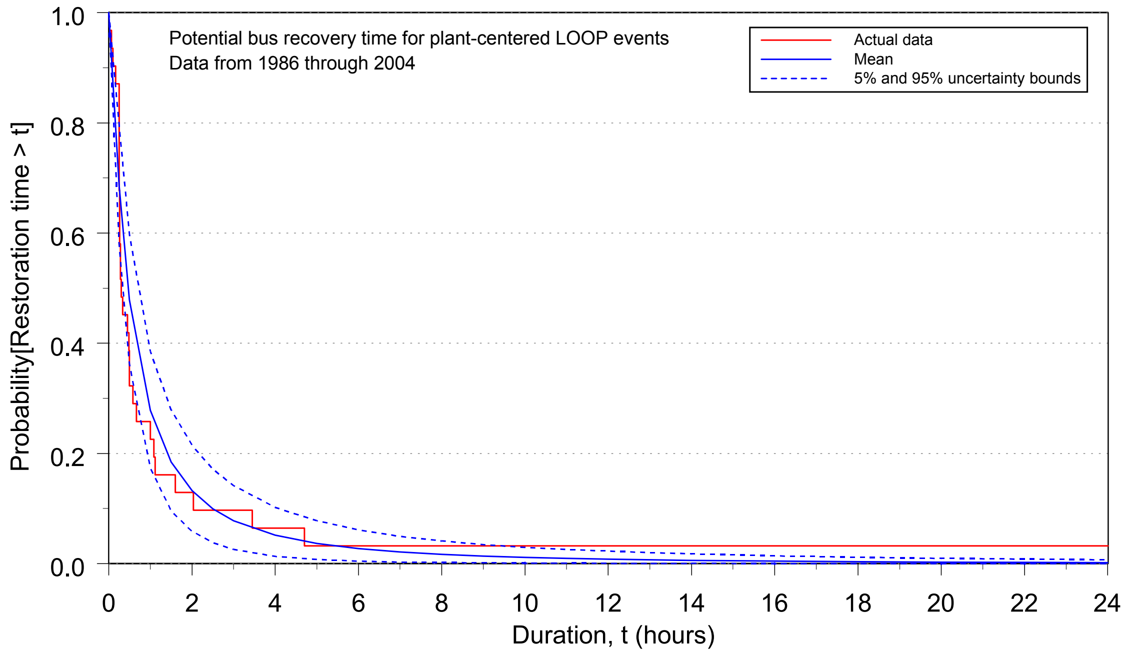


Figure 4-1. Plant-centered LOOPs: probability of exceedance versus duration for critical and shutdown operation.

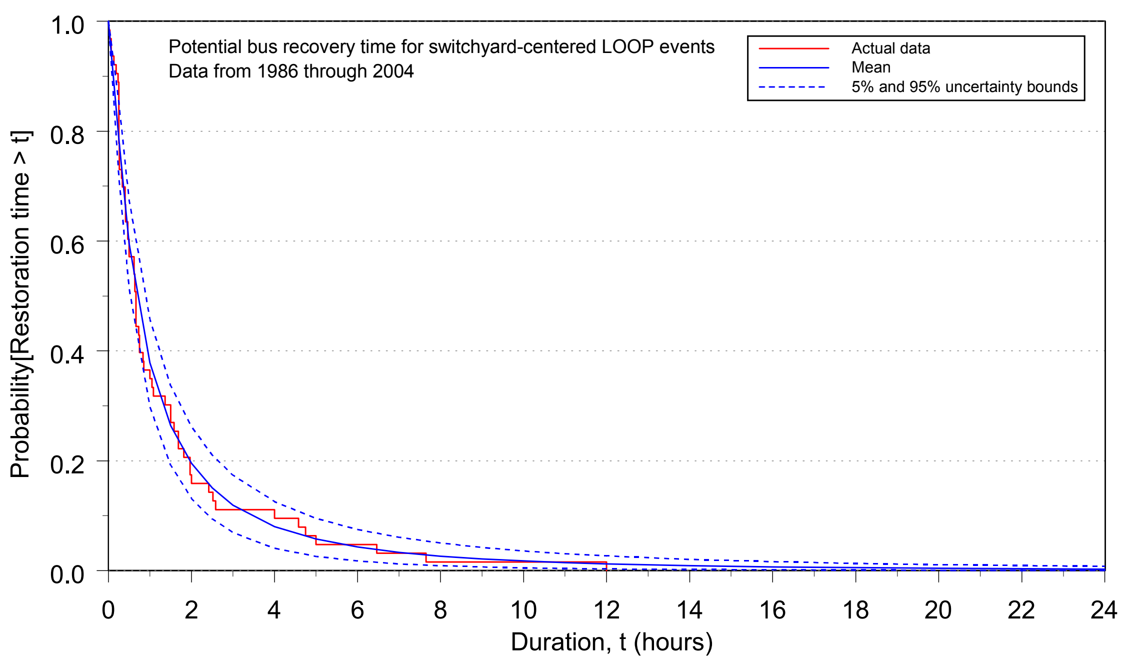


Figure 4-2. Switchyard-centered LOOPs: probability of exceedance versus duration for critical and shutdown operation.

Loop Durations

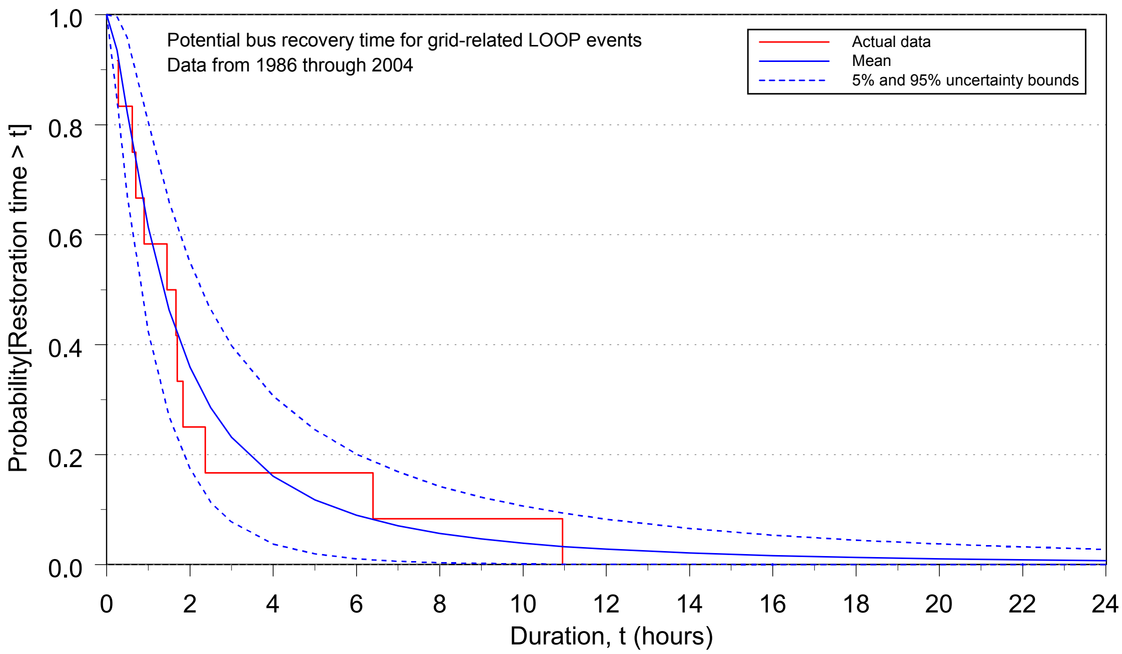


Figure 4-3. Grid-related LOOPs: probability of exceedance versus duration for critical and shutdown operation.

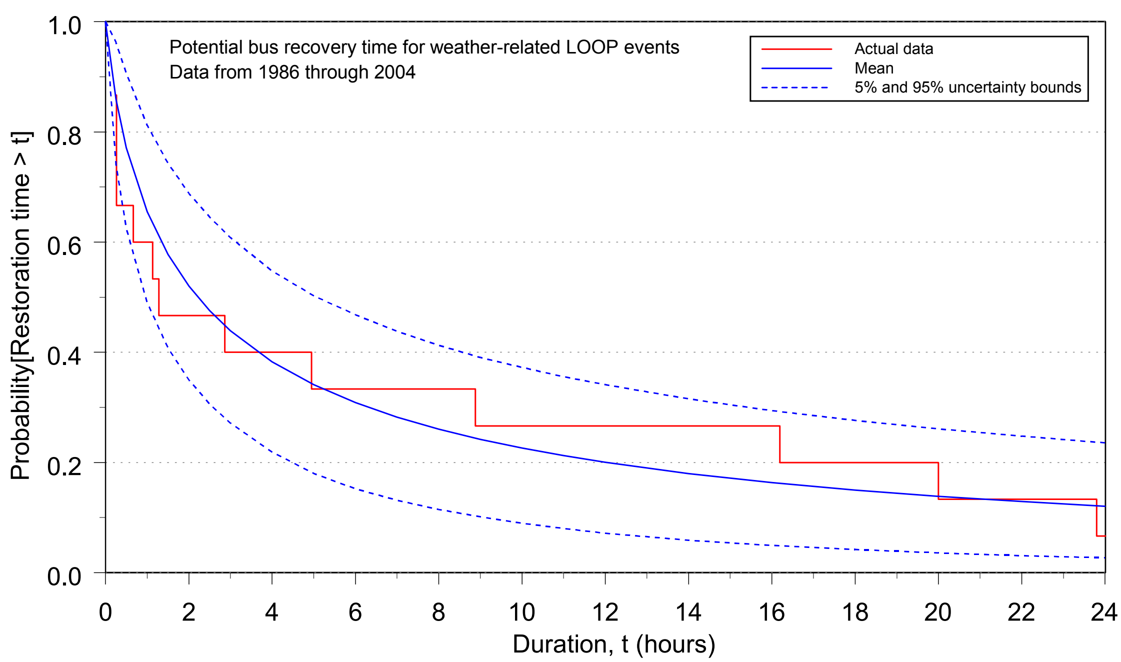


Figure 4-4. Weather-related LOOPs: probability of exceedance versus duration for critical and shutdown operation.

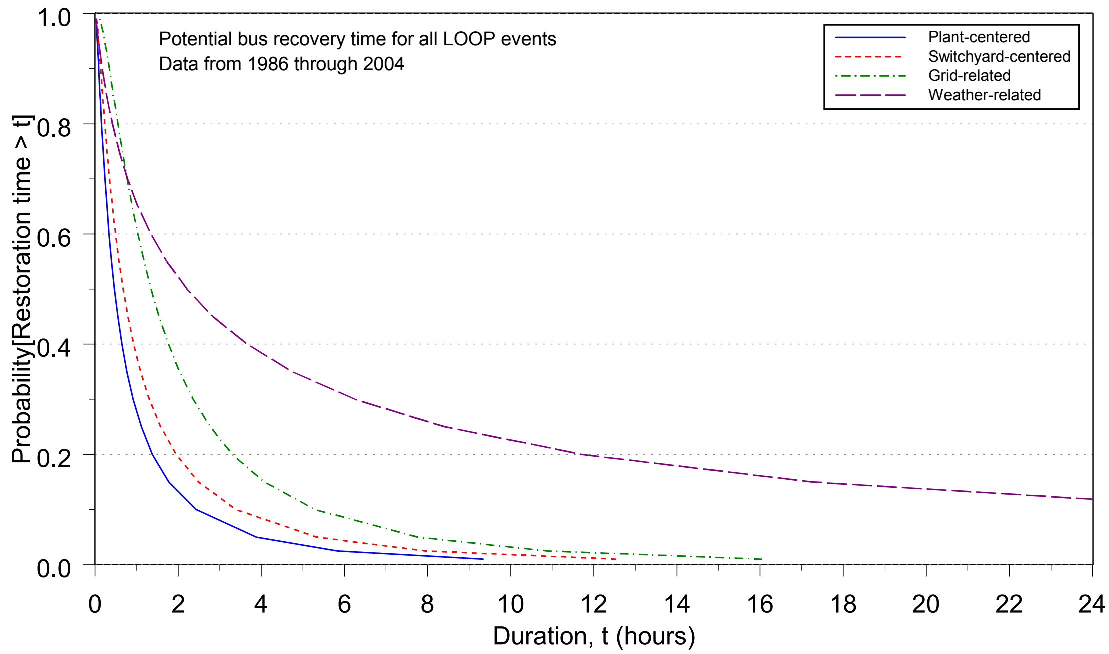


Figure 4-5. Summary of probability of exceedance versus duration curves for critical and shutdown operation.

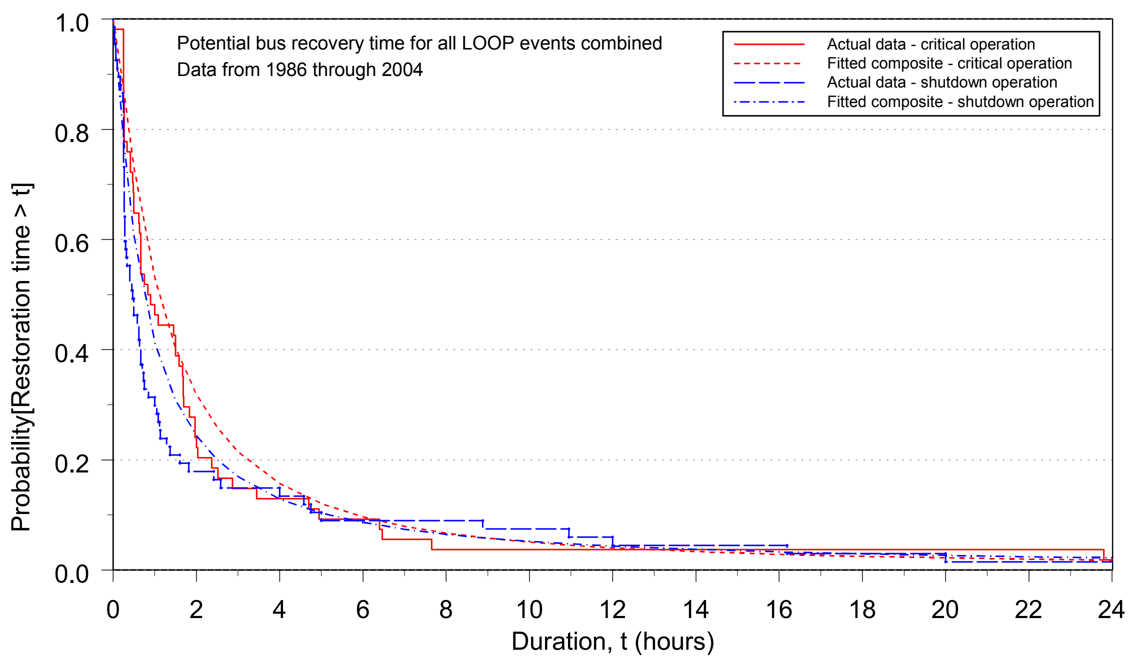


Figure 4-6. Probability of exceedance versus duration composite for all LOOPs.

Table 4-2. Probability of exceedance curve fit uncertainty parameters for critical and shutdown operation.

LOOP Category	Curve Fit Parameter	Curve Fit Parameter Mean	Underlying Distribution for Curve Fit Parameter	Mean[a]	Error Factor[a]
Plant Centered	Median	0.468	Lognormal	0.468	1.463
	Error Factor	8.306	Lognormal	8.306	1.556
Switchyard Centered	Median	0.677	Lognormal	0.677	1.297
	Error Factor	7.895	Lognormal	7.895	1. 354
Grid Related	Median	1.350	Lognormal	1.350	1.658
	Error Factor	5.759	Lognormal	5.759	1.800
Weather Related	Median	2.211	Lognormal	2.211	2.321
	Error Factor	26.071	Lognormal	26.071	2.662

a. To perform an uncertainty analysis, the lognormal distributions are first sampled to obtain values for the curve fit parameters, which are then used to determine a sample estimate for the nonrecovery probability.

The composite probability of exceedance curves summarized in Table 4-1 and illustrated in Figure 4-6 for critical operation and shutdown operation are frequency-weighted averages of the four individual category curves. Although the individual LOOP 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 4-7 through Figure 4-10 show, for each LOOP category, the probability of exceedance curves based on switchyard, potential bus, and actual bus restoration times. The potential bus curves generally lie between those for the switchyard and actual bus curves and typically are closer to the switchyard curves. Cases where the potential bus recovery curve drops below the switchyard restoration curve do not reflect reality; the potential bus recovery time is always greater than or equal to the switchyard restoration time. Figure 4-1 through Figure 4-4 indicate that the lognormal fits for the potential bus recovery times are very good, so the cases where the two curves intersect are mainly the result of poorer fits for the switchyard restoration times. Switchyard curves do not start at 1.0 at the left of each figure because some LOOPs do not result in loss of offsite power to the switchyard.

4.2 Trending of LOOP Durations

As discussed in Section 4.1, LOOP duration data for critical and shutdown operation over the entire period 1986–2004 were used to generate probability of exceedance versus duration curves for each of the four LOOP categories. Statistical analyses indicated that within each category, there was not a statistically significant difference between the 1986–1996 data and the 1997–2004 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 1997–2004 duration data do not exhibit a significant trend. The results of this trending analysis are presented in Figure 4-11. Finally, if the entire period 1986–2004 is considered, there is no statistically significant trend in LOOP durations.

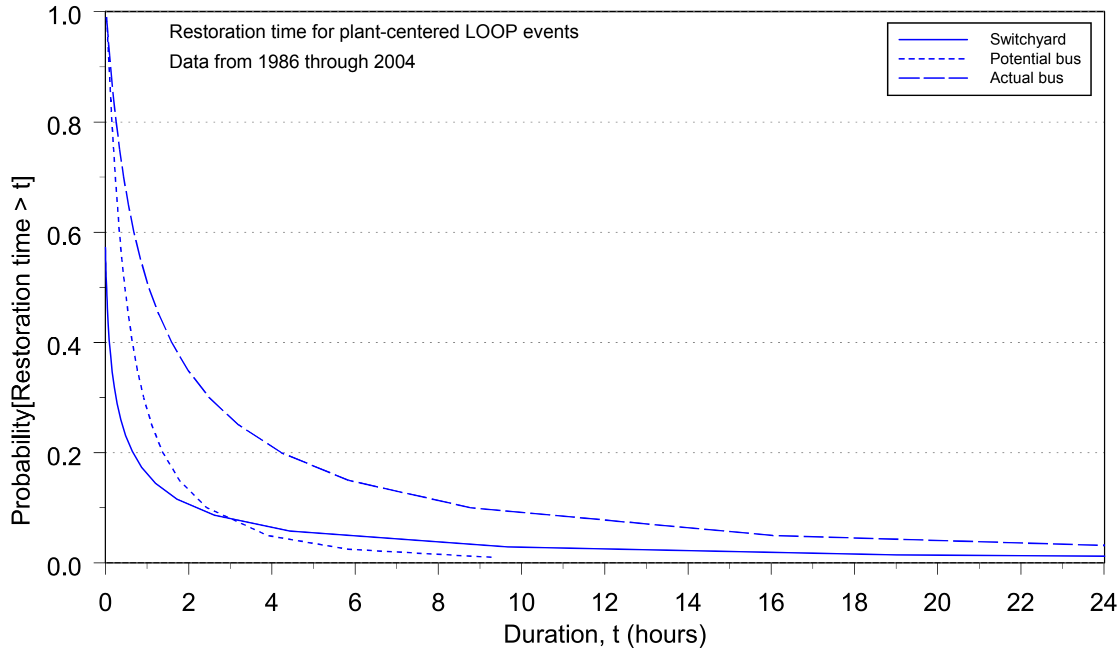


Figure 4-7. Plant-centered LOOPs: probability of exceedance versus duration for switchyard, potential bus, and actual bus restoration for critical and shutdown operation.

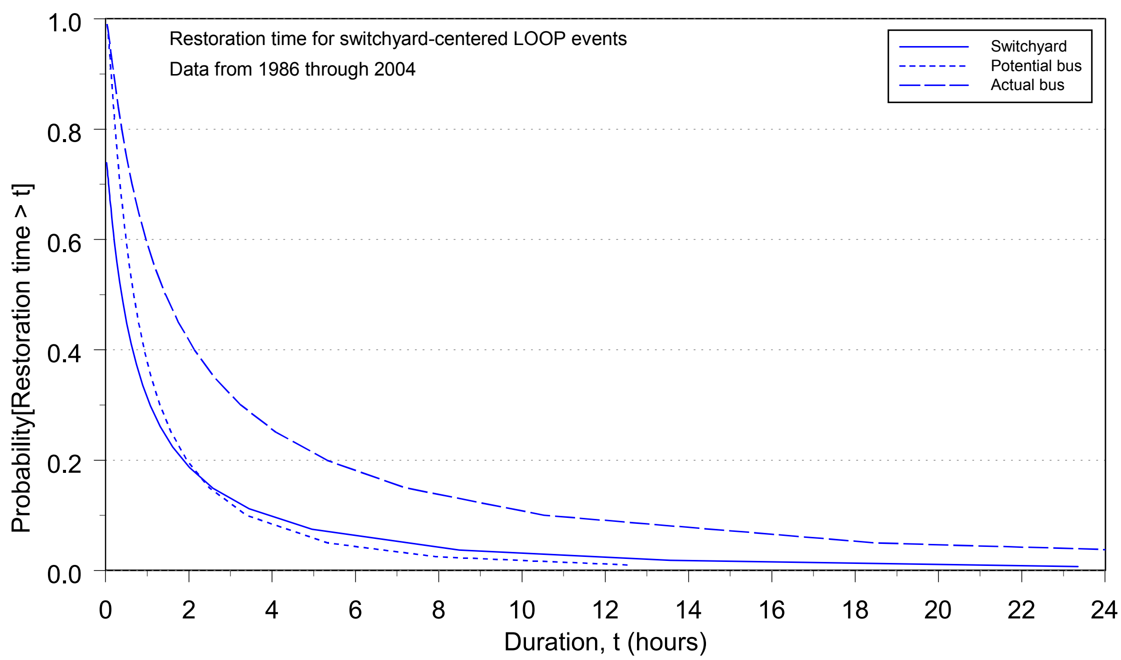


Figure 4-8. Switchyard-centered LOOPs: probability of exceedance versus duration for switchyard, potential bus, and actual bus restoration for critical and shutdown operation.

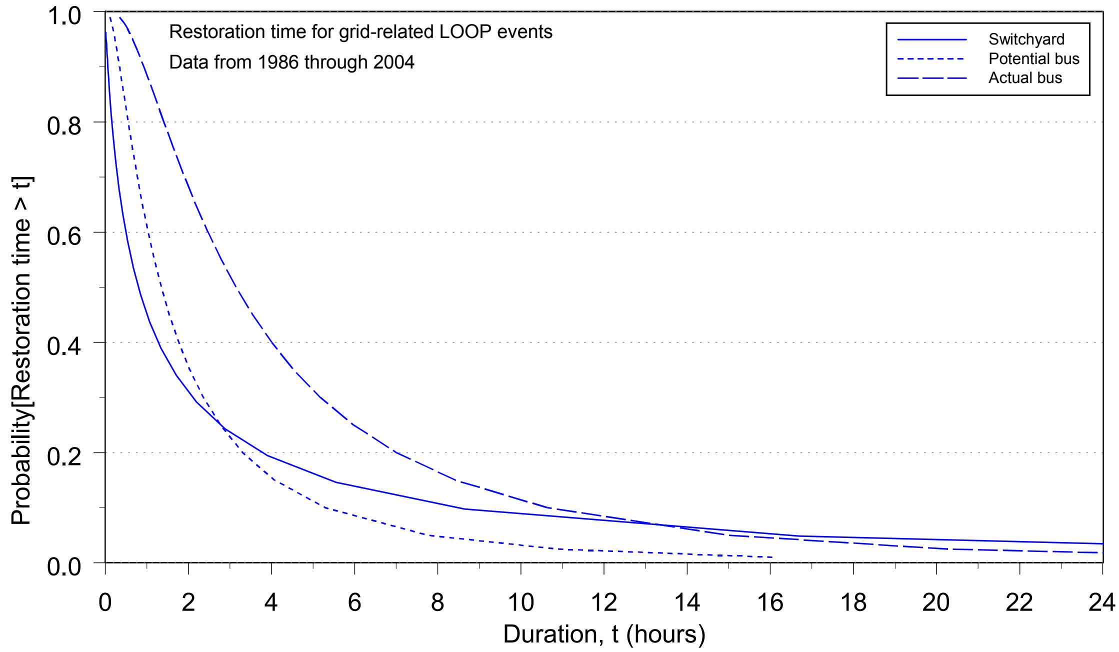


Figure 4-9. Grid-related LOOPs: probability of exceedance versus duration for switchyard, potential bus, and actual bus restoration for critical and shutdown operation.

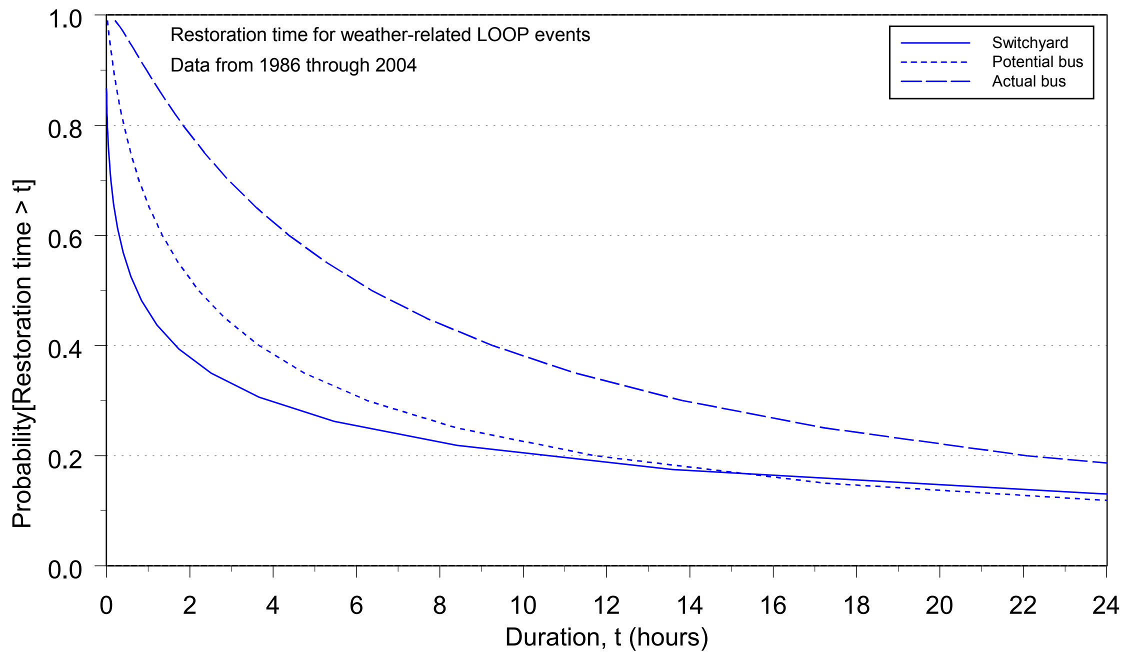
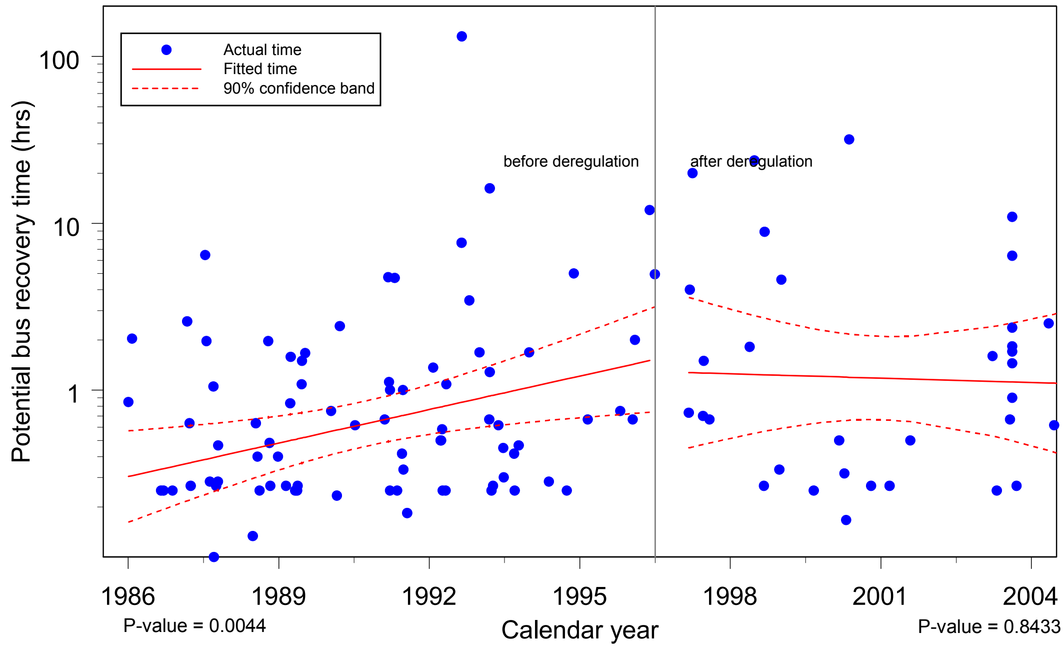


Figure 4-10. Weather-related LOOPs: probability of exceedance versus duration for switchyard, potential bus, and actual bus restoration for critical and shutdown operation.



Note: *The increasing trend over 1986–1996 is statistically significant (p-value for the slope is 0.004), while the slightly decreasing trend over 1997–2004 is not statistically significant (p-value for the slope is 0.843).*

Figure 4-11. Trend plot of LOOP duration for 1986–1996 and 1997–2004 for critical and shutdown operation.

4.3 Comparison with Previous Studies

The probability of exceedance versus duration curves developed in this study, based on LOOP data over the period 1986–2004, 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 and subdivided the weather category into severe weather and extreme weather. 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 weather related (including both severe and extreme weather related). In addition, NUREG-1032 does not list its actual Weibull curve parameters. However, the report ORNL/NRC/LTR-89/11 [8], which interprets NUREG-1032, does list the parameters. Finally, NUREG/CR-5496 did not include the momentary events (those with offsite power restoration times less than 2 min) in its curve fits.

Results are presented in Figure 4-12 through Figure 4-14 for these three categories, i.e., plant centered (including switchyard centered), grid related, and weather related. In addition, overall composite curves are compared in Figure 4-15. Finally, Table 4-3 lists the mean and median LOOP durations from the current study, NUREG/CR-5496, and NUREG-1032. All of the values in Table 4-3 were calculated from the actual data rather than from the curve fits.

For plant-centered (including switchyard-centered) LOOPs (Figure 4-12), the current study curve lies above the NUREG/CR-5496 curve up to 4 h and below the curve beyond 4 h. Both curves are similar, though, indicating that 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 4-3 also supports these conclusions.

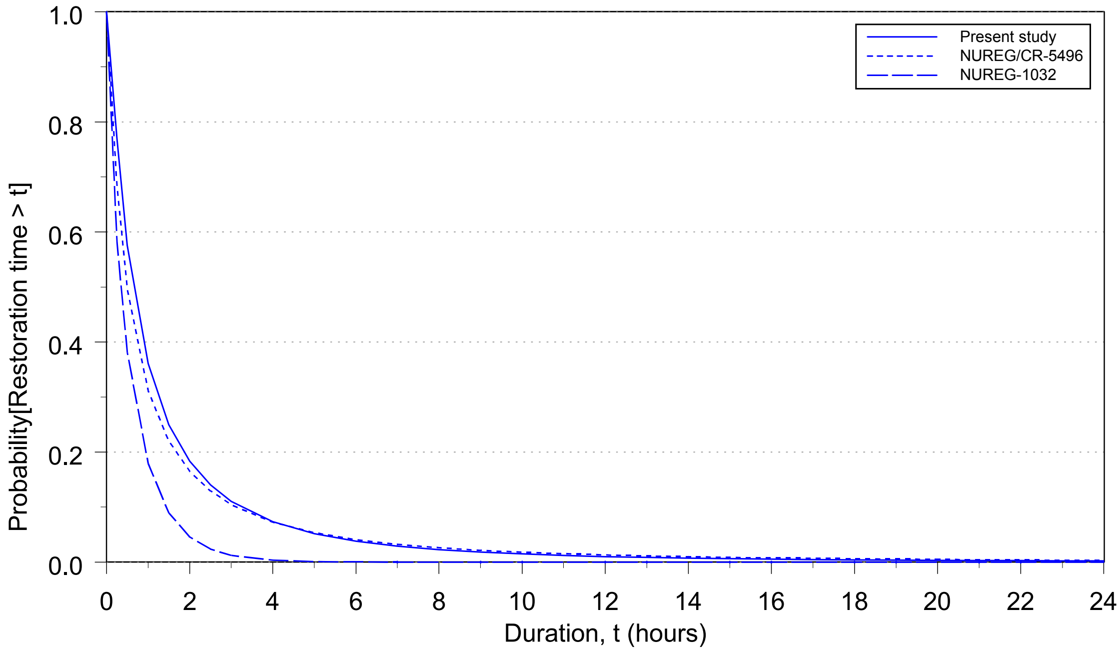


Figure 4-12. Plant-centered and switchyard-centered LOOPs: probability of exceedance versus duration comparison for critical and shutdown operation.

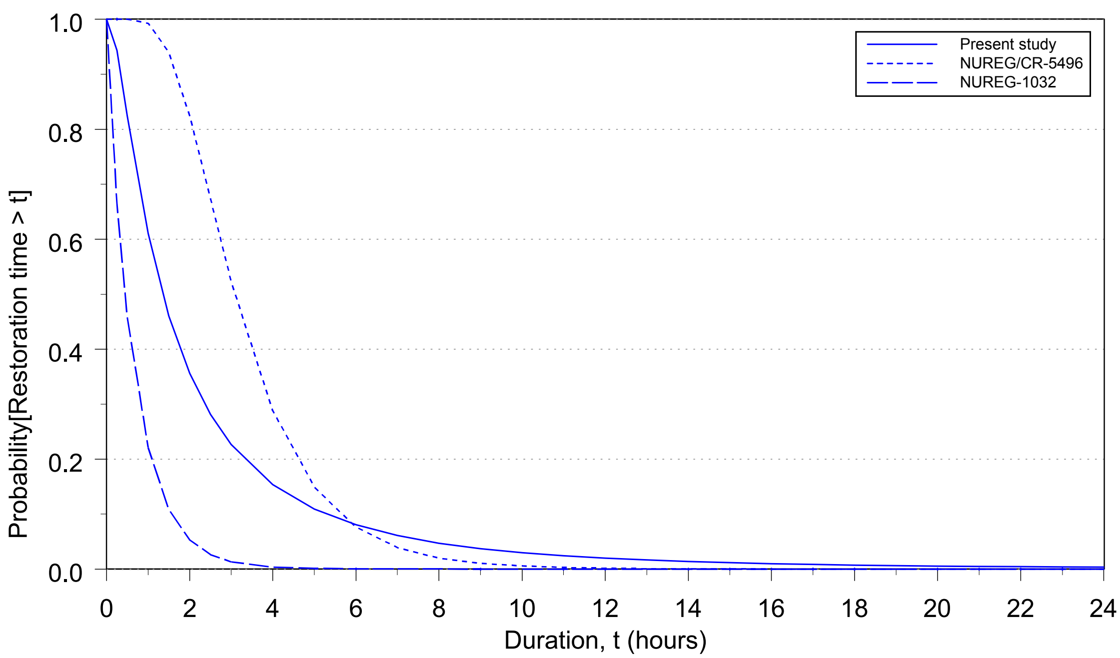


Figure 4-13. Grid-related LOOPs: probability of exceedance versus duration comparison for critical and shutdown operation.

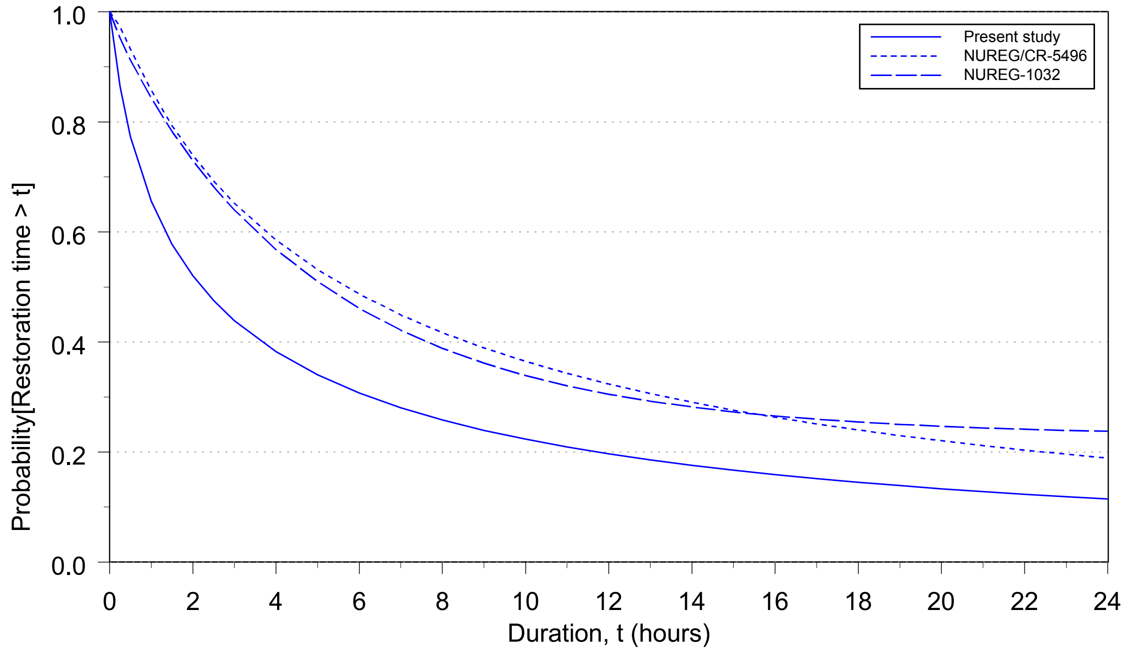


Figure 4-14. Weather-related LOOPs: probability of exceedance versus duration comparison for critical and shutdown operation.

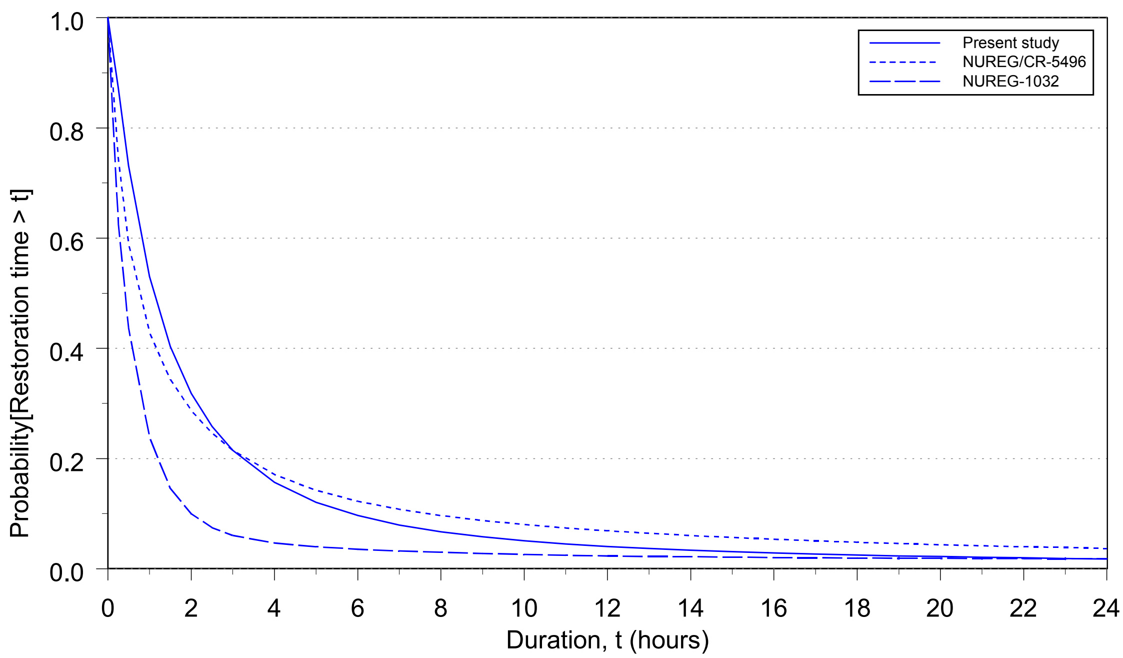


Figure 4-15. Composite of all LOOPs: probability of exceedance versus duration comparison for critical operation.

Table 4-3. LOOP duration comparison with previous studies for critical and shutdown operation.

LOOP Category	Summary Statistic	Present Study	NUREG/CR-5496	NUREG-1032	Comments
Plant Centered (including Switchyard Centered)	Data Period	1986–2004	1980–1996	1968–1985	—
	Median Duration (h) (Actual Data)	0.50	0.33	0.26	—
	Mean Duration (h) (Actual Data)	1.52	1.22	0.45	—
	Type of Fit	Lognormal	Lognormal	Weibull	NUREG/CR-5496 excluded momentary events in the curve fit.
Grid Related	Data Period	1986–2004	1980–1996	1968–1985	—
	Median Duration (h) (Actual Data)	1.56	2.38	0.55	—
	Mean Duration (h) (Actual Data)	2.43	2.64	1.24	—
	Type of Fit	Lognormal	Lognormal	Weibull	NUREG/CR-5496 excluded momentary events in the curve fit.
Weather Related (Severe and Extreme)	Data Period	1986–2004	1980–1996	1968–1985	—
	Median Duration (h) (Actual Data)	1.28	1.18	4.50	NUREG-1032 had no extreme-weather-related events. NUREG/CR-5496 excluded momentary events in the curve fit.
	Mean Duration (h) (Actual Data)	14.2	11.8	4.64	
	Type of Fit	Lognormal	Lognormal	Weibull	

Grid-related LOOP durations in Figure 4-13 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 6 h and then above for beyond 6 h. Table 4-3 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.

Weather-related (including extreme-weather-related) LOOP duration curves are presented in Figure 4-14. Unlike the other two cases, the NUREG-1032 and NUREG/CR-5496 curves are similar, while the current study curve lies below them. This behavior is not obvious from the summary statistics presented in Table 4-3. 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 4-15. With respect to composite curves, the current study results lie above the NUREG/CR-5496 results up to 3 h and then lie below the NUREG/CR-5496 results. In addition, the current study results lie significantly above the NUREG-1032 results.

Loop Durations

5. COMBINING LOOP FREQUENCY AND DURATION

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 of Section 4, but multiplied by the corresponding LOOP category frequency. Frequency of exceedance versus duration curves for the four LOOP categories in the current study 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 approximate indications of the relative risk from SBO core damage scenarios for 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 6 h. This reflects the relatively high frequency for grid-related LOOPs during critical operation and their moderate durations. Beyond 6 h, the weather-related LOOPs dominate. In addition, up to approximately 2 h, the switchyard-centered LOOPs are important contributors, again mainly because of their relatively high frequency.

For shutdown operation (Figure 5-2), the switchyard-centered LOOPs dominate the frequency of exceedance curves up to approximately 2 h. This reflects the high relative frequency of such events during shutdown operation and their moderate durations. Beyond 2 h, the weather-related LOOPs dominate.

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. The curve presented for NUREG/CR-5496 uses the frequencies from that study that do not include momentary LOOPs. Because NUREG/CR-5496 did not use the momentary LOOPs in its duration analysis, the most appropriate curve is one using frequencies evaluated without momentary LOOPs. Given a plant risk model with constant input parameters except for the LOOP frequencies and durations, the curves in Figure 5-3 are approximate indications of the relative risk from SBO core damage scenarios from each data set. From Figure 5-3, the composite curve based on the current study data (representative of the period 1997–2004) lies below the NUREG/CR-5496 curve (1980–1996). In addition, the current study curve lies significantly below the NUREG-1032 curve (1968–1985) up to 2 h. Therefore, the increased LOOP durations (compared with the NUREG-1032 data collection period of 1968–1985) are mitigated by the reduction in LOOP frequency.

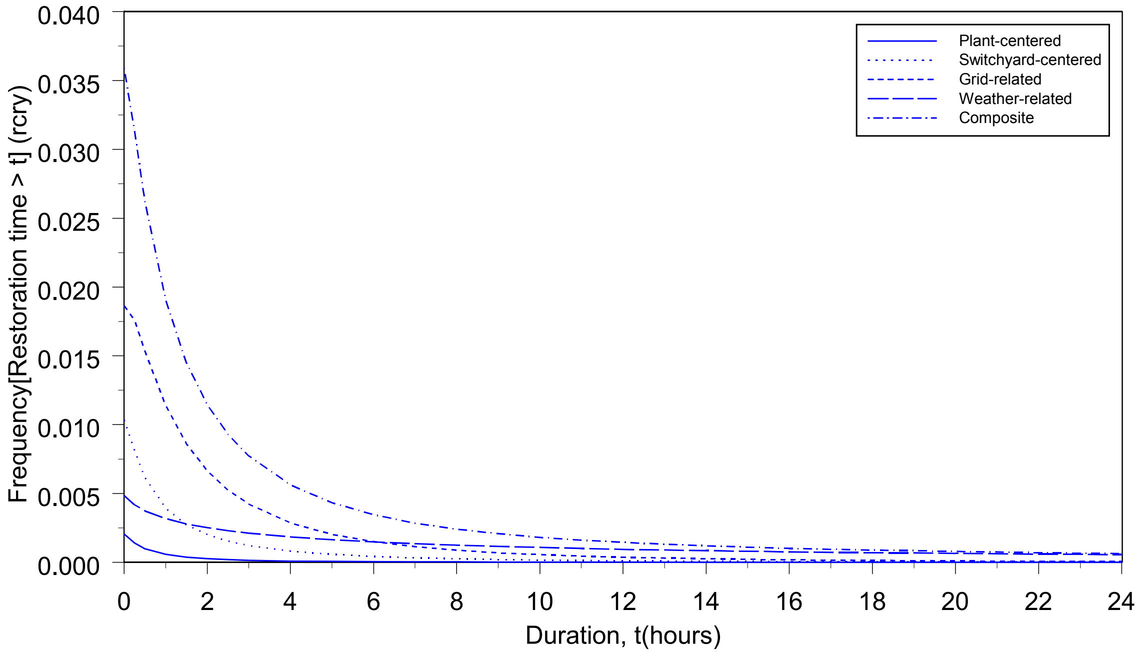


Figure 5-1. Frequency of exceedance versus duration for critical operation.

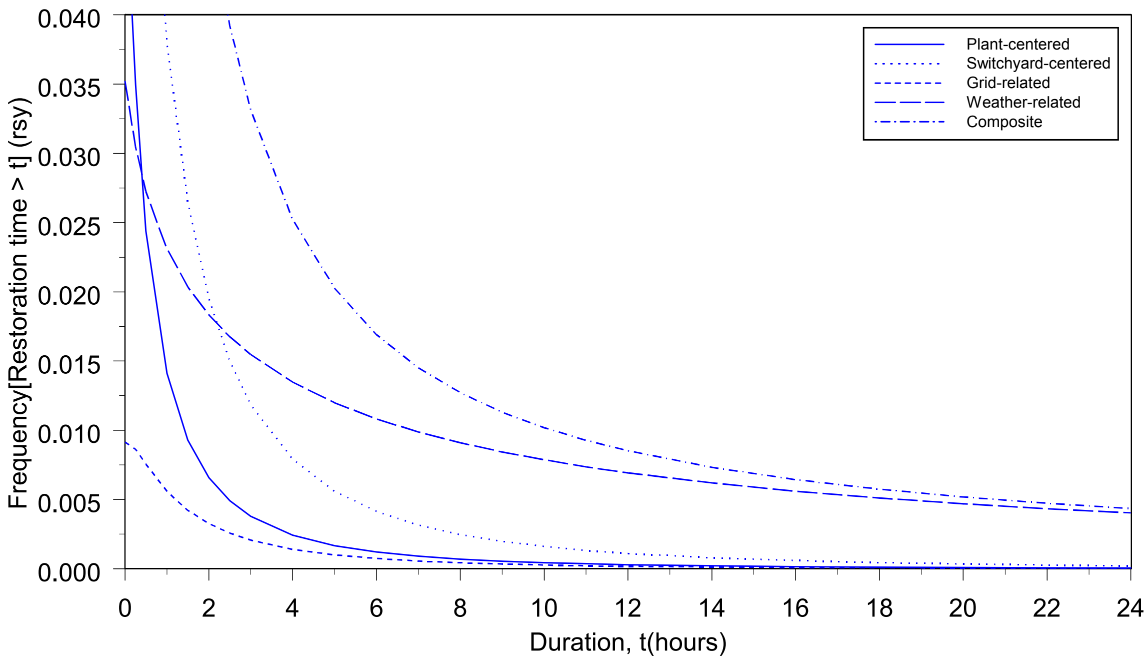


Figure 5-2. Frequency of exceedance versus duration for shutdown operation.

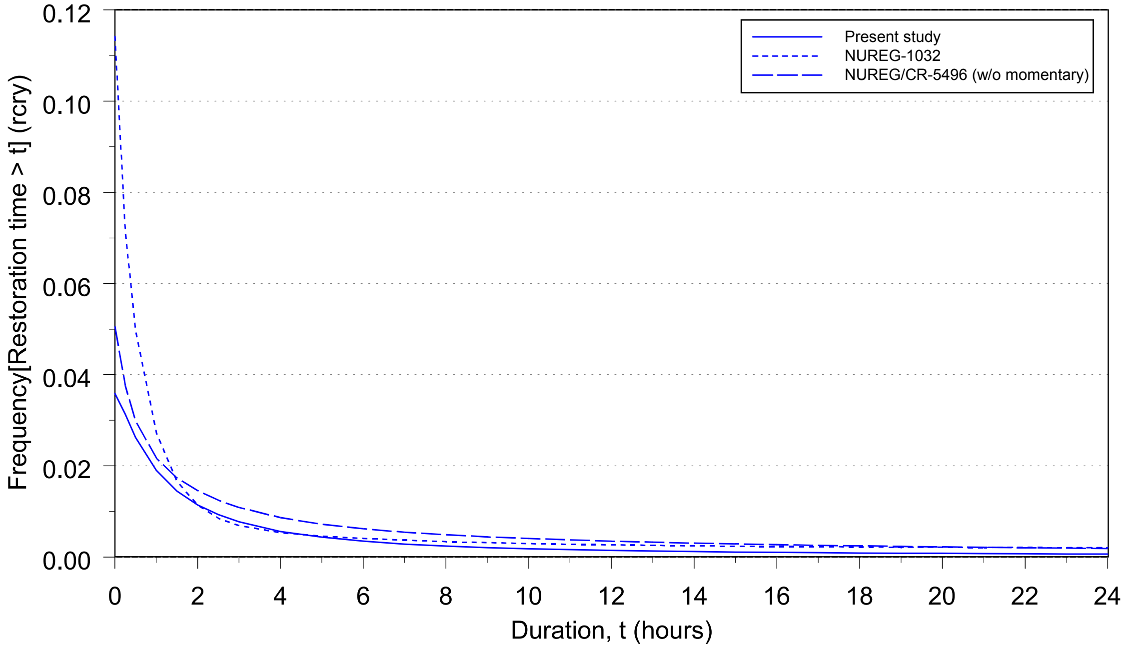


Figure 5-3. Comparison of frequency of exceedance versus duration for critical operation.

Combining Loop Frequency and Duration

6. SPECIAL TOPICS OF INTEREST

6.1 Comparison with NUREG-1784

The focus of the present study differs from that of NUREG-1784 [5], which was to evaluate the potential effects of deregulation of the electrical industry on electrical grid operation. In contrast, the major focus of the present study is estimating 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 1986–2004. 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 these two studies are mainly due to differences in the definition of the grid and treatment of restoration times.

NUREG-1784 identified the subset of LOOPs during critical operation that is grid initiated or related (switchyard, transmission line, grid, and consequential). In contrast, the present study used a more limited definition of grid events, similar to what was used 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 recovery 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 (1997–2001):

1. The frequency of LOOPs has decreased.
2. The average duration of LOOPs has increased (the percentage of LOOPs longer than 4 h has increased substantially).
3. Unlike the earlier period (1985–1996) 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, the analysis of LOOP frequencies in Section 3 of this report found that plant-centered and switchyard-centered LOOP frequencies for critical operation decreased from 1986–1996 to 1997–2004 (Table 3-5). 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 1997–2004 was used. However, grid-related LOOP occurrences have increased, as indicated in Figure 3-3. Again, to obtain a current frequency estimate for this category, only the period 1997–2004 was used. Finally, the frequencies of weather-related LOOPs appear to have remained constant over

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	1986–2004
Definitions	Grid events = consequential LOOPs, switchyard LOOPs, transmission system LOOPs, and widespread grid problems	Grid events = Transmission system LOOPs and widespread 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	4.6E−2/rcry for 1986–1996 3.6E−2/rcry for 1997–2004 (including Aug. 14, 2003, grid disturbance)
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	19 summer and 19 nonsummer events for 1986–1996 22 summer and 2 nonsummer events for 1997–2004
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	3.0E−3 for 1986–1996 5.3E−3 for 1997–2004 9.1E−3 for 1997–2004 summer months
Average LOOP duration has increased	Median Duration 60 min. for 1985–1996 688 min. for 1997–2001	Median Duration ~125 min. for actual bus restoration for 1986–1996 ~779 min. for actual bus restoration for 1997–2001 ~227 min. for actual bus restoration for 1997–2004
LOOP events exceeding 4 h	Longer LOOP durations are getting longer	Not specifically addressed in report
Trends in duration	No trends in report	Presents trends in frequency and duration

the period 1993–2004, so 1997–2004 was used to determine their frequency. The comparison of present study results with previous studies (Table 3-8) indicates that the overall LOOP frequency for critical operation has dropped steadily with time, from a high of 1.2E−1/rcry over the period 1968–1985 to the present study result of 3.6E−2/rcry for 1997–2004. 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 4-3 summarizes the LOOP duration data over three periods, 1968–1985 (NUREG-1032), 1980–1996 (NUREG/CR-5496), and 1986–2004 (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 4-3 indicates that, in general, the durations of LOOPs have increased over time. However, that table does not specifically address the period 1997–2004. 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 1986–2004. That effort included a comparison of data over the periods 1986–1996 and 1997–2004. In cases where differences were identified, results were generated using only the newer data, 1997–2004. However, the current study has not tried to identify why such differences exist. Even though 1997–2004 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 as May through September). The LOOP data used for the present study were reviewed to determine if this seasonal effect exists within the four categories of LOOPs. Higher summer frequencies were found for all four categories for critical operation, but not for shutdown operation (Section 3.2). The present section analyzes each LOOP category over the periods 1986–1996 and 1997–2004 in order to identify seasonal differences between the two periods. Results for critical and shutdown operation are presented in Table 6-2. The results indicate no major seasonal effects on the shutdown overall LOOP frequency for either period. However, the critical operation LOOPs over the more recent period, 1997–2004, indicate a large seasonal difference in the overall LOOP frequency. This seasonal difference for the more recent period for critical operation results mainly from grid-related and switchyard-centered LOOPs. All three grid disturbance events (August 14, 2003, event contributing eight LOOPs; September 15, 2003, event contributing two LOOPs; and June 14, 2004, event contributing three LOOPs) occurred during the summer months. In addition, six switchyard-centered LOOPs occurred during the summer months, while only one occurred during the nonsummer months.

Figure 6-1 through Figure 6-4 present LOOP counts by month and corresponding plant operating time (critical or shutdown) for 1986–1996 and 1997–2004. This breakdown by month provides more detail than the seasonal comparison discussed above. For 1986–1996, the LOOP event counts for shutdown operation vary by month, with the highest numbers of LOOPs occurring during March, April, June, and October. These months generally also have higher shutdown outage times (Figure 6-2). However, on a seasonal basis (summer or nonsummer), the overall results do not indicate any significant difference in LOOP frequencies. The same is true for the critical operation LOOPs during this period.

Table 6-2. Plant-level LOOP events by season.

		1986–1996				1997–2004				
		Summer		Nonsummer		Summer		Nonsummer		
Mode	LOOP Category	Events	Mean Frequency[a]	Events	Mean Frequency[a]	Events	Mean Frequency[a]	Events	Mean Frequency[a]	Frequency Units[b]
Critical operation	Plant centered	5	1.45E−02	6	1.31E−02	1	4.80E−03	0	1.21E−03	/rcry
	Switchyard centered	11	3.02E−02	12	2.52E−02	6	2.08E−02	1	3.64E−03	/rcry
	Grid related	1	3.94E−03	0	1.01E−03	13	4.32E−02	0	1.21E−03	/rcry
	Weather related	2	6.57E−03	1	3.02E−03	2	8.01E−03	1	3.64E−03	/rcry
	All	19	5.52E−02	19	4.23E−02	22	7.69E−02	2	9.71E−03	/rcry
	Reactor Critical Years (rcry)	380.5	—	496.7	—	312.2	—	412.1	—	—
Shutdown operation	Plant centered	6	6.37E−02	8	4.81E−02	1	4.50E−02	4	6.31E−02	/rsy
	Switchyard centered	11	1.13E−01	20	1.16E−01	1	4.50E−02	6	9.12E−02	/rsy
	Grid related	1	1.47E−02	0	2.83E−03	2	7.51E−02	0	7.01E−03	/rsy
	Weather related	2	2.45E−02	7	4.25E−02	3	1.05E−01	1	2.10E−02	/rsy
	All	20	2.16E−01	35	2.10E−01	7	2.70E−01	11	1.82E−01	/rsy
	Reactor Shutdown Years (rsy)	102.0	—	176.6	—	33.3	—	71.3	—	—

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).

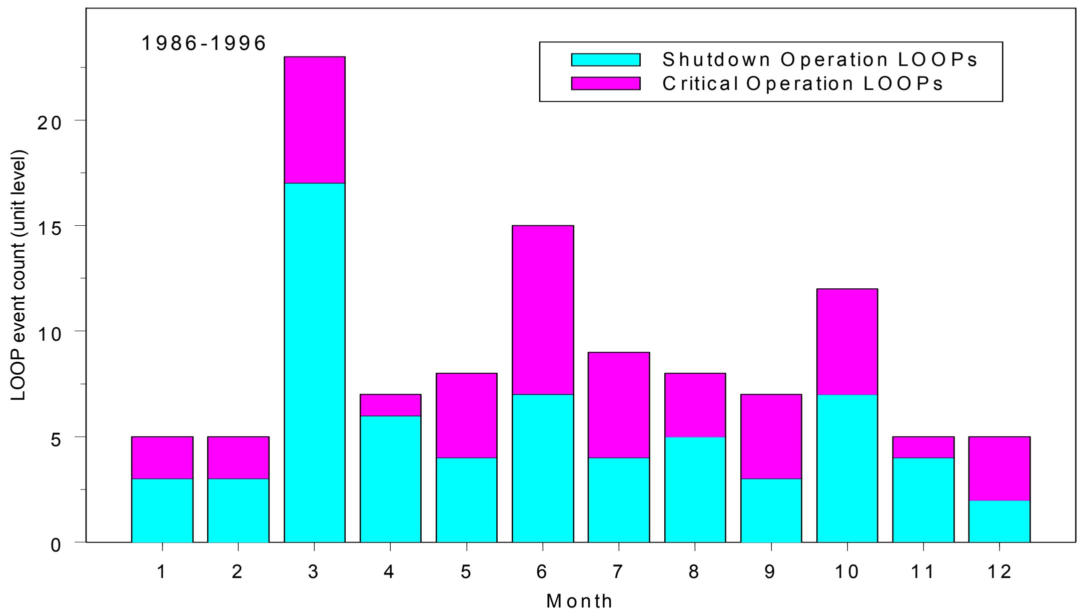
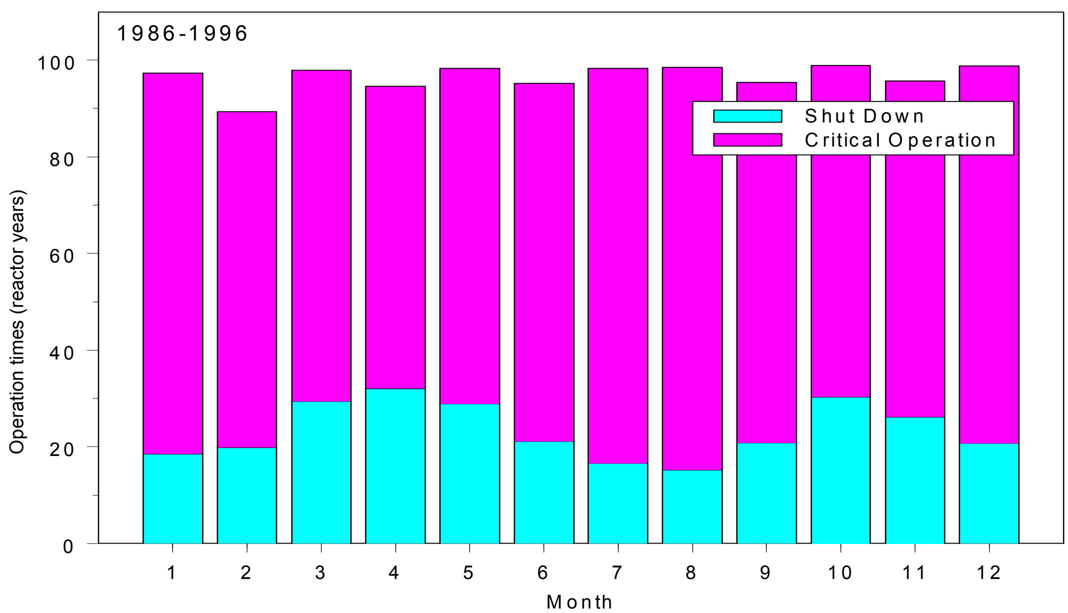


Figure 6-1. LOOP events by month for 1986–1996.



Note: Heights of the bars vary because of different lengths of months.

Figure 6-2. Plant operational status by month for 1986–1996.

In contrast, when the 1997–2004 data are analyzed (Figure 6-3 and Figure 6-4), the summer months of June and August have high LOOP counts during critical operation. August has by far the highest LOOP counts, mainly because of the August 14, 2003, grid disturbance. This supports the strong seasonal variation discussed above. In contrast, March, April, and September have the highest LOOP counts during shutdown operation.

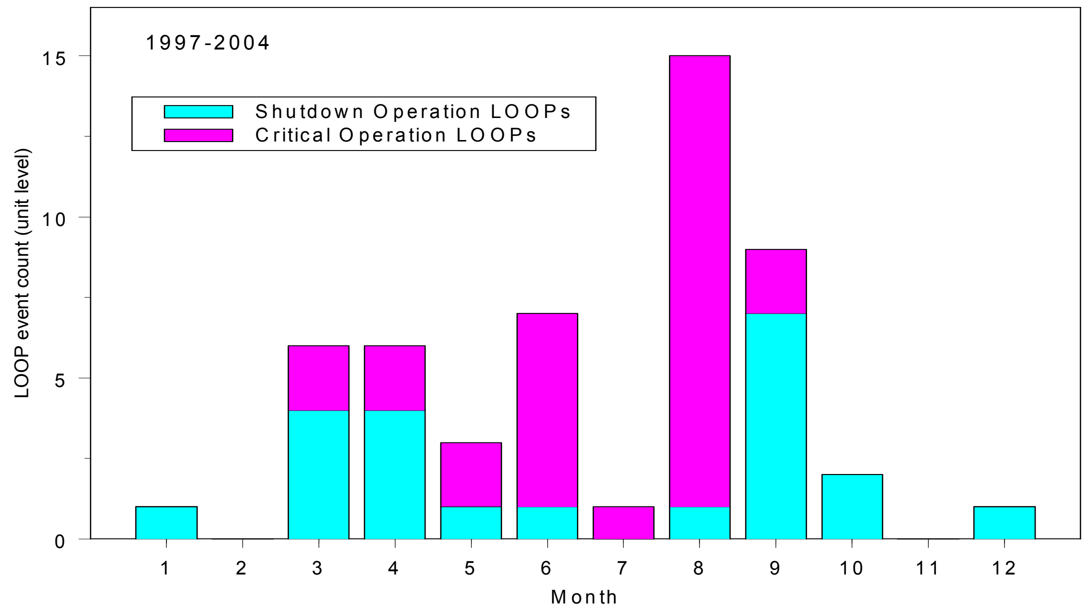
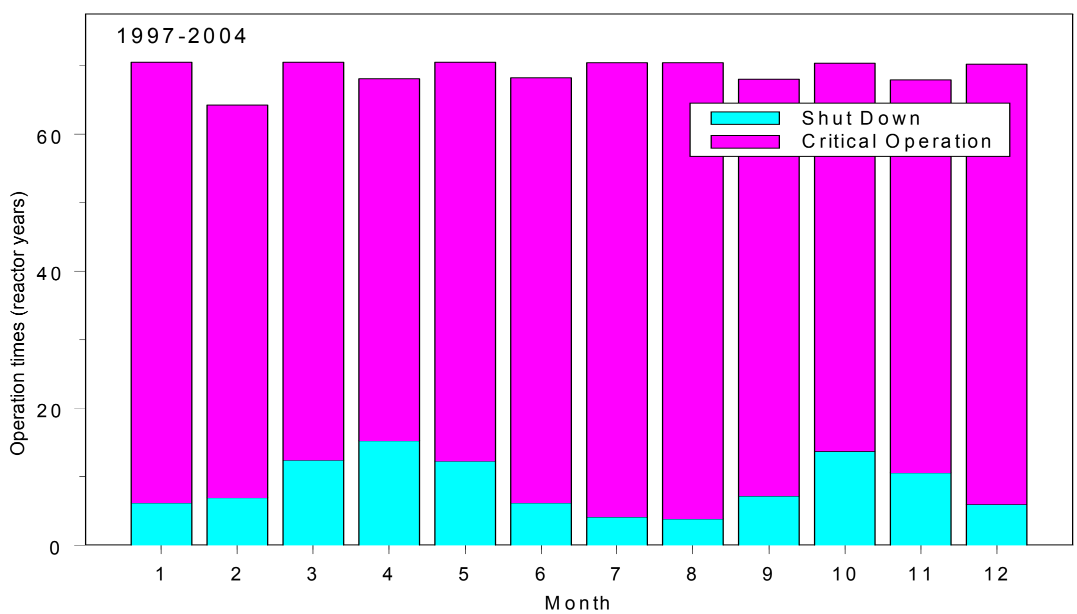


Figure 6-3. LOOP events by month for 1997–2004.



Note: Heights of bars vary because of different lengths of months.

Figure 6-4. Plant operational status by month for 1997–2004.

6.3 Consequential LOOPs

NUREG-1784 identified events in which a reactor trip (unrelated to a LOOP) occurred and subsequently a LOOP occurred in 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 1986–2004 (identified in

Appendix A by the classification designation LOOP-IE-C). Three of these nine consequential LOOPs occurred during 1997–2004. The consequential LOOPs are included in the frequency calculations presented in Table 3-1. Although nine consequential LOOP events are identified in both NUREG-1784 and this report, they are not the same nine events. 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. Similarly, the Grand Gulf event on April 24, 2003, is included in the present report but is outside the data collection period for NUREG-1784.

The data analyzed in the present report indicate that six consequential LOOPs occurred during 1986–1996, while three occurred during 1997–2004. Therefore, the frequency of consequential LOOPs has decreased in recent years, from (6 + 0.5)/(877.2rcry) = 7.4E−3/rcry (1986–1996) to (3 + 0.5)/(724.3rcry) = 4.8E−3/rcry (1997–2004). This latter frequency contributes approximately 13% to the overall total of 3.6E−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 1997–2004 and a seasonal estimate. 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 32 LOOP-IE-I events (from Appendix A), there were 2136 reactor trips not initiated by a LOOP. Of these, six resulted in consequential LOOPs. Therefore, the conditional probability of a consequential LOOP given a reactor trip during the period 1986–1996 is

(6 + 0.5)/(2136 +1) = 3.0E−3.

Similarly, over the period 1997–2004, there were approximately 680 reactor trips. Subtracting the 19 LOOP-IE-I events yields 661 reactor trips not initiated by a LOOP. Of these 661 reactor trips, three resulted in consequential LOOPs. Therefore, the conditional probability of a consequential LOOP given a reactor trip is

(3 + 0.5)/(661 + 1) = 5.3E−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.

The possibility of a seasonal variation in this conditional probability of a consequential LOOP was also investigated. For the period 1986–1996, the six consequential LOOPs include two during the five summer months and four during the seven nonsummer months. In addition, the three consequential LOOP events during 1997–2004 divide into two during the summer and one during the nonsummer months. Both results have too few events to conclude that there is a significant difference between summer and nonsummer performance. However, to compare with NUREG-1784, results for the period 1997–2004 can be calculated. Reactor trip data presented in NUREG-1784 indicate that there is no significant seasonal variation in overall reactor trips. The approximately 661 reactor trips in the present study not initiated by a LOOP over 1997–2004 can, therefore, be split into approximately 275 (5/12 of the total) reactor trips during the five summer months and 386 (7/12 of the total) during the nonsummer 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

(2 + 0.5)/(275 + 1) = 9.1E−3.

NUREG-1784 estimated this conditional probability to be 1.0E−2.

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 1997–2004, contributing eight of the 13 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 five LOOPs (rather than 13) over 724.3rcry (from Table 3-1). The resulting frequency would have been 7.6E−3/rcry, rather than the study result of 1.9E−2/rcry. This would then have decreased the overall LOOP frequency for critical operation from 3.6E−2/rcry to 2.5E−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 1986–2004 would have been 0.7 h rather than 2.4 h (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. In 2004, a grid-related event occurred that resulted in three LOOPs.

6.5 Multi-Unit Site Considerations

Among the 135 LOOP plant-level events considered in this study for frequency and duration analyses (148 total events, minus 10 LOOP-NTs, and with the LaCrosse and two Pilgrim salt spray LOOPs removed), there were 12 occurrences involving more than one plant at a site resulting from the same event (over a period of 24 h). The LaCrosse event was removed because of atypical plant design, while the two Pilgrim events were removed because plant modifications were made to minimize salt spray impacts. These events are listed in chronological order in Table 6-3. Eleven involved both plants at two-plant sites, while one (Palo Verde on June 14, 2004) involved all three plants at the site. The

Table 6-3. LOOP events (1986–2004) 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	Weather Related	Shutdown Operation[a]
Sequoyah	12/31/1992	2	2	Switchyard Centered	Critical Operation
Brunswick	03/16–17/1993	2	2	Weather Related	Shutdown Operation
Beaver Valley	10/12/1993	2	2	Switchyard Centered	Critical Operation/ Shutdown Operation
Prairie Island	6/29/1996	2	2	Weather Related	Critical Operation
Fitzpatrick and Nine Mile Point 1	8/14/2003	2	2	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
Palo Verde	6/14/2004	3	3	Grid Related	Critical Operation
St. Lucie	9/25/04	2	2	Weather Related	Shutdown Operation[a]

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

remaining events were single-plant events. Of the 103 presently operating plants, there are 28 single-plant sites, 33 dual-plant sites, and three three-plant sites (Oconee, Palo Verde, and Hope Creek/Salem.) However, if all plants that operated sometime during 1986–2004 are included, the numbers are 34, 32, and 5, respectively.

Conditional probabilities of other plants at a multi-plant site experiencing a LOOP, given a LOOP at the plant being analyzed, are presented in Table 6-4. These conditional probabilities range from 6.0E−2 for plant-centered LOOPs to 8.2E−1 for grid-related LOOPs. Because all of the 12 events listed in Table 6-3 affected all plants at a site, the probabilities listed in Table 6-4 are considered to apply to all other plants at the site. For example, if a site has three plants and one plant experiences a grid-related LOOP while at power, then the probability that the other two plants also experience the same grid-related LOOP is 8.2E−1 from Table 6-4.

Also presented in Table 6-4 are the composite conditional probabilities for critical operation and shutdown operation. These composite conditional probabilities apply if the risk model does not distinguish the individual LOOP categories. For critical operation, the composite conditional probability is 5.8E−1, while for shutdown operation the probability is 3.0E−1. Details of the statistical analysis are presented in Appendix C.

6.6 No Trip LOOPs

Of the 148 LOOP events during the period 1986–2004, 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, four of these eight plants also experienced LOOPs during critical operation that did result in reactor trips. Whether any of these eight 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.

6.7 Offsite Power Restoration Times

For each of the 148 LOOP events that occurred during 1986–2004, three restoration times or durations are presented in Appendix A: switchyard restoration, potential bus recovery, 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. Potential bus recovery time is the duration from the start of the LOOP to when offsite power could have been recovered to a safety bus. (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 higher priorities related to the LOOP event.) Actual bus restoration time is the duration from the start of the LOOP to when offsite power was actually restored to a safety bus.

Table 6-4. Conditional probability of all plants at a site experiencing a LOOP given a LOOP at the plant being analyzed.

LOOP Category	LOOP Events at Multi-Plant Sites Affecting all Plants at Site	Total Number of LOOP Events at Multi-Plant Sites	Conditional Probability of All Plants at a Multi-Plant Site Experiencing a LOOP Given a LOOP at One of the Plants at the Site[a]				Beta Distribution Parameters		Critical Operation Plant-Level Frequency Weight	Shutdown Operation Plant-Level Frequency Weight
			5%	Median	Mean	95%	α	β		
Plant Centered	0	7.333	6.71E−05	2.39E−02	6.00E−02	2.43E−01	0.398	6.235	8.82E−02	2.07E−1
Switchyard Centered	4	20.333	8.00E−05	9.37E−02	2.11E−01	7.80E−01	0.327	1.222	2.65E−01	5.49E−01
Grid Related	4	4.5	2.92E−01	9.26E−01	8.18E−01	1.00E+00	1.447	0.322	5.59E−01	3.66E−02
Weather Related	4	5.5	7.55E−02	8.11E−01	6.92E−01	1.00E+00	0.816	0.363	8.82E−02	2.07E−01
All (Critical Operation)			1.28E−01	6.02E−01	5.79E−1[b]	9.56E−1	1.512	1.094	—	—
All (Shutdown Operation)			2.47E−02	2.61E−01	3.02E−1[b]	7.16E−1	1.056	2.444	—	—

a. The mean is a Bayesian update using a Jeffreys prior. Mean = (0.5 + events)/(1 + total events). The beta distribution is a CNID. See Appendix C for more details concerning these calculations.

b. The mean is a frequency weighted average of the individual LOOP category means. Simulation was used to generate data that were then fitted to a beta distribution.

To obtain the best information available to aid in determining the restoration/recovery times, the following steps were taken:

1. Early in the overall project, NRC staff met with EPRI staff to review LOOP events and associated restoration/recovery times for 1997–2003. For some of these events, EPRI indicated that offsite power was never lost to the switchyard. This led to the decision to collect all three times—switchyard restoration, potential bus recovery, and actual bus restoration.
2. NRC resident inspectors were asked to confirm LOOP events and restoration/recovery times. Temporary Instruction 2525/156 [6], Appendix B, listed potential bus recovery times (from NUREG/CR-5496) for events that occurred during 1980–1996 and all three times for events during 1997–2003. (LOOP data for 2004 were added late in the study and were not covered under this Temporary Instruction.) The inspectors' responses were incorporated into the final LOOP database.
3. ASP Program analyses of LOOP events were reviewed for additional information on restoration/recovery times. Results were also incorporated into the final LOOP database.

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).

Because of incomplete information in the LER (or EPRI report if not covered by an LER), one or more of the three restoration/recovery times often was not listed. In such cases, an estimate was made, based on available information. Of the 122 site-level LOOP events listed in Appendix A, Table A-7, 35 have potential bus recovery times listed as certain. The remaining entries are listed as uncertain (except for one listed as unknown).

For purposes of risk analysis, the potential bus recovery time is generally most appropriate. Probability of exceedance versus duration curves presented in Section 4 are based on potential bus recovery times. These curves were based on LOOP events aggregated at the site level, similar to what was done in NUREG-1032 and NUREG/CR-5496.

To assist in the estimation of these uncertain potential bus recovery 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. Given these conditions, the second step was to ask engineers with previous reactor operator experience to estimate how long it would take to restore power to a safety bus. The third step was to compare these estimates with potential bus recovery data listed as certain.

The conditions identified in Step 1 as characterizing the plant status are listed below:

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

In the second step, engineers with previous reactor operator experience were given these conditions and 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 once the plant has been stabilized and the SBO procedures are entered. This conclusion was based on the 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—1 to 2 min was an appropriate estimate given the conditions listed above. With this input, and allowing some margin for stabilizing the plant and entering the SBO procedures, the following guidelines were generated for estimating the potential bus recovery times listed as uncertain:

- For switchyard restoration times less than or equal to 15 min, the corresponding potential bus recovery time is 15 min beyond the switchyard restoration time. This allows operators to stabilize plant conditions and then devote attention to the recovery of offsite power to vital buses. (If this rule results in a potential bus recovery time greater than the actual bus restoration time, then the actual bus restoration time is used.)
- For switchyard restoration times greater than 15 min but less than or equal to 30 min, 10 min is added to the switchyard restoration time to obtain an estimate for the potential bus recovery time. (If this rule results in a potential bus recovery time greater than the actual bus restoration time, then the actual bus restoration time is used.)
- For switchyard restoration times greater than 30 min, the corresponding potential bus recovery time is 5 min beyond the switchyard restoration time. (If this rule results in a potential bus recovery time greater than the actual bus restoration time, then the actual bus restoration time is used.)
- Finally, for plant conditions involving complex situations or equipment damage, additional time may be required to recover offsite power to the vital buses. Each such case is examined individually to estimate the potential bus recovery time.

For some LOOP events, the actual bus restoration time is also listed as uncertain. In such cases, 60 min were added to the potential bus recovery time to obtain an estimate for the actual bus restoration time.

In the third step, these guidelines were compared with potential bus recovery data listed as certain. The LOOP data in Appendix A were examined to identify cases where both the switchyard restoration and potential bus recovery times are known with certainty (denoted by "C"). For cases in which the switchyard restoration time is less than or equal to 15 min, the additional time required to recover offsite power to a safety bus was tabulated. For these cases, the mean additional time is 19.3 min and the median is 11.0 min, which are close to the guideline of 15 min. In addition, for cases in which the switchyard restoration time is greater than 30 min, the mean additional time required to recover offsite power to a safety bus is 8.0 min and the median is 0.5 min, which are close to the guideline of 5 min. (Two outliers were eliminated from this second set of cases because of extraordinary conditions.)

Based on the results of this three-step process, the guidelines listed in Step 2 appeared to be reasonable and, therefore, were applied to the uncertain potential bus recovery times. A review of the restoration times associated with the LOOP events indicate that these 15, 10, and 5 min assumptions were used for 75 of the 86 potential bus restoration times listed as estimated in Appendix A.

As a sensitivity study on these guidelines, the uncertain potential bus restoration times were modified using 30, 20, and 10 min assumptions (double the baseline values of 15, 10, and five), as long as the results were not longer than the actual bus restoration times. Probability of exceedance versus duration curves were then generated for all four LOOP categories and the composite. The composite curves for both critical operation and shutdown operation from this sensitivity case are compared with the baseline composite curve in Figure 6-5. Using 30, 20, and 10 min in the guidelines rather than the baseline values of 15, 10, and five results in approximately a 10% increase in the probability of exceedance up to 6 h.

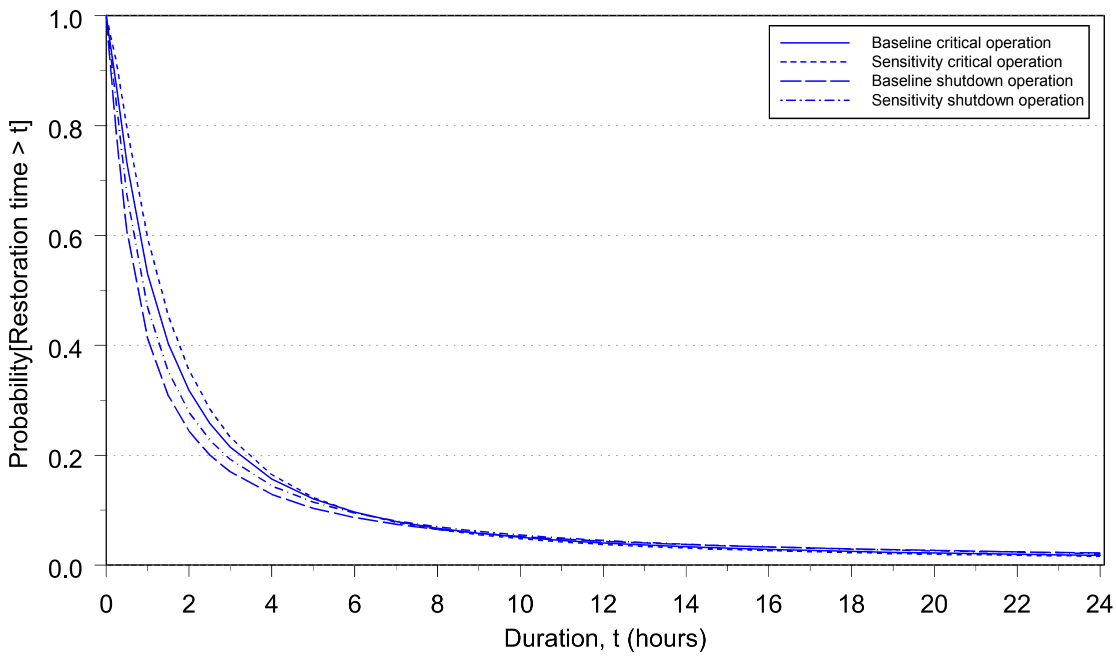


Figure 6-5. Probability of exceedance versus duration composite curve comparison for sensitivity analysis on potential bus restoration times.

For example, at 2 h, the baseline composite curve indicates a 0.37 probability of not having recovered offsite power, while the sensitivity curve indicates a 0.40 probability. After 6 h, the two curves are similar. Therefore, this sensitivity study indicates that the potential bus recovery results are not overly sensitive to the use of 15, 10, and 5 min in the guidelines discussed above.

6.8 Momentary versus Sustained LOOPs

NUREG/CR-5496 distinguished between momentary LOOPs (those with durations less than 2 min) and sustained LOOPs (those with duration equal to or greater than 2 min). In that study, LOOP frequencies were generated separately for the momentary LOOPs and the sustained LOOPs. In addition, 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. These characteristics were classified into three design groups, designated 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 unavailable (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 (0.20 h). 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 h). 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 h. 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. In addition, 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 1997–2004 data are used, there are too few events to distinguish the three design groups. Differences were identified if the entire data period 1986–2004 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 (1997–2004) 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 1986–2004 because the duration analysis in Section 4 used the entire data period. (No significant differences were noted between the current period, 1997–2004, and the entire period in that analysis.)

6.10 Abnormal Electrical Configurations

Each LOOP event was reviewed to identify abnormal electrical system configurations that may have increased either the vulnerability to a loss of offsite power or the recovery time. Table 6-5 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 6-5 indicate that only four of the 62 LOOPs involved an abnormal electrical configuration. However, 45 of the 73 LOOPs occurring during shutdown involved such configurations. Results for the two periods, 1986–1996 and 1997–2004, do not indicate significant differences from these overall results. 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 6-5. LOOP event counts for abnormal electrical system configuration.

		1986–1996		1997–2004	
Mode	LOOP Category	Abnormal Configuration LOOPs	Total LOOPs	Abnormal Configuration LOOPs	Total LOOPs
Critical operation	Plant centered	1	11	0	1
	Switchyard centered	2	23	1	7
	Grid related	0	1	0	13
	Weather related	0	3	0	3
	All	3	38	1	24
Shutdown operation	Plant centered	10	14	4	5
	Switchyard centered	19	31	4	7
	Grid related	1	2	1	1
	Weather related	4	9	2	4
	All	34	56	11	17

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 1986–2004 LOOP events by category and operational mode. Of the 148 LOOP events, 49% occurred while critical and 51% occurred while shutdown. During the period 1986–2004, 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 3.6E−2/rcry, while the corresponding frequency during shutdown operation is 2.0E−1/rsy.

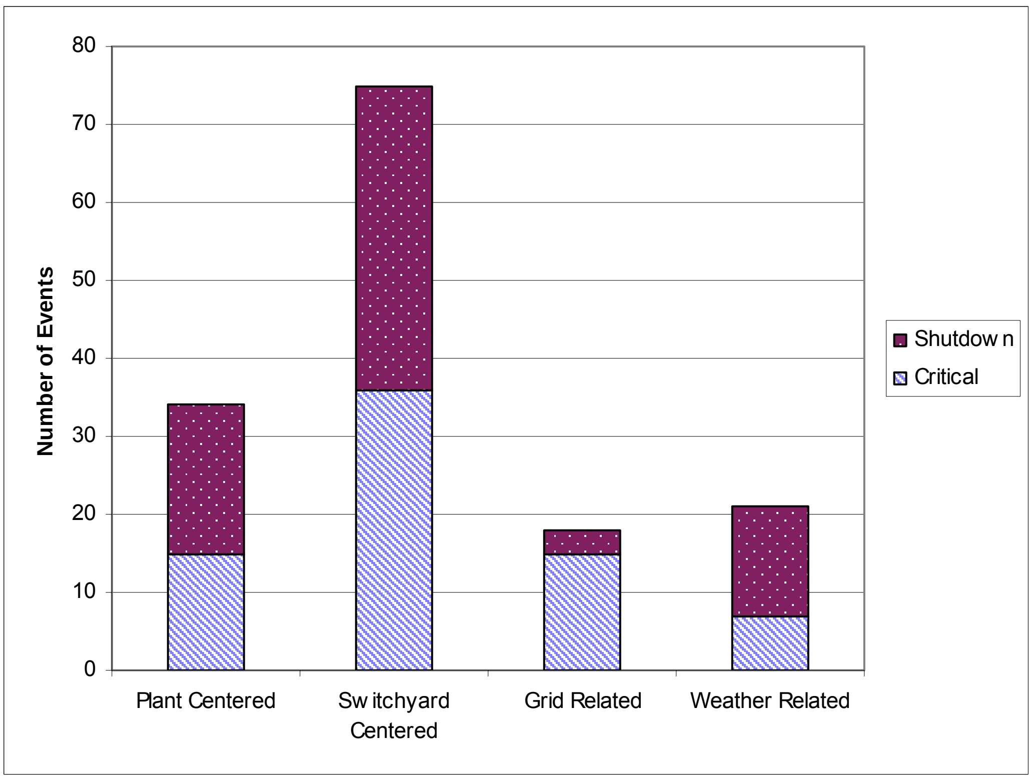


Figure 7-1. LOOP event counts by category and operational mode, 1986–2004.

Switchyard-centered LOOPs is the largest category, accounting for approximately 51% of all events. Plant-centered LOOPs is the second largest, accounting for approximately 23%. Weather related LOOPs contribute 14%. In addition, 17 of these 21 weather-related LOOPs occurred at only six sites—Pilgrim, Crystal River, Brunswick, Prairie Island, St. Lucie, 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 were less likely if 1986–2004 is considered. 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 12% to the total when considering the entire period, but are dominant if only 1997–2004 is considered.

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 (see 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 38% of the events are caused by equipment failures, and approximately 30% 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.

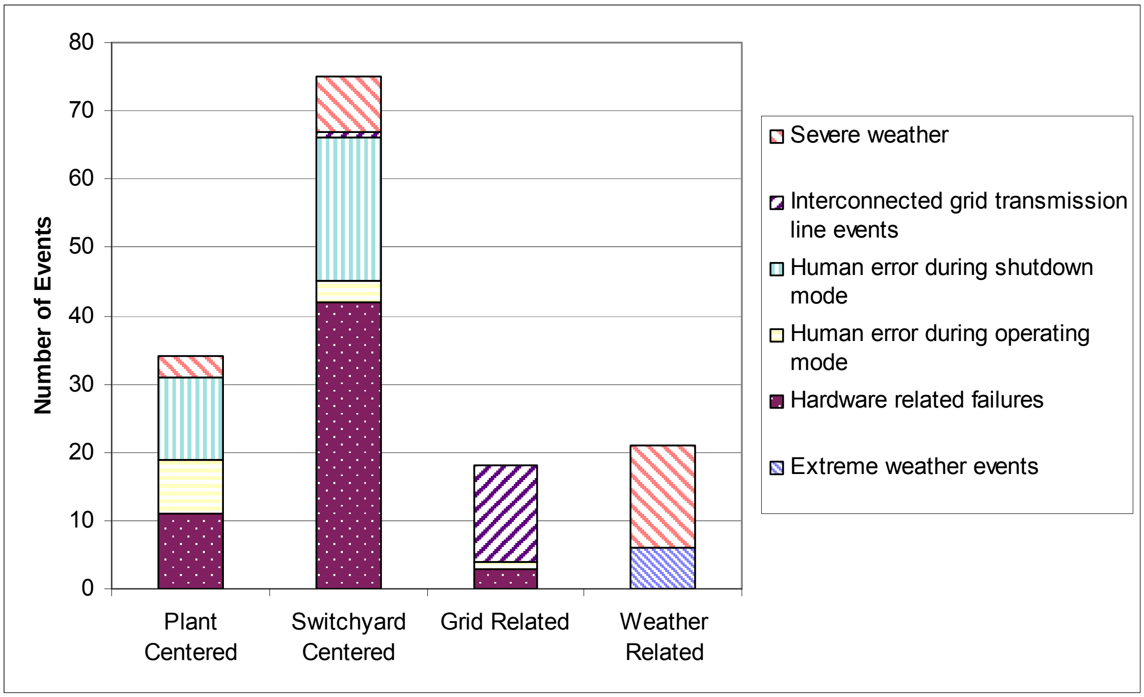


Figure 7-2. LOOP event counts by cause, 1986–2004.

Table 7-1. LOOP event counts by cause, 1986–2004.

LOOP Category	Extreme External Events	Hardware Related Failures	Human Error During Operating Mode	Human Error During Shutdown Mode	Interconnected Grid Transmission Line Events	Severe Weather	Total Events	Percent
Plant Centered	—	11	8	12	—	3	34	23%
Switchyard Centered	—	42	3	21	1	8	75	51%
Grid Related	—	3	1	—	14	—	18	12%
Weather Related	6	—	—	—	—	15	21	14%
Total	6	56	12	33	15	26	148	100%
Percent	4%	38%	8%	22%	10%	18%	100%	—

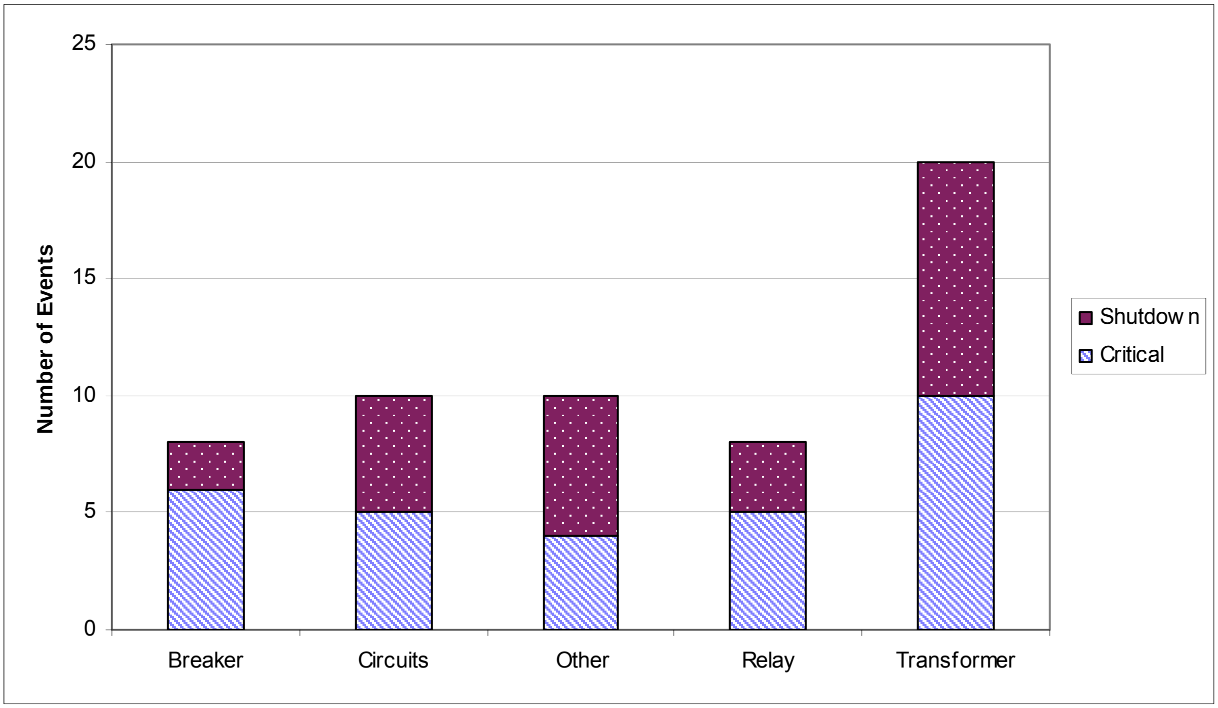


Figure 7-3. LOOP due to equipment failure by cause, 1986–2004.

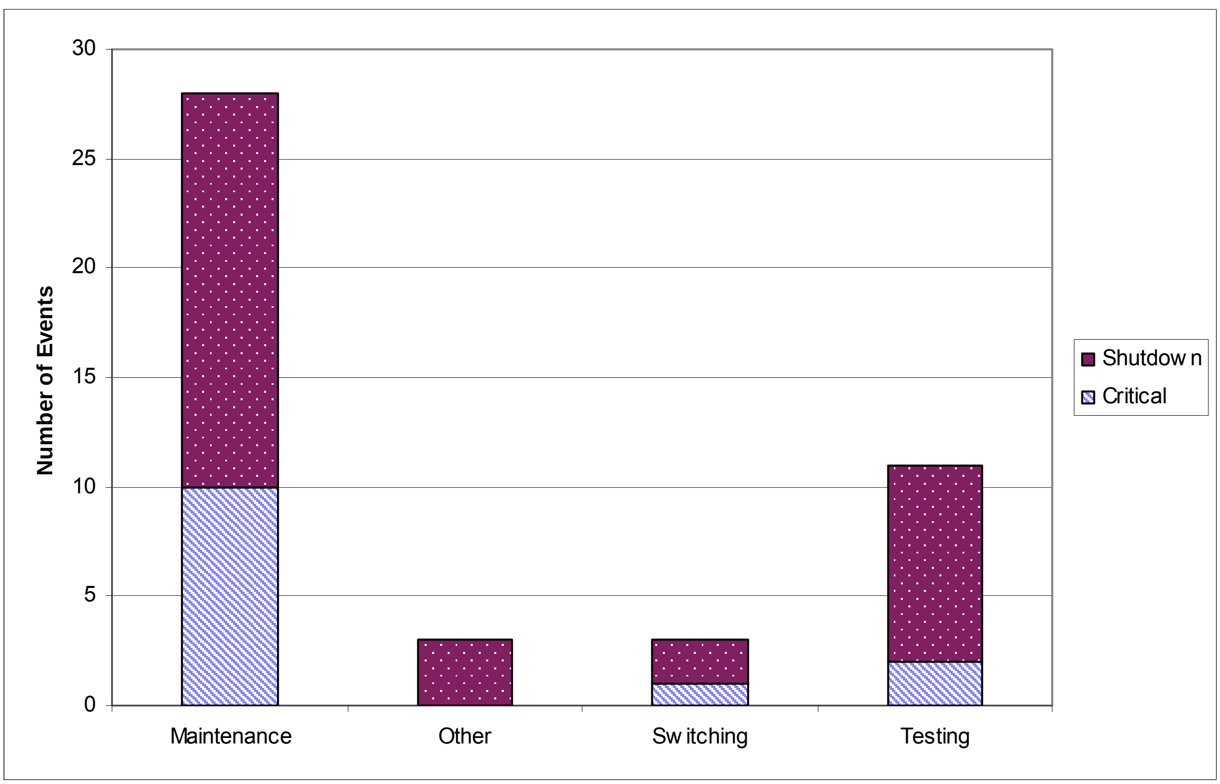


Figure 7-4. LOOP due to human error by type, 1986–2004.

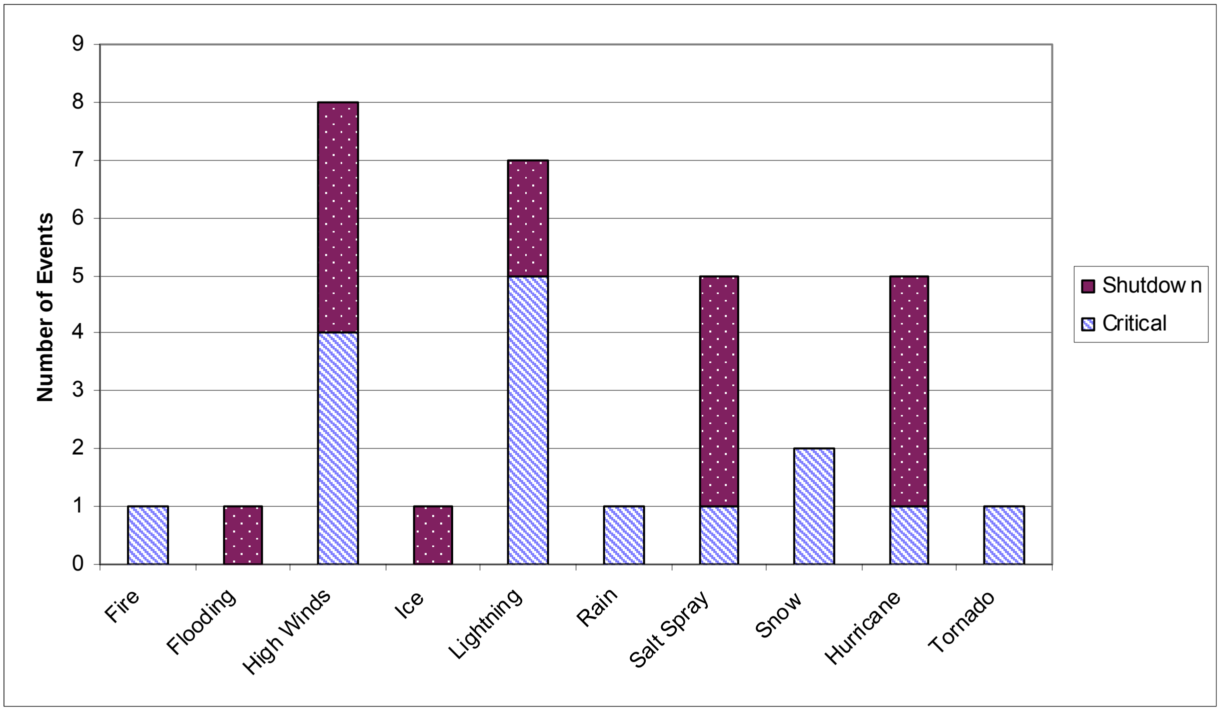


Figure 7-5. LOOP due to weather by cause, 1986–2004.

8. SUMMARY AND CONCLUSIONS

LOOP data over the period 1986–2004 were collected and analyzed. Frequency and duration estimates for critical and shutdown operations were generated for four categories of LOOPs: plant centered, switchyard centered, grid related, and weather related. These four categories were used (rather than those used in previous studies) because the frequency and duration results are statistically different for most of these categories. Because of trends in three of the four categories for critical operation, the more recent data (1997–2004) were used to estimate frequencies for all four LOOP categories 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 for the more recent data period. However, the degraded grid performance is mainly the result of one large grid blackout, the August 14, 2003, event that resulted in LOOPs at nine plants.

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 and switchyard-centered LOOPs have the lowest mean duration, while weather-related LOOPs have the highest. Similarly, the plant-centered and switchyard-centered probability of exceedance versus duration curves lie below those for the grid-related LOOPs, while the weather-related curve lies above all 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 6 h, while weather-related LOOPs dominate beyond 6 h. Switchyard-centered LOOPs are most significant for shutdown operation up to 2 h, while weather-related LOOPs dominate beyond 2 h.

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, is that the current results predict lower frequencies of exceedance up to approximately 2 h and beyond 5 h (compared with NUREG-1032). For all durations, the current results are below those from NUREG/CR-5496.

Various topics of interest were also addressed. These topics include 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 study updates estimates for LOOP frequencies for both critical and shutdown operation. In addition, LOOP duration information was 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 nonsummer months).

9. REFERENCES

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

2. C. L. Atwood, 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. J. P. Poloski, 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. H. L. Wyckoff, *Losses of Off-Site Power at U.S. Nuclear Power Plants—Through 2003*, Electric Power Research Institute, March 2004.

5. W. S. Raughley, and G. F. Lanik, *Operating Experience Assessment—Effects of Grid Events on Nuclear Power Plant Performance*, U.S. Nuclear Regulatory Commission, NUREG-1784, December 2003.

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

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

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

References

10. GLOSSARY

Actual bus restoration time—the duration, in minutes, from event initiation until offsite electrical power is 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. Extreme-weather-related events are included in the weather-related events category in this volume.

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 nonessential 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 recovery time is less than 2 min.

Nonconsequential 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 buses that requires 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 recovery time—the duration, in minutes, from the event initiation until offsite electrical power could have been recovered to a safety bus. This estimated time 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 nonlocalized 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 was 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. Severe-weather-related events are included in the weather-related category in this volume.

Station blackout (SBO)—the complete loss of ac 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 ac power system. It does not include the loss of available ac power to safety buses fed by station batteries through inverters or successful high pressure core spray operation.

Sustained loss of offsite power event—a LOOP event in which the potential bus recovery time is equal to or greater than 2 min.

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. Switchyard-centered failures typically involve hardware failures, design deficiencies, human errors, and localized weather-induced faults such as lightning. 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 event initiation until offsite electrical power is 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.

Weather-related loss of offsite power event—a LOOP event caused by severe or extreme weather.

Glossary

Appendix A

LOOP Event Database

CONTENTS

TABLES

Appendix A

LOOP Event Database

Loss of offsite power (LOOP) events were identified from Licensee Event Reports (LERs) and other sources for the period 1986–2004 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	List of all LOOP events for 1986–2004, sorted by plant name.
Table A–2	Similar to Table A–1, but covering only 1997–2004.
Table A–3	List of nuclear power plants and their regional assignments (regions as defined in this study, such as coast versus noncoast, and various electrical grid geographical breakdowns).
Table A–4	List of all LOOP events for 1986–2004 (with LOOP-NT, Lacrosse, and two Pilgrim salt spray events removed), sorted by category, and date. This table supports the LOOP category frequencies presented in Table 3–1 in the report.
Table A–5	List of all LOOP events for 1986–2004 aggregated at the site level (with LOOP-NT, Lacrosse, and two Pilgrim salt spray 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 lognormal 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 of the report.

A-1. EXPLANATION OF COLUMN HEADINGS

A-1.1 LER

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

A-1.2 Plant Name

The name of the plant experiencing the LOOP event.

A-1.3 Date

The date of the LOOP event.

A-1.4 Operational Mode

The operational mode when the LOOP occurred. This information is provided to determine which events are applicable to full-power risk assessments and which are applicable to low-power and shutdown risk assessments. The dividing line between these two risk assessments is whether the plant can use low pressure shutdown cooling (shutdown) or if it requires the power conversion system to safely shutdown and cool down (power operations). The four operational modes are described as follows.

Power Ops—The LOOP event caused a plant trip during power operation. This ensures that the plant has to cool down without the aid of the power conversion system which is lost due to the LOOP. These events apply to full power risk assessments.

Power Ops–No Trip—The LOOP event occurred during power operation and the plant remained at power. The Power Ops–No Trip events are not included in the frequency or duration analyses.

Decay Heat—The plant is at a significant decay heat point after the scram or shutdown, and it is not in a position to put a low-pressure shutdown cooling system on-line. Because of the inability to put the low-pressure shutdown cooling system on-line, the event is most appropriately modeled in the full power risk assessment.

Shutdown—The LOOP event occurred during plant hot or cold shutdown or during plant startup. The event characteristics and plant configuration apply to shutdown conditions (e.g., the low-pressure shutdown cooling system is currently supplying cooling and if the system is lost, shutdown cooling can be put on line without much cool down, or decay heat is very low).

A-1.5 Loop Class

The classification (see Figure 2–1 in the report) 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 during a LOOP.)

LOOP-IE—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-I—a LOOP-IE in which the LOOP event causes the reactor to trip.

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-NC—a LOOP-IE in which the LOOP occurs following, but is not related to, the reactor trip.

A-1.6 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 (e.g., caused by 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-centered 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.

Weather related—a LOOP event caused by severe or extreme 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 nonlocalized effects. 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 examples of extreme-weather-related LOOPs.

A-1.7 Restoration Time

Switchyard Restoration Time—the duration, in minutes, from the event initiation until 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 are considered in determining the time. The switchyard restoration time can be zero.

Potential Bus Recovery Time—the duration, in minutes, from the event initiation until 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. The potential bus recovery time is defined in the context of the time it takes to recover the switchyard and by the complexity of the evolution. Generally, this time is not explicitly provided in the LER. The following are the minimum times entered into the field, subject to the conditions listed below.

For switchyard times

≤15 min, the minimum potential bus recovery time is 15 min beyond the switchyard restoration time. This allows the operators to handle plant conditions, and then devote attention to the restoration of power to the vital buses.

>15 min and ≤30 min, the minimum potential bus recovery time shall be 10 min beyond the switchyard restoration time. This allows the operators to finish handling plant conditions, and then devote attention to the restoration of power to the vital buses.

>30 min, the minimum potential bus recovery time shall be 5 min beyond the switchyard restoration time. This assumes that the operators have finished handling plant conditions, and are waiting to restore power to the vital buses.

Conditions:

- If conditions in the switchgear are such that restoration is not immediately possible, then the potential recovery time shall be equal to the actual restoration time.
- If conditions in the switchgear are slightly complicated, damaged, or uncertain; establish an increase to the minimum time. This can be done by multiplying by a complexity factor (2, 3, 5, etc) or a fraction of the actual recovery time. The new time must then be greater than the minimum time and less than or equal to the actual restoration time. The decision is documented in the comment section of the LOOP database.
- The potential recovery data are based on no offsite and no emergency power supply to any safety buses. This means that the operators' attention is immediately focused to the electric plant and the failure of the emergency power supply. In addition, the bus is 'dead'. The operator does not have to strip the bus(s) gracefully or synchronize the offsite power with the emergency power supply.
- The actual restoration time is the time when the operators have no other concerns and are ready to go through the evolution of paralleling the emergency power supply with offsite power and shutting down the emergency power supply.

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

A-1.8 Restoration Time Uncertainty

Acronym	Description
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-1.9 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 recovery time is less than 2 min.

Sustained—a LOOP event in which the potential bus recovery time is equal to or greater than 2 min.

A-1.10 Cause

Acronym	Description
EEE	Extreme external events: hurricane, winds > 125 mph, tornado, earthquake > R7, flooding > 500 year flood for the site, sabotage.
EQUIP	Hardware related failures
G	Interconnected grid transmission line events, outside direct plant control.

Acronym	Description
HE	Human error during any operating mode.
HES	Human error during any shutdown mode.
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-1.11 Specific Cause

Cause Group	Specific Cause	Specific Cause Description
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
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 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
Other	Sabotage	Sabotage
SEE	Dust	Dust raised up by the wind
SEE	Earthquake	< 7.0
SEE	Fire	Fire
SEE	Flooding	< 500 year

Cause Group	Specific Cause	Specific Cause Description
SEE	High Winds	High winds < 125 mph
SEE	Ice	Ice
SEE	Lightning	Lightning
SEE	Rain	Rain
SEE	Salt Spray	Salt spray
SEE	Smoke	Smoke contamination
SEE	Snow	Snow
SEE	Snow and Wind	Combination of snow and wind

A-1.12 Abnormal Electrical 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.

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

A-1.13 Anticipatory Shutdown

Yes—the plant was shut down in anticipation of loss of offsite power conditions, usually extreme weather.

Dash—there was no anticipatory shutdown before the LOOP event

No—The plant was in shutdown condition already.

A-1.14 Plant Regional Assignments

Acronym	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-1.15 Coastal

Term	Description
Coastal	The east and gulf coast (up to approximately 100 miles inland).
Noncoastal	All other plant locations.

(See Figure 3–6 in the report.)

A-1.16 NERC Reliability Council Interconnection

Acronym	Description
E	Eastern
W	Western
T	Texas

(See Figure 3–7 in the report.)

A-1.17 NERC Reliability Council

Acronym	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 Electricity Coordinating Council

(See Figure 3–8 in the report.)

A-1.18 NERC Sub Regions

Acronym	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 Electricity Coordinating Council—US

Acronym	Description
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

(See Figure 3–9 in the report.)

A-2. DATA TABLES

Table A–1. LOOP events for 1986–2004, sorted by plant.

						Restoration Time (minutes)							
LER	Plant Name	Date	Operational Mode	LOOP Class	LOOP Category	Switchyard Restoration Time	Potential Bus Recovery Time	Actual Bus Restoration Time	Duration Category	Cause	Specific Cause	Abnormal Electrical Configuration	Anticipatory Shutdown
3341993013	Beaver Valley 1	10/12/1993	Power Ops	LOOP-IE-I	Switchyard Centered	15	28	28	Sustained	HES	Maintenance	Yes	—
4121987036	Beaver Valley 2	11/17/1987	Power Ops	LOOP-IE-I	Switchyard Centered	0	4	4	Sustained	Equip	Breaker	No	—
3341993013	Beaver Valley 2	10/12/1993	Shutdown	LOOP-SD	Switchyard Centered	15	28	28	Sustained	HES	Maintenance	Yes	No
1551992000	Big Rock Point	1/29/1992	Shutdown	LOOP-SD	Switchyard Centered	77	82	82	Sustained	Equip	Other	Yes	No
4561987048	Braidwood 1	9/11/1987	Shutdown	LOOP-SD	Switchyard Centered	62	63	63	Sustained	Equip	Transformer	No	No
4561988022	Braidwood 1	10/16/1988	Power Ops	LOOP-IE-I	Switchyard Centered	95	118	213	Sustained	Equip	Breaker	No	—
4561998003	Braidwood 1	9/6/1998	Shutdown	LOOP-SD	Weather Related	528	533	533	Sustained	SEE	High Winds	No	No
4571996001	Braidwood 2	1/18/1996	Power Ops-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	39	44	44	Sustained	Equip	Transformer	Yes	No
3251986024	Brunswick 1	9/13/1986	Power Ops	LOOP-IE-I	Plant Centered	0	15	159	Sustained	HE	Maintenance	No	—
3251993008	Brunswick 1	3/17/1993	Shutdown	LOOP-SD	Weather Related	1120	1125	1508	Sustained	SEE	Salt Spray	No	No
3252000001	Brunswick 1	3/3/2000	Shutdown	LOOP-SD	Switchyard Centered	15	30	136	Sustained	HES	Testing	Yes	No
3252004002	Brunswick 1	8/14/2004	Power Ops	LOOP-IE-I	Weather Related	167	172	183	Sustained	EEE	Hurricane	No	—
3241989009	Brunswick 2	6/17/1989	Power Ops	LOOP-IE-I	Switchyard Centered	85	90	403	Sustained	HE	Maintenance	No	—
3251993008	Brunswick 2	3/16/1993	Shutdown	LOOP-SD	Weather Related	813	818	1018	Sustained	SEE	Salt Spray	No	No
3241994008	Brunswick 2	5/21/1994	Shutdown	LOOP-SD	Plant Centered	2	17	42	Sustained	HES	Testing	Yes	No

Table A-1. (continued)

LER	Plant Name	Date	Operational Mode	LOOP Class	LOOP Category	Restoration Time (minutes): Switchyard Restoration Time	Potential Bus Recovery Time	Actual Bus Restoration Time	Duration Category	Cause	Specific Cause	Abnormal Electrical Configuration	Anticipatory Shutdown
4541996007	Byron 1	5/23/1996	Shutdown	LOOP-SD	Switchyard Centered	715	720	1763	Sustained	Equip	Transformer	No	No
4541998017	Byron 1	8/4/1998	Power Ops-No Trip	LOOP-NT	Plant Centered	502	507	554	Sustained	SEE	Lightning	No	—
4551987019	Byron 2	10/2/1987	Power Ops	LOOP-IE-C	Switchyard Centered	1	16	507	Sustained	HES	Switching	No	No
3171987012	Calvert Cliffs 1	7/23/1987	Power Ops	LOOP-IE-I	Switchyard Centered	113	118	118	Sustained	Equip	Circuits	No	—
3171987012	Calvert Cliffs 2	7/23/1987	Power Ops	LOOP-IE-I	Switchyard Centered	113	118	118	Sustained	Equip	Circuits	No	—
4141996001	Catawba 2	2/6/1996	Power Ops	LOOP-IE-I	Switchyard Centered	115	120	330	Sustained	Equip	Transformer	No	—
4611999002	Clinton 1	1/6/1999	Shutdown	LOOP-SD	Switchyard Centered	270	275	492	Sustained	Equip	Other	Yes	No
3971989016	Columbia 2	5/14/1989	Shutdown	LOOP-SD	Switchyard Centered	0	15	29	Sustained	HES	Maintenance	Yes	No
3151991004	Cook 1	5/12/1991	Power Ops	LOOP-IE-I	Plant Centered	0	15	81	Sustained	Equip	Other	Yes	—
3021987025	Crystal River 3	10/16/1987	Shutdown	LOOP-SD	Switchyard Centered	18	28	59	Sustained	HES	Maintenance	Yes	No
3021989023	Crystal River 3	6/16/1989	Shutdown	LOOP-SD	Switchyard Centered	60	65	65	Sustained	HES	Testing	No	No
3021989025	Crystal River 3	6/29/1989	Shutdown	LOOP-SD	Switchyard Centered	0	2	2	Momentary	SEE	Lightning	No	No
3021991010	Crystal River 3	10/20/1991	Shutdown	LOOP-SD	Plant Centered	0	4	4	Sustained	HES	Other	No	No
3021992001	Crystal River 3	3/27/1992	Power Ops	LOOP-IE-I	Plant Centered	20	30	150	Sustained	HE	Maintenance	No	—
3021993000	Crystal River 3	3/17/1993	Shutdown	LOOP-SD	Weather Related	72	77	102	Sustained	SEE	Salt Spray	Yes	No
3021993002	Crystal River 3	3/29/1993	Shutdown	LOOP-SD	Weather Related	0	15	37	Sustained	SEE	Flooding	Yes	No
3021993004	Crystal River 3	4/8/1993	Shutdown	LOOP-SD	Plant Centered	1	16	136	Sustained	HES	Maintenance	Yes	No

Table A-1. (continued)

						Restoration Time (minutes)							
LER	Plant Name	Date	Operational Mode	LOOP Class	LOOP Category	Switchyard Restoration Time	Potential Bus Recovery Time	Actual Bus Restoration Time	Duration Category	Cause	Specific Cause	Abnormal Electrical Configuration	Anticipatory Shutdown
3461998006	Davis-Besse	6/24/1998	Power Ops	LOOP-IE-I	Weather Related	1364	1428	1495	Sustained	EEE	Tornado	No	—
3462000004	Davis-Besse	4/22/2000	Shutdown	LOOP-SD	Plant Centered	0	10	10	Sustained	HES	Testing	Yes	No
3462003009	Davis-Besse	8/14/2003	Shutdown	LOOP-SD	Grid Related	652	657	849	Sustained	G	Other–load	No	No
2751991004	Diablo Canyon 1	3/7/1991	Shutdown	LOOP-SD	Switchyard Centered	261	285	285	Sustained	HES	Maintenance	Yes	No
2751995014	Diablo Canyon 1	10/21/1995	Shutdown	LOOP-SD	Switchyard Centered	40	45	951	Sustained	HES	Maintenance	Yes	No
2752000004	Diablo Canyon 1	5/15/2000	Power Ops	LOOP-IE-I	Plant Centered	1901	1906	1996	Sustained	Equip	Other	No	—
3231988008	Diablo Canyon 2	7/17/1988	Power Ops	LOOP-IE-I	Switchyard Centered	33	38	38	Sustained	Equip	Transformer	Yes	—
2371990002	Dresden 2	1/16/1990	Decay Heat	LOOP-IE-C	Switchyard Centered	0	45	759	Sustained	Equip	Transformer	No	No
2491989001	Dresden 3	3/25/1989	Power Ops	LOOP-IE-I	Switchyard Centered	45	50	50	Sustained	Equip	Breaker	No	—
2492004003	Dresden 3	5/5/2004	Power Ops	LOOP-IE-I	Switchyard Centered	146	151	151	Sustained	Equip	Breaker	No	—
3311990007	Duane Arnold	7/9/1990	Shutdown	LOOP-SD	Switchyard Centered	0	37	37	Sustained	HES	Testing	Yes	No
3482000005	Farley 1	4/9/2000	Shutdown	LOOP-SD	Switchyard Centered	0	19	19	Sustained	Equip	Relay	Yes	No
3412003002	Fermi 2	8/14/2003	Power Ops	LOOP-IE-I	Grid Related	379	384	582	Sustained	G	Other–load	No	—
3331988011	FitzPatrick	10/31/1988	Shutdown	LOOP-SD	Weather Related	1	16	70	Sustained	SEE	High Winds	Yes	No
3332003001	FitzPatrick	8/14/2003	Power Ops	LOOP-IE-I	Grid Related	169	174	414	Sustained	G	Other–load	No	—
2851987008	Fort Calhoun	3/21/1987	Shutdown	LOOP-SD	Switchyard Centered	37	38	38	Sustained	HES	Maintenance	Yes	No
2851987009	Fort Calhoun	4/4/1987	Shutdown	LOOP-SD	Switchyard Centered	0	4	4	Sustained	HES	Maintenance	Yes	No
2851990006	Fort Calhoun	2/26/1990	Shutdown	LOOP-SD	Switchyard Centered	0	14	14	Sustained	HES	Maintenance	Yes	No
2851998005	Fort Calhoun	5/20/1998	Shutdown	LOOP-SD	Switchyard Centered	104	109	109	Sustained	Equip	Transformer	No	No

Table A-1. (continued)

LER	Plant Name	Date	Operational Mode	LOOP Class	LOOP Category	Restoration Time (minutes) Switchyard Restoration Time	Potential Bus Recovery Time	Actual Bus Restoration Time	Duration Category	Cause	Specific Cause	Abnormal Electrical Configuration	Anticipatory Shutdown
2851999004	Fort Calhoun	10/26/1999	Shutdown	LOOP-SD	Plant Centered	2	2	2	Momentary	Equip	Other	Yes	No
2441988006	Ginna	7/16/1988	Power Ops-No Trip	LOOP-NT	Switchyard Centered	65	70	225	Sustained	Equip	Transformer	No	—
2442003002	Ginna	8/14/2003	Power Ops	LOOP-IE-I	Grid Related	49	54	297	Sustained	G	Other–load	No	—
4162003002	Grand Gulf	4/24/2003	Power Ops	LOOP-IE-C	Switchyard Centered	0	15	75	Sustained	SEE	High Winds	Yes	—
2131993009	Haddam Neck	6/22/1993	Shutdown	LOOP-SD	Plant Centered	12	27	35	Sustained	Equip	Circuits	Yes	No
2131993010	Haddam Neck	6/26/1993	Shutdown	LOOP-SD	Plant Centered	3	18	40	Sustained	Equip	Circuits	Yes	No
2471991006	Indian Point 2	3/20/1991	Shutdown	LOOP-SD	Switchyard Centered	0	15	29	Sustained	Equip	Other	No	No
2471991010	Indian Point 2	6/22/1991	Shutdown	LOOP-SD	Plant Centered	0	60	60	Sustained	Equip	Breaker	Yes	No
2471998013	Indian Point 2	9/1/1998	Shutdown	LOOP-SD	Plant Centered	1	16	67	Sustained	HES	Testing	Yes	No
2471999015	Indian Point 2	8/31/1999	Decay Heat	LOOP-IE-C	Switchyard Centered	0	15	779	Sustained	Equip	Circuits	No	No
2472003005	Indian Point 2	8/14/2003	Power Ops	LOOP-IE-I	Grid Related	97	102	214	Sustained	G	Other–load	No	—
2861995004	Indian Point 3	2/27/1995	Shutdown	LOOP-SD	Switchyard Centered	30	40	132	Sustained	HES	Maintenance	No	No
2861996002	Indian Point 3	1/20/1996	Shutdown	LOOP-SD	Switchyard Centered	30	40	145	Sustained	Equip	Transformer	No	No
2861997008	Indian Point 3	6/16/1997	Shutdown	LOOP-SD	Grid Related	37	42	42	Sustained	HE	Maintenance	No	No
2862003005	Indian Point 3	8/14/2003	Power Ops	LOOP-IE-I	Grid Related	97	102	241	Sustained	G	Other–load	No	—
4091986023	La Crosse	7/19/1986	Shutdown	LOOP-SD	Switchyard Centered	12	15	15	Sustained	SEE	Lightning	No	No
3731993015	La Salle 1	9/14/1993	Power Ops	LOOP-IE-I	Switchyard Centered	0	15	70	Sustained	Equip	Transformer	No	—
3091988006	Maine Yankee	8/13/1988	Power Ops	LOOP-IE-I	Switchyard Centered	14	15	15	Sustained	Equip	Transformer	No	—
3691987021	McGuire 1	9/16/1987	Shutdown	LOOP-SD	Plant Centered	0	6	6	Sustained	HES	Testing	Yes	No

Table A-1. (continued)

LER	Plant Name	Date	Operational Mode	LOOP Class	LOOP Category	Restoration Time (minutes) Switchyard Restoration Time	Potential Bus Recovery Time	Actual Bus Restoration Time	Duration Category	Cause	Specific Cause	Abnormal Electrical Configuration	Anticipatory Shutdown
3691991001	McGuire 1	2/11/1991	Power Ops	LOOP-IE-I	Plant Centered	0	40	60	Sustained	HE	Testing	No	—
3691988014	McGuire 2	6/24/1988	Shutdown	LOOP-SD	Switchyard Centered	8	8	8	Sustained	HES	Switching	Yes	No
3701993008	McGuire 2	12/27/1993	Power Ops	LOOP-IE-I	Switchyard Centered	96	101	131	Sustained	Equip	Transformer	No	—
2451989012	Millstone 1	4/29/1989	Shutdown	LOOP-SD	Switchyard Centered	0	15	75	Sustained	HES	Other	Yes	No
3361986017	Millstone 2	11/5/1986	Shutdown	LOOP-SD	Switchyard Centered	(a)	(a)	(a)	Momentary	HES	Maintenance	Yes	No
3361988011	Millstone 2	10/25/1988	Power Ops	LOOP-IE-I	Plant Centered	19	29	29	Sustained	HE	Maintenance	No	—
2201990023	Nine Mile Pt. 1	11/12/1990	Power Ops-No Trip	LOOP-NT	Switchyard Centered	355	360	360	Sustained	Equip	Transformer	No	—
2201993007	Nine Mile Pt. 1	8/31/1993	Power Ops-No Trip	LOOP-NT	Plant Centered	1	16	18	Sustained	SEE	Lightning	No	—
2202002001	Nine Mile Pt. 1	11/1/2002	Power Ops-No Trip	LOOP-NT	Switchyard Centered	0	15	482	Sustained	G	Equip–other	Yes	—
2202003002	Nine Mile Pt. 1	8/14/2003	Power Ops	LOOP-IE-I	Grid Related	105	110	448	Sustained	G	Other–load	No	—
4101988062	Nine Mile Pt. 2	12/26/1988	Shutdown	LOOP-SD	Switchyard Centered	9	24	54	Sustained	Equip	Transformer	Yes	No
4101992006	Nine Mile Pt. 2	3/23/1992	Shutdown	LOOP-SD	Plant Centered	20	30	50	Sustained	HES	Maintenance	No	No
4102003002	Nine Mile Pt. 2	8/14/2003	Power Ops	LOOP-IE-I	Grid Related	105	110	551	Sustained	G	Other–load	No	—
2701992004	Oconee 2	10/19/1992	Power Ops	LOOP-IE-I	Plant Centered	207	207	207	Sustained	HE	Maintenance	No	—
2871987002	Oconee 3	3/5/1987	Shutdown	LOOP-SD	Switchyard Centered	150	155	155	Sustained	HES	Maintenance	No	No
2191989015	Oyster Creek	5/18/1989	Power Ops	LOOP-IE-I	Plant Centered	1	16	54	Sustained	HE	Maintenance	No	—
2191992005	Oyster Creek	5/3/1992	Power Ops	LOOP-IE-I	Plant Centered	5	65	1029	Sustained	SEE	Fire	No	—
2191997010	Oyster Creek	8/1/1997	Power Ops	LOOP-IE-C	Switchyard Centered	30	40	40	Sustained	Equip	Relay	No	—

Table A-1. (continued)

LER	Plant Name	Date	Operational Mode	LOOP Class	LOOP Category	Restoration Time (minutes) Switchyard Restoration Time	Potential Bus Recovery Time	Actual Bus Restoration Time	Duration Category	Cause	Specific Cause	Abnormal Electrical Configuration	Anticipatory Shutdown
2551987024	Palisades	7/14/1987	Power Ops	LOOP-IE-I	Switchyard Centered	388	388	446	Sustained	HE	Maintenance	No	—
2551992032	Palisades	4/6/1992	Shutdown	LOOP-SD	Plant Centered	0	15	30	Sustained	HES	Testing	No	No
2551998013	Palisades	12/22/1998	Shutdown	LOOP-SD	Plant Centered	0	20	20	Sustained	Equip	Transformer	No	No
2552003003	Palisades	3/25/2003	Shutdown	LOOP-SD	Plant Centered	91	96	3261	Sustained	HES	Maintenance	Yes	No
5282004006	Palo Verde 1	6/14/2004	Power Ops	LOOP-IE-I	Grid Related	32	37	57	Sustained	G	Equip–other	No	—
5291989001	Palo Verde 2	1/3/1989	Power Ops-No Trip	LOOP-NT	Switchyard Centered	1138	1143	1266	Sustained	SEE	Rain	No	—
5282004006	Palo Verde 2	6/14/2004	Power Ops	LOOP-IE-I	Grid Related	32	37	106	Sustained	G	Equip–other	No	—
5282004006	Palo Verde 3	6/14/2004	Power Ops	LOOP-IE-I	Grid Related	32	37	59	Sustained	G	Equip–other	No	—
2771988020	Peach Bottom 2	7/29/1988	Shutdown	LOOP-SD	Switchyard Centered	9	24	125	Sustained	Equip	Transformer	Yes	No
2772003004	Peach Bottom 2	9/15/2003	Power Ops	LOOP-IE-I	Grid Related	1	16	41	Sustained	Equip	Relay	No	—
2771988020	Peach Bottom 3	7/29/1988	Shutdown	LOOP-SD	Switchyard Centered	9	24	125	Sustained	Equip	Transformer	Yes	No
2772003004	Peach Bottom 3	9/15/2003	Power Ops	LOOP-IE-I	Grid Related	1	16	103	Sustained	Equip	Relay	No	—
4402003002	Perry	8/14/2003	Power Ops	LOOP-IE-I	Grid Related	82	87	123	Sustained	G	Other–load	No	—
2931986027	Pilgrim	11/19/1986	Shutdown	LOOP-SD	Weather Related	0	15	213	Sustained	SEE	Ice	No	No
2931986029	Pilgrim	12/23/1986	Shutdown	LOOP-SD	Switchyard Centered	0	1	1	Momentary	HES	Maintenance	No	No
2931987005	Pilgrim	3/31/1987	Shutdown	LOOP-SD	Weather Related	1	16	45	Sustained	SEE	High Winds	Yes	No
2931987014	Pilgrim	11/12/1987	Shutdown	LOOP-SD	Weather Related	1258	1263	1263	Sustained	SEE	Salt Spray	No	No
2931989010	Pilgrim	2/21/1989	Shutdown	LOOP-SD	Switchyard Centered	1	16	920	Sustained	Equip	Other	No	No
2931991024	Pilgrim	10/30/1991	Decay Heat	LOOP-IE-NC	Weather Related	109	114	152	Sustained	SEE	Salt Spray	No	No
2931993004	Pilgrim	3/13/1993	Power Ops	LOOP-IE-I	Weather Related	30	40	298	Sustained	SEE	Snow	No	—

Table A-1. (continued)

LER	Plant Name	Date	Operational Mode	LOOP Class	LOOP Category	Restoration Time (minutes) Switchyard Restoration Time	Restoration Time (minutes) Potential Bus Recovery Time	Restoration Time (minutes) Actual Bus Restoration Time	Duration Category	Cause	Specific Cause	Abnormal Electrical Configuration	Anticipatory Shutdown
2931993010	Pilgrim	5/19/1993	Shutdown	LOOP-SD	Switchyard Centered	36	37	37	Sustained	HES	Testing	No	No
2931993022	Pilgrim	9/10/1993	Power Ops	LOOP-IE-I	Switchyard Centered	10	25	200	Sustained	SEE	Lightning	No	—
2931997007	Pilgrim	4/1/1997	Shutdown	LOOP-SD	Weather Related	347	1200	1208	Sustained	SEE	High Winds	No	No
2661992003	Point Beach 1	4/28/1992	Shutdown	LOOP-SD	Plant Centered	0	15	30	Sustained	HES	Maintenance	Yes	No
2661998002	Point Beach 1	1/8/1998	Power Ops-No Trip	LOOP-NT	Switchyard Centered	337	342	557	Sustained	Equip	Other	No	—
3011989002	Point Beach 2	3/29/1989	Power Ops	LOOP-IE-C	Switchyard Centered	90	95	202	Sustained	HE	Maintenance	No	—
2661994010	Point Beach 2	9/27/1994	Shutdown	LOOP-SD	Plant Centered	0	15	15	Sustained	HES	Switching	Yes	No
2821996012	Prairie Island 1	6/29/1996	Power Ops	LOOP-IE-I	Weather Related	292	297	297	Sustained	SEE	High Winds	No	—
2821996012	Prairie Island 2	6/29/1996	Power Ops	LOOP-IE-I	Weather Related	292	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	No
2652001001	Quad Cities 2	8/2/2001	Power Ops	LOOP-IE-I	Switchyard Centered	15	30	154	Sustained	SEE	Lightning	No	—
4581986002	River Bend	1/1/1986	Shutdown	LOOP-SD	Switchyard Centered	46	51	51	Sustained	Equip	Circuits	No	No
2611986005	Robinson 2	1/28/1986	Power Ops	LOOP-IE-C	Plant Centered	117	122	403	Sustained	Equip	Relay	No	—
2611992017	Robinson 2	8/22/1992	Power Ops	LOOP-IE-I	Switchyard Centered	454	459	914	Sustained	Equip	Transformer	No	—
2722003002	Salem 1	7/29/2003	Power Ops	LOOP-IE-I	Switchyard Centered	30	40	480	Sustained	Equip	Circuits	No	—
3111986007	Salem 2	8/26/1986	Decay Heat	LOOP-IE-C	Plant Centered	0	15	75	Sustained	Equip	Other	No	No
3111994007	Salem 2	4/11/1994	Power Ops-No Trip	LOOP-NT	Plant Centered	0	15	385	Sustained	HE	Testing	No	—

Table A-1. (continued)

LER	Plant Name	Date	Operational Mode	LOOP Class	LOOP Category	Restoration Time (minutes) Switchyard Restoration Time	Potential Bus Recovery Time	Actual Bus Restoration Time	Duration Category	Cause	Specific Cause	Abnormal Electrical Configuration	Anticipatory Shutdown
3111994014	Salem 2	11/18/1994	Shutdown	LOOP-SD	Switchyard Centered	295	300	1675	Sustained	Equip	Relay	Yes	No
4431991008	Seabrook	6/27/1991	Power Ops	LOOP-IE-I	Switchyard Centered	0	20	20	Sustained	Equip	Relay	No	—
4432001002	Seabrook	3/5/2001	Power Ops	LOOP-IE-I	Weather Related	1	16	2122	Sustained	SEE	Snow	No	—
3271992027	Sequoyah 1	12/31/1992	Power Ops	LOOP-IE-I	Switchyard Centered	96	101	116	Sustained	Equip	Breaker	No	—
3271992027	Sequoyah 2	12/31/1992	Power Ops	LOOP-IE-I	Switchyard Centered	96	101	116	Sustained	Equip	Breaker	No	—
3352004004	St. Lucie 1	9/25/2004	Shutdown	LOOP-SD	Weather Related	8	68	667	Sustained	EEE	Hurricane	Yes	Yes
3352004004	St. Lucie 2	9/25/2004	Shutdown	LOOP-SD	Weather Related	8	68	613	Sustained	EEE	Hurricane	Yes	Yes
3951989012	Summer	7/11/1989	Decay Heat	LOOP-IE-C	Grid Related	95	100	120	Sustained	G	Equip–other	No	No
2891997007	Three Mile Isl 1	6/21/1997	Power Ops	LOOP-IE-I	Switchyard Centered	85	90	90	Sustained	Equip	Circuits	No	—
2501991003	Turkey Point 3	7/24/1991	Shutdown	LOOP-SD	Switchyard Centered	0	11	11	Sustained	Equip	Breaker	Yes	No
2501992000	Turkey Point 3	8/24/1992	Shutdown	LOOP-SD	Weather Related	7916	7921	7921	Sustained	EEE	Hurricane	No	Yes
2511991001	Turkey Point 4	3/13/1991	Shutdown	LOOP-SD	Plant Centered	62	67	67	Sustained	Equip	Relay	Yes	No
2501992000	Turkey Point 4	8/24/1992	Shutdown	LOOP-SD	Weather Related	7916	7921	7921	Sustained	EEE	Hurricane	No	Yes
2512000004	Turkey Point 4	10/21/2000	Shutdown	LOOP-SD	Switchyard Centered	1	16	111	Sustained	Equip	Circuits	No	No
2711987008	Vermont Yankee	8/17/1987	Shutdown	LOOP-SD	Grid Related	2	17	77	Sustained	Equip	Other	Yes	No
2711991009	Vermont Yankee	4/23/1991	Power Ops	LOOP-IE-I	Plant Centered	277	282	822	Sustained	HE	Maintenance	No	—
4241990006	Vogtle 1	3/20/1990	Shutdown	LOOP-SD	Switchyard Centered	140	145	217	Sustained	HES	Other	Yes	No
3902002005	Watts Bar 1	9/27/2002	Power Ops-No Trip	LOOP-NT	Grid Related	1	16	1003	Sustained	G	Other–fire	No	—

Table A-1. (continued)

LER	Plant Name	Date	Operational Mode	LOOP Class	LOOP Category	Restoration Time (minutes) Switchyard Restoration Time	Potential Bus Recovery Time	Actual Bus Restoration Time	Duration Category	Cause	Specific Cause	Abnormal Electrical Configuration	Anticipatory Shutdown
4821987048	Wolf Creek	10/14/1987	Shutdown	LOOP-SD	Plant Centered	0	17	17	Sustained	HES	Maintenance	Yes	No
0291991002	Yankee-Rowe	6/15/1991	Power Ops	LOOP-IE-I	Switchyard Centered	24	25	25	Sustained	SEE	Lightning	No	—
2951997007	Zion 1	3/11/1997	Shutdown	LOOP-SD	Switchyard Centered	235	240	240	Sustained	Equip	Circuits	No	No
3041991002	Zion 2	3/21/1991	Power Ops	LOOP-IE-I	Switchyard Centered	0	60	60	Sustained	Equip	Transformer	No	—

a. The recovery/restoration times were unknown for this event.

Table A-2. LOOP events for 1997–2004, sorted by plant.

LER	Plant Name	Date	Operational Mode	LOOP Class	LOOP Category	Restoration Time (minutes) Switchyard Restoration Time	Potential Bus Recovery Time	Actual Bus Restoration Time	Duration Category	Cause	Specific Cause	Abnormal Electrical Configuration	Anticipatory Shutdown
4561998003	Braidwood 1	9/6/1998	Shutdown	LOOP-SD	Weather Related	528	533	533	Sustained	SEE	High Winds	No	No
2961997001	Browns Ferry 3	3/5/1997	Shutdown	LOOP-SD	Switchyard Centered	39	44	44	Sustained	Equip	Transformer	Yes	No
3252000001	Brunswick 1	3/3/2000	Shutdown	LOOP-SD	Switchyard Centered	15	30	136	Sustained	HES	Testing	Yes	No
3252004002	Brunswick 1	8/14/2004	Power Ops	LOOP-IE-I	Weather Related	167	172	183	Sustained	EEE	Hurricane	No	—
4541998017	Byron 1	8/4/1998	Power Ops-No Trip	LOOP-NT	Plant Centered	502	507	554	Sustained	SEE	Lightning	No	—
4611999002	Clinton 1	1/6/1999	Shutdown	LOOP-SD	Switchyard Centered	270	275	492	Sustained	Equip	Other	Yes	No
3461998006	Davis-Besse	6/24/1998	Power Ops	LOOP-IE-I	Weather Related	1364	1428	1495	Sustained	EEE	Tornado	No	—
3462000004	Davis-Besse	4/22/2000	Shutdown	LOOP-SD	Plant Centered	0	10	10	Sustained	HES	Testing	Yes	No
3462003009	Davis-Besse	8/14/2003	Shutdown	LOOP-SD	Grid Related	652	657	849	Sustained	G	Other–load	No	No
2752000004	Diablo Canyon 1	5/15/2000	Power Ops	LOOP-IE-I	Plant Centered	1901	1906	1996	Sustained	Equip	Other	No	—
2492004003	Dresden 3	5/5/2004	Power Ops	LOOP-IE-I	Switchyard Centered	146	151	151	Sustained	Equip	Breaker	No	—
3482000005	Farley 1	4/9/2000	Shutdown	LOOP-SD	Switchyard Centered	0	19	19	Sustained	Equip	Relay	Yes	No
3412003002	Fermi 2	8/14/2003	Power Ops	LOOP-IE-I	Grid Related	379	384	582	Sustained	G	Other–load	No	—
3332003001	FitzPatrick	8/14/2003	Power Ops	LOOP-IE-I	Grid Related	169	174	414	Sustained	G	Other–load	No	—
2851998005	Fort Calhoun	5/20/1998	Shutdown	LOOP-SD	Switchyard Centered	104	109	109	Sustained	Equip	Transformer	No	No
2851999004	Fort Calhoun	10/26/1999	Shutdown	LOOP-SD	Plant Centered	2	2	2	Momentary	Equip	Other	Yes	No
2442003002	Ginna	8/14/2003	Power Ops	LOOP-IE-I	Grid Related	49	54	297	Sustained	G	Other–load	No	—
4162003002	Grand Gulf	4/24/2003	Power Ops	LOOP-IE-C	Switchyard Centered	0	15	75	Sustained	SEE	High Winds	Yes	—
2471998013	Indian Point 2	9/1/1998	Shutdown	LOOP-SD	Plant Centered	1	16	67	Sustained	HES	Testing	Yes	No

Table A-2. (continued)

						Restoration Time (minutes)							
LER	Plant Name	Date	Operational Mode	LOOP Class	LOOP Category	Switchyard Restoration Time	Potential Bus Recovery Time	Actual Bus Restoration Time	Duration Category	Cause	Specific Cause	Abnormal Electrical Configuration	Anticipatory Shutdown
2471999015	Indian Point 2	8/31/1999	Decay Heat	LOOP-IE-C	Switchyard Centered	0	15	779	Sustained	Equip	Circuits	No	No
2472003005	Indian Point 2	8/14/2003	Power Ops	LOOP-IE-I	Grid Related	97	102	214	Sustained	G	Other–load	No	—
2861997008	Indian Point 3	6/16/1997	Shutdown	LOOP-SD	Grid Related	37	42	42	Sustained	HE	Maintenance	No	No
2862003005	Indian Point 3	8/14/2003	Power Ops	LOOP-IE-I	Grid Related	97	102	241	Sustained	G	Other–load	No	—
2202002001	Nine Mile Pt. 1	11/1/2002	Power Ops-No Trip	LOOP-NT	Switchyard Centered	0	15	482	Sustained	G	Equip–other	Yes	—
2202003002	Nine Mile Pt. 1	8/14/2003	Power Ops	LOOP-IE-I	Grid Related	105	110	448	Sustained	G	Other–load	No	—
4102003002	Nine Mile Pt. 2	8/14/2003	Power Ops	LOOP-IE-I	Grid Related	105	110	551	Sustained	G	Other–load	No	—
2191997010	Oyster Creek	8/1/1997	Power Ops	LOOP-IE-C	Switchyard Centered	30	40	40	Sustained	Equip	Relay	No	—
2551998013	Palisades	12/22/1998	Shutdown	LOOP-SD	Plant Centered	0	20	20	Sustained	Equip	Transformer	No	No
2552003003	Palisades	3/25/2003	Shutdown	LOOP-SD	Plant Centered	91	96	3261	Sustained	HES	Maintenance	Yes	No
5282004006	Palo Verde 1	6/14/2004	Power Ops	LOOP-IE-I	Grid Related	32	37	57	Sustained	G	Equip–other	No	—
5282004006	Palo Verde 2	6/14/2004	Power Ops	LOOP-IE-I	Grid Related	32	37	106	Sustained	G	Equip–other	No	—
5282004006	Palo Verde 3	6/14/2004	Power Ops	LOOP-IE-I	Grid Related	32	37	59	Sustained	G	Equip–other	No	—
2772003004	Peach Bottom 2	9/15/2003	Power Ops	LOOP-IE-I	Grid Related	1	16	41	Sustained	Equip	Relay	No	—
2772003004	Peach Bottom 3	9/15/2003	Power Ops	LOOP-IE-I	Grid Related	1	16	103	Sustained	Equip	Relay	No	—
4402003002	Perry	8/14/2003	Power Ops	LOOP-IE-I	Grid Related	82	87	123	Sustained	G	Other–load	No	—
2931997007	Pilgrim	4/1/1997	Shutdown	LOOP-SD	Weather Related	347	1200	1208	Sustained	SEE	High Winds	No	No
2661998002	Point Beach 1	1/8/1998	Power Ops-No Trip	LOOP-NT	Switchyard Centered	337	342	557	Sustained	Equip	Other	No	—
2652001001	Quad Cities 2	8/2/2001	Power Ops	LOOP-IE-I	Switchyard Centered	15	30	154	Sustained	SEE	Lightning	No	—
2722003002	Salem 1	7/29/2003	Power Ops	LOOP-IE-I	Switchyard Centered	30	40	480	Sustained	Equip	Circuits	No	—

Table A-2. (continued)

LER	Plant Name	Date	Operational Mode	LOOP Class	LOOP Category	Restoration Time (minutes) Switchyard Restoration Time	Potential Bus Recovery Time	Actual Bus Restoration Time	Duration Category	Cause	Specific Cause	Abnormal Electrical Configuration	Anticipatory Shutdown
4432001002	Seabrook	3/5/2001	Power Ops	LOOP-IE-I	Weather Related	1	16	2122	Sustained	SEE	Snow	No	—
3352004004	St. Lucie 1	9/25/2004	Shutdown	LOOP-SD	Weather Related	8	68	667	Sustained	EEE	Hurricane	Yes	Yes
3352004004	St. Lucie 2	9/25/2004	Shutdown	LOOP-SD	Weather Related	8	68	613	Sustained	EEE	Hurricane	Yes	Yes
2891997007	Three Mile Isl 1	6/21/1997	Power Ops	LOOP-IE-I	Switchyard Centered	85	90	90	Sustained	Equip	Circuits	No	—
2512000004	Turkey Point 4	10/21/2000	Shutdown	LOOP-SD	Switchyard Centered	1	16	111	Sustained	Equip	Circuits	No	No
3902002005	Watts Bar 1	9/27/2002	Power Ops-No Trip	LOOP-NT	Grid Related	1	16	1003	Sustained	G	Other–fire	No	—
2951997007	Zion 1	3/11/1997	Shutdown	LOOP-SD	Switchyard Centered	235	240	240	Sustained	Equip	Circuits	No	No

Table A-3. Plant regional assignments.

Plant Name	State	State Group	Coastal? (True or False)	NERC Subregion	Reliability Council	Interconnection	NUREG-1032 Design Group[a]
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
Farley 2	AL	SE	T	SERC-S	SERC	E	I3
Fermi 2	MI	NE	F	ECAR	ECAR	E	I3

Table A-3. (continued)

Plant Name	State	State Group	Coastal? (True or False)	NERC Subregion	Reliability Council	Interconnection	NUREG-1032 Design Group[a]
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
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

Table A-3. (continued)

Plant Name	State	State Group	Coastal? (True or False)	NERC Subregion	Reliability Council	Interconnection	NUREG-1032 Design Group[a]
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	T	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
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*

Table A-3. (continued)

Plant Name	State	State Group	Coastal? (**T**rue or **F**alse)	NERC Subregion	Reliability Council	Interconnection	NUREG-1032 Design Group[a]
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*

a. The plants with asterisks were classified as to design group in NUREG/CR-5496.

Table A-4. LOOP events grouped by category and date for 1986–2004.

LOOP Category	Date	LER	Plant Name	Operational Mode	LOOP Class	Restoration Time (minutes): Switchyard Restoration Time	Restoration Time (minutes): Potential Bus Recovery Time	Restoration Time (minutes): Actual Bus Restoration Time	Duration Category	Cause	Specific Cause
Grid Related	8/17/1987	2711987008	Vermont Yankee	Shutdown	LOOP-SD	2	17	77	Sustained	Equip	Other
Grid Related	7/11/1989	3951989012	Summer	Decay Heat	LOOP-IE-C	95	100	120	Sustained	G	Equip–other
Grid Related	6/16/1997	2861997008	Indian Point 3	Shutdown	LOOP-SD	37	42	42	Sustained	HE	Maintenance
Grid Related	8/14/2003	3462003009	Davis-Besse	Shutdown	LOOP-SD	652	657	849	Sustained	G	Other–load
Grid Related	8/14/2003	3412003002	Fermi 2	Power Ops	LOOP-IE-I	379	384	582	Sustained	G	Other–load
Grid Related	8/14/2003	3332003001	FitzPatrick	Power Ops	LOOP-IE-I	169	174	414	Sustained	G	Other–load
Grid Related	8/14/2003	2442003002	Ginna	Power Ops	LOOP-IE-I	49	54	297	Sustained	G	Other–load
Grid Related	8/14/2003	2472003005	Indian Point 2	Power Ops	LOOP-IE-I	97	102	214	Sustained	G	Other–load
Grid Related	8/14/2003	2862003005	Indian Point 3	Power Ops	LOOP-IE-I	97	102	241	Sustained	G	Other–load
Grid Related	8/14/2003	2202003002	Nine Mile Pt. 1	Power Ops	LOOP-IE-I	105	110	448	Sustained	G	Other–load
Grid Related	8/14/2003	4102003002	Nine Mile Pt. 2	Power Ops	LOOP-IE-I	105	110	551	Sustained	G	Other–load
Grid Related	8/14/2003	4402003002	Perry	Power Ops	LOOP-IE-I	82	87	123	Sustained	G	Other–load
Grid Related	9/15/2003	2772003004	Peach Bottom 2	Power Ops	LOOP-IE-I	1	16	41	Sustained	Equip	Relay
Grid Related	9/15/2003	2772003004	Peach Bottom 3	Power Ops	LOOP-IE-I	1	16	103	Sustained	Equip	Relay
Grid Related	6/14/2004	5282004006	Palo Verde 1	Power Ops	LOOP-IE-I	32	37	57	Sustained	G	Equip–other
Grid Related	6/14/2004	5282004006	Palo Verde 2	Power Ops	LOOP-IE-I	32	37	106	Sustained	G	Equip–other
Grid Related	6/14/2004	5282004006	Palo Verde 3	Power Ops	LOOP-IE-I	32	37	59	Sustained	G	Equip–other
Plant Centered	1/28/1986	2611986005	Robinson 2	Power Ops	LOOP-IE-C	117	122	403	Sustained	Equip	Relay
Plant Centered	8/26/1986	3111986007	Salem 2	Decay Heat	LOOP-IE-C	0	15	75	Sustained	Equip	Other
Plant Centered	9/13/1986	3251986024	Brunswick 1	Power Ops	LOOP-IE-I	0	15	159	Sustained	HE	Maintenance
Plant Centered	9/16/1987	3691987021	McGuire 1	Shutdown	LOOP-SD	0	6	6	Sustained	HES	Testing
Plant Centered	10/14/1987	4821987048	Wolf Creek	Shutdown	LOOP-SD	0	17	17	Sustained	HES	Maintenance
Plant Centered	10/25/1988	3361988011	Millstone 2	Power Ops	LOOP-IE-I	19	29	29	Sustained	HE	Maintenance
Plant Centered	5/18/1989	2191989015	Oyster Creek	Power Ops	LOOP-IE-I	1	16	54	Sustained	HE	Maintenance
Plant Centered	2/11/1991	3691991001	McGuire 1	Power Ops	LOOP-IE-I	0	40	60	Sustained	HE	Testing
Plant Centered	3/13/1991	2511991001	Turkey Point 4	Shutdown	LOOP-SD	62	67	67	Sustained	Equip	Relay
Plant Centered	4/23/1991	2711991009	Vermont Yankee	Power Ops	LOOP-IE-I	277	282	822	Sustained	HE	Maintenance
Plant Centered	5/12/1991	3151991004	Cook 1	Power Ops	LOOP-IE-I	0	15	81	Sustained	Equip	Other
Plant Centered	6/22/1991	2471991010	Indian Point 2	Shutdown	LOOP-SD	0	60	60	Sustained	Equip	Breaker

Table A-4. (continued)

						Restoration Time (minutes)					
LOOP Category	Date	LER	Plant Name	Operational Mode	LOOP Class	Switchyard Restoration Time	Potential Bus Recovery Time	Actual Bus Restoration Time	Duration Category	Cause	Specific Cause
Plant Centered	10/20/1991	3021991010	Crystal River 3	Shutdown	LOOP-SD	0	4	4	Sustained	HES	Other
Plant Centered	3/23/1992	4101992006	Nine Mile Pt. 2	Shutdown	LOOP-SD	20	30	50	Sustained	HES	Maintenance
Plant Centered	3/27/1992	3021992001	Crystal River 3	Power Ops	LOOP-IE-I	20	30	150	Sustained	HE	Maintenance
Plant Centered	4/2/1992	2651992011	Quad Cities 2	Shutdown	LOOP-SD	35	35	35	Sustained	Equip	Transformer
Plant Centered	4/6/1992	2551992032	Palisades	Shutdown	LOOP-SD	0	15	30	Sustained	HES	Testing
Plant Centered	4/28/1992	2661992003	Point Beach 1	Shutdown	LOOP-SD	0	15	30	Sustained	HES	Maintenance
Plant Centered	5/3/1992	2191992005	Oyster Creek	Power Ops	LOOP-IE-I	5	65	1029	Sustained	SEE	Fire
Plant Centered	10/19/1992	2701992004	Oconee 2	Power Ops	LOOP-IE-I	207	207	207	Sustained	HE	Maintenance
Plant Centered	4/8/1993	3021993004	Crystal River 3	Shutdown	LOOP-SD	1	16	136	Sustained	HES	Maintenance
Plant Centered	6/22/1993	2131993009	Haddam Neck	Shutdown	LOOP-SD	12	27	35	Sustained	Equip	Circuits
Plant Centered	6/26/1993	2131993010	Haddam Neck	Shutdown	LOOP-SD	3	18	40	Sustained	Equip	Circuits
Plant Centered	5/21/1994	3241994008	Brunswick 2	Shutdown	LOOP-SD	2	17	42	Sustained	HES	Testing
Plant Centered	9/27/1994	2661994010	Point Beach 2	Shutdown	LOOP-SD	0	15	15	Sustained	HES	Switching
Plant Centered	9/1/1998	2471998013	Indian Point 2	Shutdown	LOOP-SD	1	16	67	Sustained	HES	Testing
Plant Centered	12/22/1998	2551998013	Palisades	Shutdown	LOOP-SD	0	20	20	Sustained	Equip	Transformer
Plant Centered	10/26/1999	2851999004	Fort Calhoun	Shutdown	LOOP-SD	2	2	2	Momentary	Equip	Other
Plant Centered	4/22/2000	3462000004	Davis-Besse	Shutdown	LOOP-SD	0	10	10	Sustained	HES	Testing
Plant Centered	5/15/2000	2752000004	Diablo Canyon 1	Power Ops	LOOP-IE-I	1901	1906	1996	Sustained	Equip	Other
Plant Centered	3/25/2003	2552003003	Palisades	Shutdown	LOOP-SD	91	96	3261	Sustained	HES	Maintenance
Switchyard Centered	1/1/1986	4581986002	River Bend	Shutdown	LOOP-SD	46	51	51	Sustained	Equip	Circuits
Switchyard Centered	11/5/1986	3361986017	Millstone 2	Shutdown	LOOP-SD	(a)	(a)	(a)	Momentary	HES	Maintenance
Switchyard Centered	12/23/1986	2931986029	Pilgrim	Shutdown	LOOP-SD	0	1	1	Momentary	HES	Maintenance
Switchyard Centered	3/5/1987	2871987002	Oconee 3	Shutdown	LOOP-SD	150	155	155	Sustained	HES	Maintenance
Switchyard Centered	3/21/1987	2851987008	Fort Calhoun	Shutdown	LOOP-SD	37	38	38	Sustained	HES	Maintenance
Switchyard Centered	4/4/1987	2851987009	Fort Calhoun	Shutdown	LOOP-SD	0	4	4	Sustained	HES	Maintenance
Switchyard Centered	7/14/1987	2551987024	Palisades	Power Ops	LOOP-IE-I	388	388	446	Sustained	HE	Maintenance
Switchyard Centered	7/23/1987	3171987012	Calvert Cliffs 1	Power Ops	LOOP-IE-I	113	118	118	Sustained	Equip	Circuits
Switchyard Centered	7/23/1987	3171987012	Calvert Cliffs 2	Power Ops	LOOP-IE-I	113	118	118	Sustained	Equip	Circuits
Switchyard Centered	9/11/1987	4561987048	Braidwood 1	Shutdown	LOOP-SD	62	63	63	Sustained	Equip	Transformer
Switchyard Centered	10/2/1987	4551987019	Byron 2	Power Ops	LOOP-IE-C	1	16	507	Sustained	HES	Switching

Table A-4. (continued)

LOOP Category	Date	LER	Plant Name	Operational Mode	LOOP Class	Restoration Time (minutes) Switchyard Restoration Time	Potential Bus Recovery Time	Actual Bus Restoration Time	Duration Category	Cause	Specific Cause
Switchyard Centered	10/16/1987	3021987025	Crystal River 3	Shutdown	LOOP-SD	18	28	59	Sustained	HES	Maintenance
Switchyard Centered	11/17/1987	4121987036	Beaver Valley 2	Power Ops	LOOP-IE-I	0	4	4	Sustained	Equip	Breaker
Switchyard Centered	6/24/1988	3691988014	McGuire 2	Shutdown	LOOP-SD	8	8	8	Sustained	HES	Switching
Switchyard Centered	7/17/1988	3231988008	Diablo Canyon 2	Power Ops	LOOP-IE-I	33	38	38	Sustained	Equip	Transformer
Switchyard Centered	7/29/1988	2771988020	Peach Bottom 2	Shutdown	LOOP-SD	9	24	125	Sustained	Equip	Transformer
Switchyard Centered	7/29/1988	2771988020	Peach Bottom 3	Shutdown	LOOP-SD	9	24	125	Sustained	Equip	Transformer
Switchyard Centered	8/13/1988	3091988006	Maine Yankee	Power Ops	LOOP-IE-I	14	15	15	Sustained	Equip	Transformer
Switchyard Centered	10/16/1988	4561988022	Braidwood 1	Power Ops	LOOP-IE-I	95	118	213	Sustained	Equip	Breaker
Switchyard Centered	12/26/1988	4101988062	Nine Mile Pt. 2	Shutdown	LOOP-SD	9	24	54	Sustained	Equip	Transformer
Switchyard Centered	2/21/1989	2931989010	Pilgrim	Shutdown	LOOP-SD	1	16	920	Sustained	Equip	Other
Switchyard Centered	3/25/1989	2491989001	Dresden 3	Power Ops	LOOP-IE-I	45	50	50	Sustained	Equip	Breaker
Switchyard Centered	3/29/1989	3011989002	Point Beach 2	Power Ops	LOOP-IE-C	90	95	202	Sustained	HE	Maintenance
Switchyard Centered	4/29/1989	2451989012	Millstone 1	Shutdown	LOOP-SD	0	15	75	Sustained	HES	Other
Switchyard Centered	5/14/1989	3971989016	Columbia 2	Shutdown	LOOP-SD	0	15	29	Sustained	HES	Maintenance
Switchyard Centered	6/16/1989	3021989023	Crystal River 3	Shutdown	LOOP-SD	60	65	65	Sustained	HES	Testing
Switchyard Centered	6/17/1989	3241989009	Brunswick 2	Power Ops	LOOP-IE-I	85	90	403	Sustained	HE	Maintenance
Switchyard Centered	6/29/1989	3021989025	Crystal River 3	Shutdown	LOOP-SD	0	2	2	Momentary	SEE	Lightning
Switchyard Centered	1/16/1990	2371990002	Dresden 2	Decay Heat	LOOP-IE-C	0	45	759	Sustained	Equip	Transformer
Switchyard Centered	2/26/1990	2851990006	Fort Calhoun	Shutdown	LOOP-SD	0	14	14	Sustained	HES	Maintenance
Switchyard Centered	3/20/1990	4241990006	Vogtle 1	Shutdown	LOOP-SD	140	145	217	Sustained	HES	Other
Switchyard Centered	7/9/1990	3311990007	Duane Arnold	Shutdown	LOOP-SD	0	37	37	Sustained	HES	Testing
Switchyard Centered	3/7/1991	2751991004	Diablo Canyon 1	Shutdown	LOOP-SD	261	285	285	Sustained	HES	Maintenance
Switchyard Centered	3/20/1991	2471991006	Indian Point 2	Shutdown	LOOP-SD	0	15	29	Sustained	Equip	Other
Switchyard Centered	3/21/1991	3041991002	Zion 2	Power Ops	LOOP-IE-I	0	60	60	Sustained	Equip	Transformer
Switchyard Centered	6/15/1991	0291991002	Yankee-Rowe	Power Ops	LOOP-IE-I	24	25	25	Sustained	SEE	Lightning
Switchyard Centered	6/27/1991	4431991008	Seabrook	Power Ops	LOOP-IE-I	0	20	20	Sustained	Equip	Relay
Switchyard Centered	7/24/1991	2501991003	Turkey Point 3	Shutdown	LOOP-SD	0	11	11	Sustained	Equip	Breaker
Switchyard Centered	1/29/1992	1551992000	Big Rock Point	Shutdown	LOOP-SD	77	82	82	Sustained	Equip	Other
Switchyard Centered	8/22/1992	2611992017	Robinson 2	Power Ops	LOOP-IE-I	454	459	914	Sustained	Equip	Transformer
Switchyard Centered	12/31/1992	3271992027	Sequoyah 1	Power Ops	LOOP-IE-I	96	101	116	Sustained	Equip	Breaker

Table A-4. (continued)

LOOP Category	Date	LER	Plant Name	Operational Mode	LOOP Class	Restoration Time (minutes) Switchyard Restoration Time	Potential Bus Recovery Time	Actual Bus Restoration Time	Duration Category	Cause	Specific Cause
Switchyard Centered	12/31/1992	3271992027	Sequoyah 2	Power Ops	LOOP-IE-I	96	101	116	Sustained	Equip	Breaker
Switchyard Centered	5/19/1993	2931993010	Pilgrim	Shutdown	LOOP-SD	36	37	37	Sustained	HES	Testing
Switchyard Centered	9/10/1993	2931993022	Pilgrim	Power Ops	LOOP-IE-I	10	25	200	Sustained	SEE	Lightning
Switchyard Centered	9/14/1993	3731993015	La Salle 1	Power Ops	LOOP-IE-I	0	15	70	Sustained	Equip	Transformer
Switchyard Centered	10/12/1993	3341993013	Beaver Valley 1	Power Ops	LOOP-IE-I	15	28	28	Sustained	HES	Maintenance
Switchyard Centered	10/12/1993	3341993013	Beaver Valley 2	Shutdown	LOOP-SD	15	28	28	Sustained	HES	Maintenance
Switchyard Centered	12/27/1993	3701993008	McGuire 2	Power Ops	LOOP-IE-I	96	101	131	Sustained	Equip	Transformer
Switchyard Centered	11/18/1994	3111994014	Salem 2	Shutdown	LOOP-SD	295	300	1675	Sustained	Equip	Relay
Switchyard Centered	2/27/1995	2861995004	Indian Point 3	Shutdown	LOOP-SD	30	40	132	Sustained	HES	Maintenance
Switchyard Centered	10/21/1995	2751995014	Diablo Canyon 1	Shutdown	LOOP-SD	40	45	951	Sustained	HES	Maintenance
Switchyard Centered	1/20/1996	2861996002	Indian Point 3	Shutdown	LOOP-SD	30	40	145	Sustained	Equip	Transformer
Switchyard Centered	2/6/1996	4141996001	Catawba 2	Power Ops	LOOP-IE-I	115	120	330	Sustained	Equip	Transformer
Switchyard Centered	5/23/1996	4541996007	Byron 1	Shutdown	LOOP-SD	715	720	1763	Sustained	Equip	Transformer
Switchyard Centered	3/5/1997	2961997001	Browns Ferry 3	Shutdown	LOOP-SD	39	44	44	Sustained	Equip	Transformer
Switchyard Centered	3/11/1997	2951997007	Zion 1	Shutdown	LOOP-SD	235	240	240	Sustained	Equip	Circuits
Switchyard Centered	6/21/1997	2891997007	Three Mile Isl 1	Power Ops	LOOP-IE-I	85	90	90	Sustained	Equip	Circuits
Switchyard Centered	8/1/1997	2191997010	Oyster Creek	Power Ops	LOOP-IE-C	30	40	40	Sustained	Equip	Relay
Switchyard Centered	5/20/1998	2851998005	Fort Calhoun	Shutdown	LOOP-SD	104	109	109	Sustained	Equip	Transformer
Switchyard Centered	1/6/1999	4611999002	Clinton 1	Shutdown	LOOP-SD	270	275	492	Sustained	Equip	Other
Switchyard Centered	8/31/1999	2471999015	Indian Point 2	Decay Heat	LOOP-IE-C	0	15	779	Sustained	Equip	Circuits
Switchyard Centered	3/3/2000	3252000001	Brunswick 1	Shutdown	LOOP-SD	15	30	136	Sustained	HES	Testing
Switchyard Centered	4/9/2000	3482000005	Farley 1	Shutdown	LOOP-SD	0	19	19	Sustained	Equip	Relay
Switchyard Centered	10/21/2000	2512000004	Turkey Point 4	Shutdown	LOOP-SD	1	16	111	Sustained	Equip	Circuits
Switchyard Centered	8/2/2001	2652001001	Quad Cities 2	Power Ops	LOOP-IE-I	15	30	154	Sustained	SEE	Lightning
Switchyard Centered	4/24/2003	4162003002	Grand Gulf	Power Ops	LOOP-IE-C	0	15	75	Sustained	SEE	High Winds
Switchyard Centered	7/29/2003	2722003002	Salem 1	Power Ops	LOOP-IE-I	30	40	480	Sustained	Equip	Circuits
Switchyard Centered	5/5/2004	2492004003	Dresden 3	Power Ops	LOOP-IE-I	146	151	151	Sustained	Equip	Breaker
Weather Related	11/19/1986	2931986027	Pilgrim	Shutdown	LOOP-SD	0	15	213	Sustained	SEE	Ice
Weather Related	3/31/1987	2931987005	Pilgrim	Shutdown	LOOP-SD	1	16	45	Sustained	SEE	High Winds

Table A-4. (continued)

LOOP Category	Date	LER	Plant Name	Operational Mode	LOOP Class	Restoration Time (minutes) Switchyard Restoration Time	Potential Bus Recovery Time	Actual Bus Restoration Time	Duration Category	Cause	Specific Cause
Weather Related	10/31/1988	3331988011	FitzPatrick	Shutdown	LOOP-SD	1	16	70	Sustained	SEE	High Winds
Weather Related	8/24/1992	2501992000	Turkey Point 3	Shutdown	LOOP-SD	7916	7921	7921	Sustained	EEE	Hurricane
Weather Related	8/24/1992	2501992000	Turkey Point 4	Shutdown	LOOP-SD	7916	7921	7921	Sustained	EEE	Hurricane
Weather Related	3/13/1993	2931993004	Pilgrim	Power Ops	LOOP-IE-I	30	40	298	Sustained	SEE	Snow
Weather Related	3/16/1993	3251993008	Brunswick 2	Shutdown	LOOP-SD	813	818	1018	Sustained	SEE	Salt Spray
Weather Related	3/17/1993	3251993008	Brunswick 1	Shutdown	LOOP-SD	1120	1125	1508	Sustained	SEE	Salt Spray
Weather Related	3/17/1993	3021993000	Crystal River 3	Shutdown	LOOP-SD	72	77	102	Sustained	SEE	Salt Spray
Weather Related	3/29/1993	3021993002	Crystal River 3	Shutdown	LOOP-SD	0	15	37	Sustained	SEE	Flooding
Weather Related	6/29/1996	2821996012	Prairie Island 1	Power Ops	LOOP-IE-I	292	297	297	Sustained	SEE	High Winds
Weather Related	6/29/1996	2821996012	Prairie Island 2	Power Ops	LOOP-IE-I	292	297	297	Sustained	SEE	High Winds
Weather Related	4/1/1997	2931997007	Pilgrim	Shutdown	LOOP-SD	347	1200	1208	Sustained	SEE	High Winds
Weather Related	6/24/1998	3461998006	Davis-Besse	Power Ops	LOOP-IE-I	1364	1428	1495	Sustained	EEE	Tornado
Weather Related	9/6/1998	4561998003	Braidwood 1	Shutdown	LOOP-SD	528	533	533	Sustained	SEE	High Winds
Weather Related	3/5/2001	4432001002	Seabrook	Power Ops	LOOP-IE-I	1	16	2122	Sustained	SEE	Snow
Weather Related	8/14/2004	3252004002	Brunswick 1	Power Ops	LOOP-IE-I	167	172	183	Sustained	EEE	Hurricane
Weather Related	9/25/2004	3352004004	St. Lucie 1	Shutdown	LOOP-SD	8	68	667	Sustained	EEE	Hurricane
Weather Related	9/25/2004	3352004004	St. Lucie 2	Shutdown	LOOP-SD	8	68	613	Sustained	EEE	Hurricane

a. The recovery/restoration times were unknown for this event.

Table A-5. LOOP events aggregated at site level for 1986–2004.

						Restoration Time (minutes)					
Site	Date	LER	Operational Mode	LOOP Category	LOOP Class	Switchyard Restoration Time	Potential Bus Recovery Time	Actual Bus Restoration Time	Duration Category	Cause	Specific Cause
Beaver Valley	11/17/1987	4121987036	Power Ops	Switchyard Centered	LOOP-IE-I	0	4	4	Sustained	Equip	Breaker
Beaver Valley	10/12/1993	3341993013	Shutdown/ Power Ops	Switchyard Centered	LOOP-SD	15	28	28	Sustained	HES	Maintenance
Big Rock Point	1/29/1992	1551992000	Shutdown	Switchyard Centered	LOOP-SD	77	82	82	Sustained	Equip	Other
Braidwood	9/11/1987	4561987048	Shutdown	Switchyard Centered	LOOP-SD	62	63	63	Sustained	Equip	Transformer
Braidwood	10/16/1988	4561988022	Power Ops	Switchyard Centered	LOOP-IE-I	95	118	213	Sustained	Equip	Breaker
Braidwood	9/6/1998	4561998003	Shutdown	Weather Related	LOOP-SD	528	533	533	Sustained	SEE	High Winds
Browns Ferry	3/5/1997	2961997001	Shutdown	Switchyard Centered	LOOP-SD	39	44	44	Sustained	Equip	Transformer
Brunswick	9/13/1986	3251986024	Power Ops	Plant Centered	LOOP-IE-I	0	15	159	Sustained	HE	Maintenance
Brunswick	6/17/1989	3241989009	Power Ops	Switchyard Centered	LOOP-IE-I	85	90	403	Sustained	HE	Maintenance
Brunswick	3/16/1993– 3/17/1993	3251993008	Shutdown	Weather Related	LOOP-SD	967	972	1263	Sustained	SEE	Salt Spray
Brunswick	5/21/1994	3241994008	Shutdown	Plant Centered	LOOP-SD	2	17	42	Sustained	HES	Testing
Brunswick	3/3/2000	3252000001	Shutdown	Switchyard Centered	LOOP-SD	15	30	136	Sustained	HES	Testing
Brunswick	8/14/2004	3252004002	Power Ops	Weather Related	LOOP-IE-I	167	172	183	Sustained	EEE	Hurricane
Byron	10/2/1987	4551987019	Power Ops	Switchyard Centered	LOOP-IE-C	1	16	507	Sustained	HES	Switching
Byron	5/23/1996	4541996007	Shutdown	Switchyard Centered	LOOP-SD	715	720	1763	Sustained	Equip	Transformer
Calvert Cliffs	7/23/1987	3171987012	Power Ops	Switchyard Centered	LOOP-IE-I	113	118	118	Sustained	Equip	Circuits
Catawba	2/6/1996	4141996001	Power Ops	Switchyard Centered	LOOP-IE-I	115	120	330	Sustained	Equip	Transformer
Clinton	1/6/1999	4611999002	Shutdown	Switchyard Centered	LOOP-SD	270	275	492	Sustained	Equip	Other
Columbia	5/14/1989	3971989016	Shutdown	Switchyard Centered	LOOP-SD	0	15	29	Sustained	HES	Maintenance
Cook	5/12/1991	3151991004	Power Ops	Plant Centered	LOOP-IE-I	0	15	81	Sustained	Equip	Other
Crystal River	10/16/1987	3021987025	Shutdown	Switchyard Centered	LOOP-SD	18	28	59	Sustained	HES	Maintenance
Crystal River	6/16/1989	3021989023	Shutdown	Switchyard Centered	LOOP-SD	60	65	65	Sustained	HES	Testing
Crystal River	6/29/1989	3021989025	Shutdown	Switchyard Centered	LOOP-SD	0	2	2	Momentary	SEE	Lightning
Crystal River	10/20/1991	3021991010	Shutdown	Plant Centered	LOOP-SD	0	4	4	Sustained	HES	Other
Crystal River	3/27/1992	3021992001	Power Ops	Plant Centered	LOOP-IE-I	20	30	150	Sustained	HE	Maintenance
Crystal River	3/17/1993	3021993000	Shutdown	Weather Related	LOOP-SD	72	77	102	Sustained	SEE	Salt Spray
Crystal River	3/29/1993	3021993002	Shutdown	Weather Related	LOOP-SD	0	15	37	Sustained	SEE	Flooding
Crystal River	4/8/1993	3021993004	Shutdown	Plant Centered	LOOP-SD	1	16	136	Sustained	HES	Maintenance
Davis-Besse	6/24/1998	3461998006	Power Ops	Weather Related	LOOP-IE-I	1364	1428	1495	Sustained	EEE	Tornado
Davis-Besse	4/22/2000	3462000004	Shutdown	Plant Centered	LOOP-SD	0	10	10	Sustained	HES	Testing
Davis-Besse	8/14/2003	3462003009	Shutdown	Grid Related	LOOP-SD	652	657	849	Sustained	G	Other–load
Diablo Canyon	7/17/1988	3231988008	Power Ops	Switchyard Centered	LOOP-IE-I	33	38	38	Sustained	Equip	Transformer
Diablo Canyon	3/7/1991	2751991004	Shutdown	Switchyard Centered	LOOP-SD	261	285	285	Sustained	HES	Maintenance
Diablo Canyon	10/21/1995	2751995014	Shutdown	Switchyard Centered	LOOP-SD	40	45	951	Sustained	HES	Maintenance

Table A-5. (continued)

Site	Date	LER	Operational Mode	LOOP Category	LOOP Class	Restoration Time (minutes) Switchyard Restoration Time	Potential Bus Recovery Time	Actual Bus Restoration Time	Duration Category	Cause	Specific Cause
Diablo Canyon	5/15/2000	2752000004	Power Ops	Plant Centered	LOOP-IE-I	1901	1906	1996	Sustained	Equip	Other
Dresden	3/25/1989	2491989001	Power Ops	Switchyard Centered	LOOP-IE-I	45	50	50	Sustained	Equip	Breaker
Dresden	1/16/1990	2371990002	Decay Heat	Switchyard Centered	LOOP-IE-C	0	45	759	Sustained	Equip	Transformer
Dresden	5/5/2004	2492004003	Power Ops	Switchyard Centered	LOOP-IE-I	146	151	151	Sustained	Equip	Breaker
Duane Arnold	7/9/1990	3311990007	Shutdown	Switchyard Centered	LOOP-SD	0	37	37	Sustained	HES	Testing
Farley	4/9/2000	3482000005	Shutdown	Switchyard Centered	LOOP-SD	0	19	19	Sustained	Equip	Relay
Fermi	8/14/2003	3412003002	Power Ops	Grid Related	LOOP-IE-I	379	384	582	Sustained	G	Other–load
FitzPatrick-Nine Mile Pt. 1	10/31/1988	3331988011	Shutdown	Weather Related	LOOP-SD	1	16	70	Sustained	SEE	High Winds
FitzPatrick-Nine Mile Pt. 1	8/14/2003	3332003001–2202003002	Power Ops	Grid Related	LOOP-IE-I	137	142	431	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	0	14	14	Sustained	HES	Maintenance
Fort Calhoun	5/20/1998	2851998005	Shutdown	Switchyard Centered	LOOP-SD	104	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	Power Ops	Grid Related	LOOP-IE-I	49	54	297	Sustained	G	Other–load
Grand Gulf	4/24/2003	4162003002	Power Ops	Switchyard Centered	LOOP-IE-C	0	15	75	Sustained	SEE	High Winds
Haddam Neck	6/22/1993	2131993009	Shutdown	Plant Centered	LOOP-SD	12	27	35	Sustained	Equip	Circuits
Haddam Neck	6/26/1993	2131993010	Shutdown	Plant Centered	LOOP-SD	3	18	40	Sustained	Equip	Circuits
Indian Point	3/20/1991	2471991006	Shutdown	Switchyard Centered	LOOP-SD	0	15	29	Sustained	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	40	132	Sustained	HES	Maintenance
Indian Point	1/20/1996	2861996002	Shutdown	Switchyard Centered	LOOP-SD	30	40	145	Sustained	Equip	Transformer
Indian Point	6/16/1997	2861997008	Shutdown	Grid Related	LOOP-SD	37	42	42	Sustained	HE	Maintenance
Indian Point	9/1/1998	2471998013	Shutdown	Plant Centered	LOOP-SD	1	16	67	Sustained	HES	Testing
Indian Point	8/31/1999	2471999015	Decay Heat	Switchyard Centered	LOOP-IE-C	0	15	779	Sustained	Equip	Circuits
Indian Point	8/14/2003	2862003005–2472003005	Power Ops	Grid Related	LOOP-IE-I	97	102	228	Sustained	G	Other–load
La Salle	9/14/1993	3731993015	Power Ops	Switchyard Centered	LOOP-IE-I	0	15	70	Sustained	Equip	Transformer
Maine Yankee	8/13/1988	3091988006	Power Ops	Switchyard Centered	LOOP-IE-I	14	15	15	Sustained	Equip	Transformer
McGuire	9/16/1987	3691987021	Shutdown	Plant Centered	LOOP-SD	0	6	6	Sustained	HES	Testing
McGuire	6/24/1988	3691988014	Shutdown	Switchyard Centered	LOOP-SD	8	8	8	Sustained	HES	Switching
McGuire	2/11/1991	3691991001	Power Ops	Plant Centered	LOOP-IE-I	0	40	60	Sustained	HE	Testing
McGuire	12/27/1993	3701993008	Power Ops	Switchyard Centered	LOOP-IE-I	96	101	131	Sustained	Equip	Transformer
Millstone	11/5/1986	3361986017	Shutdown	Switchyard Centered	LOOP-SD	(a)	(a)	(a)	Momentary	HES	Maintenance
Millstone	10/25/1988	3361988011	Power Ops	Plant Centered	LOOP-IE-I	19	29	29	Sustained	HE	Maintenance

Table A-5. (continued)

Site	Date	LER	Operational Mode	LOOP Category	LOOP Class	Restoration Time (minutes) Switchyard Restoration Time	Potential Bus Recovery Time	Actual Bus Restoration Time	Duration Category	Cause	Specific Cause
Millstone	4/29/1989	2451989012	Shutdown	Switchyard Centered	LOOP-SD	0	15	75	Sustained	HES	Other
Nine Mile Pt. 2	12/26/1988	4101988062	Shutdown	Switchyard Centered	LOOP-SD	9	24	54	Sustained	Equip	Transformer
Nine Mile Pt. 2	3/23/1992	4101992006	Shutdown	Plant Centered	LOOP-SD	20	30	50	Sustained	HES	Maintenance
Nine Mile Pt. 2	8/14/2003	4102003002	Power Ops	Grid Related	LOOP-IE-I	105	110	551	Sustained	G	Other–load
Oconee	3/5/1987	2871987002	Shutdown	Switchyard Centered	LOOP-SD	150	155	155	Sustained	HES	Maintenance
Oconee	10/19/1992	2701992004	Power Ops	Plant Centered	LOOP-IE-I	207	207	207	Sustained	HE	Maintenance
Oyster Creek	5/18/1989	2191989015	Power Ops	Plant Centered	LOOP-IE-I	1	16	54	Sustained	HE	Maintenance
Oyster Creek	5/3/1992	2191992005	Power Ops	Plant Centered	LOOP-IE-I	5	65	1029	Sustained	SEE	Fire
Oyster Creek	8/1/1997	2191997010	Power Ops	Switchyard Centered	LOOP-IE-C	30	40	40	Sustained	Equip	Relay
Palisades	7/14/1987	2551987024	Power Ops	Switchyard Centered	LOOP-IE-I	388	388	446	Sustained	HE	Maintenance
Palisades	4/6/1992	2551992032	Shutdown	Plant Centered	LOOP-SD	0	15	30	Sustained	HES	Testing
Palisades	12/22/1998	2551998013	Shutdown	Plant Centered	LOOP-SD	0	20	20	Sustained	Equip	Transformer
Palisades	3/25/2003	2552003003	Shutdown	Plant Centered	LOOP-SD	91	96	3261	Sustained	HES	Maintenance
Palo Verde	6/14/2004	5282004006	Power Ops	Grid Related	LOOP-IE-I	32	37	74	Sustained	G	Equip–other
Peach Bottom	7/29/1988	2771988020	Shutdown	Switchyard Centered	LOOP-SD	9	24	125	Sustained	Equip	Transformer
Peach Bottom	9/15/2003	2772003004	Power Ops	Grid Related	LOOP-IE-I	1	16	72	Sustained	Equip	Relay
Perry	8/14/2003	4402003002	Power Ops	Grid Related	LOOP-IE-I	82	87	123	Sustained	G	Other–load
Pilgrim	11/19/1986	2931986027	Shutdown	Weather Related	LOOP-SD	0	15	213	Sustained	SEE	Ice
Pilgrim	12/23/1986	2931986029	Shutdown	Switchyard Centered	LOOP-SD	0	1	1	Momentary	HES	Maintenance
Pilgrim	3/31/1987	2931987005	Shutdown	Weather Related	LOOP-SD	1	16	45	Sustained	SEE	High Winds
Pilgrim	2/21/1989	2931989010	Shutdown	Switchyard Centered	LOOP-SD	1	16	920	Sustained	Equip	Other
Pilgrim	3/13/1993	2931993004	Power Ops	Weather Related	LOOP-IE-I	30	40	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	Power Ops	Switchyard Centered	LOOP-IE-I	10	25	200	Sustained	SEE	Lightning
Pilgrim	4/1/1997	2931997007	Shutdown	Weather Related	LOOP-SD	347	1200	1208	Sustained	SEE	High Winds
Point Beach	3/29/1989	3011989002	Power Ops	Switchyard Centered	LOOP-IE-C	90	95	202	Sustained	HE	Maintenance
Point Beach	4/28/1992	2661992003	Shutdown	Plant Centered	LOOP-SD	0	15	30	Sustained	HES	Maintenance
Point Beach	9/27/1994	2661994010	Shutdown	Plant Centered	LOOP-SD	0	15	15	Sustained	HES	Switching
Prairie Island	6/29/1996	2821996012	Power Ops	Weather Related	LOOP-IE-I	292	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	Power Ops	Switchyard Centered	LOOP-IE-I	15	30	154	Sustained	SEE	Lightning
River Bend	1/1/1986	4581986002	Shutdown	Switchyard Centered	LOOP-SD	46	51	51	Sustained	Equip	Circuits
Robinson	1/28/1986	2611986005	Power Ops	Plant Centered	LOOP-IE-C	117	122	403	Sustained	Equip	Relay
Robinson	8/22/1992	2611992017	Power Ops	Switchyard Centered	LOOP-IE-I	454	459	914	Sustained	Equip	Transformer
Salem-Hope Creek	8/26/1986	3111986007	Decay Heat	Plant Centered	LOOP-IE-C	0	15	75	Sustained	Equip	Other

Table A-5. (continued)

Site	Date	LER	Operational Mode	LOOP Category	LOOP Class	Restoration Time (minutes) Switchyard Restoration Time	Potential Bus Recovery Time	Actual Bus Restoration Time	Duration Category	Cause	Specific Cause
Salem-Hope Creek	11/18/1994	3111994014	Shutdown	Switchyard Centered	LOOP-SD	295	300	1675	Sustained	Equip	Relay
Salem-Hope Creek	7/29/2003	2722003002	Power Ops	Switchyard Centered	LOOP-IE-I	30	40	480	Sustained	Equip	Circuits
Seabrook	6/27/1991	4431991008	Power Ops	Switchyard Centered	LOOP-IE-I	0	20	20	Sustained	Equip	Relay
Seabrook	3/5/2001	4432001002	Power Ops	Weather Related	LOOP-IE-I	1	16	2122	Sustained	SEE	Snow
Sequoyah	12/31/1992	3271992027	Power Ops	Switchyard Centered	LOOP-IE-I	96	101	116	Sustained	Equip	Breaker
St. Lucie	9/25/2004	3352004004	Shutdown	Weather Related	LOOP-SD	8	68	640	Sustained	EEE	Hurricane
Summer	7/11/1989	3951989012	Decay Heat	Grid Related	LOOP-IE-C	95	100	120	Sustained	G	Equip–other
Three Mile Isl	6/21/1997	2891997007	Power Ops	Switchyard Centered	LOOP-IE-I	85	90	90	Sustained	Equip	Circuits
Turkey Point	3/13/1991	2511991001	Shutdown	Plant Centered	LOOP-SD	62	67	67	Sustained	Equip	Relay
Turkey Point	7/24/1991	2501991003	Shutdown	Switchyard Centered	LOOP-SD	0	11	11	Sustained	Equip	Breaker
Turkey Point	8/24/1992	2501992000	Shutdown	Weather Related	LOOP-SD	7916	7921	7921	Sustained	EEE	Hurricane
Turkey Point	10/21/2000	2512000004	Shutdown	Switchyard Centered	LOOP-SD	1	16	111	Sustained	Equip	Circuits
Vermont Yankee	8/17/1987	2711987008	Shutdown	Grid Related	LOOP-SD	2	17	77	Sustained	Equip	Other
Vermont Yankee	4/23/1991	2711991009	Power Ops	Plant Centered	LOOP-IE-I	277	282	822	Sustained	HE	Maintenance
Vogtle	3/20/1990	4241990006	Shutdown	Switchyard Centered	LOOP-SD	140	145	217	Sustained	HES	Other
Wolf Creek	10/14/1987	4821987048	Shutdown	Plant Centered	LOOP-SD	0	17	17	Sustained	HES	Maintenance
Yankee-Rowe	6/15/1991	0291991002	Power Ops	Switchyard Centered	LOOP-IE-I	24	25	25	Sustained	SEE	Lightning
Zion	3/21/1991	3041991002	Power Ops	Switchyard Centered	LOOP-IE-I	0	60	60	Sustained	Equip	Transformer
Zion	3/11/1997	2951997007	Shutdown	Switchyard Centered	LOOP-SD	235	240	240	Sustained	Equip	Circuits

a. The recovery/restoration times were unknown for this event.

Table A-6. Site-level LOOP events listed by category for 1986–2004.

LOOP Category	Site	Date	LER	Operational Mode	LOOP Class	Restoration Time (minutes)			Duration Category	Cause	Specific Cause
						Switchyard Restoration Time	Potential Bus Recovery Time	Actual Bus Restoration Time			
Grid Related	Davis-Besse	8/14/2003	3462003009	Shutdown	LOOP-SD	652	657	849	Sustained	G	Other–load
Grid Related	Fermi	8/14/2003	3412003002	Power Ops	LOOP-IE-I	379	384	582	Sustained	G	Other–load
Grid Related	FitzPatrick-Nine Mile Pt. 1	8/14/2003	3332003001–2202003002	Power Ops	LOOP-IE-I	137	142	431	Sustained	G	Other–load
Grid Related	Ginna	8/14/2003	2442003002	Power Ops	LOOP-IE-I	49	54	297	Sustained	G	Other–load
Grid Related	Indian Point	6/16/1997	2861997008	Shutdown	LOOP-SD	37	42	42	Sustained	HE	Maintenance
Grid Related	Indian Point	8/14/2003	2862003005–2472003005	Power Ops	LOOP-IE-I	97	102	228	Sustained	G	Other–load
Grid Related	Nine Mile Pt. 2	8/14/2003	4102003002	Power Ops	LOOP-IE-I	105	110	551	Sustained	G	Other–load
Grid Related	Palo Verde	6/14/2004	5282004006	Power Ops	LOOP-IE-I	32	37	74	Sustained	G	Equip–other
Grid Related	Peach Bottom	9/15/2003	2772003004	Power Ops	LOOP-IE-I	1	16	72	Sustained	Equip	Relay
Grid Related	Perry	8/14/2003	4402003002	Power Ops	LOOP-IE-I	82	87	123	Sustained	G	Other–load
Grid Related	Summer	7/11/1989	3951989012	Decay Heat	LOOP-IE-C	95	100	120	Sustained	G	Equip–other
Grid Related	Vermont Yankee	8/17/1987	2711987008	Shutdown	LOOP-SD	2	17	77	Sustained	Equip	Other
Plant Centered	Brunswick	9/13/1986	3251986024	Power Ops	LOOP-IE-I	0	15	159	Sustained	HE	Maintenance
Plant Centered	Brunswick	5/21/1994	3241994008	Shutdown	LOOP-SD	2	17	42	Sustained	HES	Testing
Plant Centered	Cook	5/12/1991	3151991004	Power Ops	LOOP-IE-I	0	15	81	Sustained	Equip	Other
Plant Centered	Crystal River	10/20/1991	3021991010	Shutdown	LOOP-SD	0	4	4	Sustained	HES	Other
Plant Centered	Crystal River	3/27/1992	3021992001	Power Ops	LOOP-IE-I	20	30	150	Sustained	HE	Maintenance
Plant Centered	Crystal River	4/8/1993	3021993004	Shutdown	LOOP-SD	1	16	136	Sustained	HES	Maintenance
Plant Centered	Davis-Besse	4/22/2000	3462000004	Shutdown	LOOP-SD	0	10	10	Sustained	HES	Testing
Plant Centered	Diablo Canyon	5/15/2000	2752000004	Power Ops	LOOP-IE-I	1901	1906	1996	Sustained	Equip	Other
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	27	35	Sustained	Equip	Circuits
Plant Centered	Haddam Neck	6/26/1993	2131993010	Shutdown	LOOP-SD	3	18	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	16	67	Sustained	HES	Testing
Plant Centered	McGuire	9/16/1987	3691987021	Shutdown	LOOP-SD	0	6	6	Sustained	HES	Testing
Plant Centered	McGuire	2/11/1991	3691991001	Power Ops	LOOP-IE-I	0	40	60	Sustained	HE	Testing
Plant Centered	Millstone	10/25/1988	3361988011	Power Ops	LOOP-IE-I	19	29	29	Sustained	HE	Maintenance
Plant Centered	Nine Mile Pt. 2	3/23/1992	4101992006	Shutdown	LOOP-SD	20	30	50	Sustained	HES	Maintenance

Table A-6. (continued)

LOOP Category	Site	Date	LER	Operational Mode	LOOP Class	Restoration Time (minutes): Switchyard Restoration Time	Potential Bus Recovery Time	Actual Bus Restoration Time	Duration Category	Cause	Specific Cause
Plant Centered	Oconee	10/19/1992	2701992004	Power Ops	LOOP-IE-I	207	207	207	Sustained	HE	Maintenance
Plant Centered	Oyster Creek	5/18/1989	2191989015	Power Ops	LOOP-IE-I	1	16	54	Sustained	HE	Maintenance
Plant Centered	Oyster Creek	5/3/1992	2191992005	Power Ops	LOOP-IE-I	5	65	1029	Sustained	SEE	Fire
Plant Centered	Palisades	4/6/1992	2551992032	Shutdown	LOOP-SD	0	15	30	Sustained	HES	Testing
Plant Centered	Palisades	12/22/1998	2551998013	Shutdown	LOOP-SD	0	20	20	Sustained	Equip	Transformer
Plant Centered	Palisades	3/25/2003	2552003003	Shutdown	LOOP-SD	91	96	3261	Sustained	HES	Maintenance
Plant Centered	Point Beach	4/28/1992	2661992003	Shutdown	LOOP-SD	0	15	30	Sustained	HES	Maintenance
Plant Centered	Point Beach	9/27/1994	2661994010	Shutdown	LOOP-SD	0	15	15	Sustained	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	Power Ops	LOOP-IE-C	117	122	403	Sustained	Equip	Relay
Plant Centered	Salem-Hope Creek	8/26/1986	3111986007	Decay Heat	LOOP-IE-C	0	15	75	Sustained	Equip	Other
Plant Centered	Turkey Point	3/13/1991	2511991001	Shutdown	LOOP-SD	62	67	67	Sustained	Equip	Relay
Plant Centered	Vermont Yankee	4/23/1991	2711991009	Power Ops	LOOP-IE-I	277	282	822	Sustained	HE	Maintenance
Plant Centered	Wolf Creek	10/14/1987	4821987048	Shutdown	LOOP-SD	0	17	17	Sustained	HES	Maintenance
Switchyard Centered	Beaver Valley	11/17/1987	4121987036	Power Ops	LOOP-IE-I	0	4	4	Sustained	Equip	Breaker
Switchyard Centered	Beaver Valley	10/12/1993	3341993013	Shutdown/ Power Ops	LOOP-SD	15	28	28	Sustained	HES	Maintenance
Switchyard Centered	Big Rock Point	1/29/1992	1551992000	Shutdown	LOOP-SD	77	82	82	Sustained	Equip	Other
Switchyard Centered	Braidwood	9/11/1987	4561987048	Shutdown	LOOP-SD	62	63	63	Sustained	Equip	Transformer
Switchyard Centered	Braidwood	10/16/1988	4561988022	Power Ops	LOOP-IE-I	95	118	213	Sustained	Equip	Breaker
Switchyard Centered	Browns Ferry	3/5/1997	2961997001	Shutdown	LOOP-SD	39	44	44	Sustained	Equip	Transformer
Switchyard Centered	Brunswick	6/17/1989	3241989009	Power Ops	LOOP-IE-I	85	90	403	Sustained	HE	Maintenance
Switchyard Centered	Brunswick	3/3/2000	3252000001	Shutdown	LOOP-SD	15	30	136	Sustained	HES	Testing
Switchyard Centered	Byron	10/2/1987	4551987019	Power Ops	LOOP-IE-C	1	16	507	Sustained	HES	Switching
Switchyard Centered	Byron	5/23/1996	4541996007	Shutdown	LOOP-SD	715	720	1763	Sustained	Equip	Transformer
Switchyard Centered	Calvert Cliffs	7/23/1987	3171987012	Power Ops	LOOP-IE-I	113	118	118	Sustained	Equip	Circuits
Switchyard Centered	Catawba	2/6/1996	4141996001	Power Ops	LOOP-IE-I	115	120	330	Sustained	Equip	Transformer
Switchyard Centered	Clinton	1/6/1999	4611999002	Shutdown	LOOP-SD	270	275	492	Sustained	Equip	Other
Switchyard Centered	Columbia	5/14/1989	3971989016	Shutdown	LOOP-SD	0	15	29	Sustained	HES	Maintenance
Switchyard Centered	Crystal River	10/16/1987	3021987025	Shutdown	LOOP-SD	18	28	59	Sustained	HES	Maintenance
Switchyard Centered	Crystal River	6/16/1989	3021989023	Shutdown	LOOP-SD	60	65	65	Sustained	HES	Testing

Table A-6. (continued)

LOOP Category	Site	Date	LER	Operational Mode	LOOP Class	Restoration Time (minutes) Switchyard Restoration Time	Potential Bus Recovery Time	Actual Bus Restoration Time	Duration Category	Cause	Specific Cause
Switchyard Centered	Crystal River	6/29/1989	3021989025	Shutdown	LOOP-SD	0	2	2	Momentary	SEE	Lightning
Switchyard Centered	Diablo Canyon	7/17/1988	3231988008	Power Ops	LOOP-IE-I	33	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	40	45	951	Sustained	HES	Maintenance
Switchyard Centered	Dresden	3/25/1989	2491989001	Power Ops	LOOP-IE-I	45	50	50	Sustained	Equip	Breaker
Switchyard Centered	Dresden	1/16/1990	2371990002	Decay Heat	LOOP-IE-C	0	45	759	Sustained	Equip	Transformer
Switchyard Centered	Dresden	5/5/2004	2492004003	Power Ops	LOOP-IE-I	146	151	151	Sustained	Equip	Breaker
Switchyard Centered	Duane Arnold	7/9/1990	3311990007	Shutdown	LOOP-SD	0	37	37	Sustained	HES	Testing
Switchyard Centered	Farley	4/9/2000	3482000005	Shutdown	LOOP-SD	0	19	19	Sustained	Equip	Relay
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	0	14	14	Sustained	HES	Maintenance
Switchyard Centered	Fort Calhoun	5/20/1998	2851998005	Shutdown	LOOP-SD	104	109	109	Sustained	Equip	Transformer
Switchyard Centered	Grand Gulf	4/24/2003	4162003002	Power Ops	LOOP-IE-C	0	15	75	Sustained	SEE	High Winds
Switchyard Centered	Indian Point	3/20/1991	2471991006	Shutdown	LOOP-SD	0	15	29	Sustained	Equip	Other
Switchyard Centered	Indian Point	2/27/1995	2861995004	Shutdown	LOOP-SD	30	40	132	Sustained	HES	Maintenance
Switchyard Centered	Indian Point	1/20/1996	2861996002	Shutdown	LOOP-SD	30	40	145	Sustained	Equip	Transformer
Switchyard Centered	Indian Point	8/31/1999	2471999015	Decay Heat	LOOP-IE-C	0	15	779	Sustained	Equip	Circuits
Switchyard Centered	La Salle	9/14/1993	3731993015	Power Ops	LOOP-IE-I	0	15	70	Sustained	Equip	Transformer
Switchyard Centered	Maine Yankee	8/13/1988	3091988006	Power Ops	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	Power Ops	LOOP-IE-I	96	101	131	Sustained	Equip	Transformer
Switchyard Centered	Millstone	11/5/1986	3361986017	Shutdown	LOOP-SD	(a)	(a)	(a)	Momentary	HES	Maintenance
Switchyard Centered	Millstone	4/29/1989	2451989012	Shutdown	LOOP-SD	0	15	75	Sustained	HES	Other
Switchyard Centered	Nine Mile Pt. 2	12/26/1988	4101988062	Shutdown	LOOP-SD	9	24	54	Sustained	Equip	Transformer
Switchyard Centered	Oconee	3/5/1987	2871987002	Shutdown	LOOP-SD	150	155	155	Sustained	HES	Maintenance
Switchyard Centered	Oyster Creek	8/1/1997	2191997010	Power Ops	LOOP-IE-C	30	40	40	Sustained	Equip	Relay
Switchyard Centered	Palisades	7/14/1987	2551987024	Power Ops	LOOP-IE-I	388	388	446	Sustained	HE	Maintenance
Switchyard Centered	Peach Bottom	7/29/1988	2771988020	Shutdown	LOOP-SD	9	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	16	920	Sustained	Equip	Other
Switchyard Centered	Pilgrim	5/19/1993	2931993010	Shutdown	LOOP-SD	36	37	37	Sustained	HES	Testing

Table A-6. (continued)

LOOP Category	Site	Date	LER	Operational Mode	LOOP Class	Restoration Time (minutes)			Duration Category	Cause	Specific Cause
						Switchyard Restoration Time	Potential Bus Recovery Time	Actual Bus Restoration Time			
Switchyard Centered	Pilgrim	9/10/1993	2931993022	Power Ops	LOOP-IE-I	10	25	200	Sustained	SEE	Lightning
Switchyard Centered	Point Beach	3/29/1989	3011989002	Power Ops	LOOP-IE-C	90	95	202	Sustained	HE	Maintenance
Switchyard Centered	Quad Cities	8/2/2001	2652001001	Power Ops	LOOP-IE-I	15	30	154	Sustained	SEE	Lightning
Switchyard Centered	River Bend	1/1/1986	4581986002	Shutdown	LOOP-SD	46	51	51	Sustained	Equip	Circuits
Switchyard Centered	Robinson	8/22/1992	2611992017	Power Ops	LOOP-IE-I	454	459	914	Sustained	Equip	Transformer
Switchyard Centered	Salem-Hope Creek	11/18/1994	3111994014	Shutdown	LOOP-SD	295	300	1675	Sustained	Equip	Relay
Switchyard Centered	Salem-Hope Creek	7/29/2003	2722003002	Power Ops	LOOP-IE-I	30	40	480	Sustained	Equip	Circuits
Switchyard Centered	Seabrook	6/27/1991	4431991008	Power Ops	LOOP-IE-I	0	20	20	Sustained	Equip	Relay
Switchyard Centered	Sequoyah	12/31/1992	3271992027	Power Ops	LOOP-IE-I	96	101	116	Sustained	Equip	Breaker
Switchyard Centered	Three Mile Isl	6/21/1997	2891997007	Power Ops	LOOP-IE-I	85	90	90	Sustained	Equip	Circuits
Switchyard Centered	Turkey Point	7/24/1991	2501991003	Shutdown	LOOP-SD	0	11	11	Sustained	Equip	Breaker
Switchyard Centered	Turkey Point	10/21/2000	2512000004	Shutdown	LOOP-SD	1	16	111	Sustained	Equip	Circuits
Switchyard Centered	Vogtle	3/20/1990	4241990006	Shutdown	LOOP-SD	140	145	217	Sustained	HES	Other
Switchyard Centered	Yankee-Rowe	6/15/1991	0291991002	Power Ops	LOOP-IE-I	24	25	25	Sustained	SEE	Lightning
Switchyard Centered	Zion	3/21/1991	3041991002	Power Ops	LOOP-IE-I	0	60	60	Sustained	Equip	Transformer
Switchyard Centered	Zion	3/11/1997	2951997007	Shutdown	LOOP-SD	235	240	240	Sustained	Equip	Circuits
Weather Related	Braidwood	9/6/1998	4561998003	Shutdown	LOOP-SD	528	533	533	Sustained	SEE	High Winds
Weather Related	Brunswick	3/16/1993–3/17/1993	3251993008	Shutdown	LOOP-SD	967	972	1263	Sustained	SEE	Salt Spray
Weather Related	Brunswick	8/14/2004	3252004002	Power Ops	LOOP-IE-I	167	172	183	Sustained	EEE	Hurricane
Weather Related	Crystal River	3/17/1993	3021993000	Shutdown	LOOP-SD	72	77	102	Sustained	SEE	Salt Spray
Weather Related	Crystal River	3/29/1993	3021993002	Shutdown	LOOP-SD	0	15	37	Sustained	SEE	Flooding
Weather Related	Davis-Besse	6/24/1998	3461998006	Power Ops	LOOP-IE-I	1364	1428	1495	Sustained	EEE	Tornado
Weather Related	FitzPatrick-Nine Mile Pt. 1	10/31/1988	3331988011	Shutdown	LOOP-SD	1	16	70	Sustained	SEE	High Winds
Weather Related	Pilgrim	11/19/1986	2931986027	Shutdown	LOOP-SD	0	15	213	Sustained	SEE	Ice
Weather Related	Pilgrim	3/31/1987	2931987005	Shutdown	LOOP-SD	1	16	45	Sustained	SEE	High Winds
Weather Related	Pilgrim	3/13/1993	2931993004	Power Ops	LOOP-IE-I	30	40	298	Sustained	SEE	Snow
Weather Related	Pilgrim	4/1/1997	2931997007	Shutdown	LOOP-SD	347	1200	1208	Sustained	SEE	High Winds
Weather Related	Prairie Island	6/29/1996	2821996012	Power Ops	LOOP-IE-I	292	297	297	Sustained	SEE	High Winds
Weather Related	Seabrook	3/5/2001	4432001002	Power Ops	LOOP-IE-I	1	16	2122	Sustained	SEE	Snow

Table A-6. (continued)

LOOP Category	Site	Date	LER	Operational Mode	LOOP Class	Restoration Time (minutes): Switchyard Restoration Time	Restoration Time (minutes): Potential Bus Recovery Time	Restoration Time (minutes): Actual Bus Restoration Time	Duration Category	Cause	Specific Cause
Weather Related	St. Lucie	9/25/2004	3352004004	Shutdown	LOOP-SD	8	68	640	Sustained	EEE	Hurricane
Weather Related	Turkey Point	8/24/1992	2501992000	Shutdown	LOOP-SD	7916	7921	7921	Sustained	EEE	Hurricane

a. The recovery/restoration times were unknown for this event.

Table A-7. Site-level LOOP events showing restoration time uncertainty for 1986–2004.

					Switchyard Restoration		Potential Bus Restoration		Actual Bus Restoration	
LER	Site	Date	Operational Mode	LOOP Category	Time	Certainty [a]	Time	Certainty [a]	Time	Certainty [a]
4121987036	Beaver Valley	11/17/1987	Power Ops	Switchyard Centered	0	C	4	C	4	C
3341993013	Beaver Valley	10/12/1993	Shutdown / Power Ops	Switchyard Centered	15	C	28	E	28	C
1551992000	Big Rock Point	1/29/1992	Shutdown	Switchyard Centered	77	E	82	E	82	E
4561987048	Braidwood	9/11/1987	Shutdown	Switchyard Centered	62	C	63	E	63	C
4561988022	Braidwood	10/16/1988	Power Ops	Switchyard Centered	95	C	118	C	213	C
4571996001	Braidwood	1/18/1996	Power Ops-No Trip	Switchyard Centered	113	C	113	C	113	C
4561998003	Braidwood	9/6/1998	Shutdown	Weather Related	528	E	533	E	533	E
2961997001	Browns Ferry	3/5/1997	Shutdown	Switchyard Centered	39	E	44	E	44	C
3251986024	Brunswick	9/13/1986	Power Ops	Plant Centered	0	C	15	E	159	C
3241989009	Brunswick	6/17/1989	Power Ops	Switchyard Centered	85	E	90	C	403	C
3251993008	Brunswick	3/16/1993–3/17/1993	Shutdown	Weather Related	967	C	972	E	1263	C
3241994008	Brunswick	5/21/1994	Shutdown	Plant Centered	2	C	17	E	42	C
3252000001	Brunswick	3/3/2000	Shutdown	Switchyard Centered	15	E	30	E	136	C
3252004002	Brunswick	8/14/2004	Power Ops	Weather Related	167	C	172	E	183	C
4551987019	Byron	10/2/1987	Power Ops	Switchyard Centered	1	E	16	E	507	C
4541996007	Byron	5/23/1996	Shutdown	Switchyard Centered	715	E	720	C	1763	E
4541998017	Byron	8/4/1998	Power Ops-No Trip	Plant Centered	502	C	507	E	554	C
3171987012	Calvert Cliffs	7/23/1987	Power Ops	Switchyard Centered	113	E	118	C	118	C
4141996001	Catawba	2/6/1996	Power Ops	Switchyard Centered	115	C	120	E	330	C
4611999002	Clinton	1/6/1999	Shutdown	Switchyard Centered	270	C	275	E	492	C
3971989016	Columbia	5/14/1989	Shutdown	Switchyard Centered	0	C	15	E	29	C
3151991004	Cook	5/12/1991	Power Ops	Plant Centered	0	C	15	E	81	C
3021987025	Crystal River	10/16/1987	Shutdown	Switchyard Centered	18	C	28	E	59	C
3021989023	Crystal River	6/16/1989	Shutdown	Switchyard Centered	60	C	65	E	65	E
3021989025	Crystal River	6/29/1989	Shutdown	Switchyard Centered	0	E	2	C	2	C
3021991010	Crystal River	10/20/1991	Shutdown	Plant Centered	0	C	4	C	4	C
3021992001	Crystal River	3/27/1992	Power Ops	Plant Centered	20	E	30	E	150	C
3021993000	Crystal River	3/17/1993	Shutdown	Weather Related	72	C	77	E	102	E
3021993002	Crystal River	3/29/1993	Shutdown	Weather Related	0	C	15	E	37	C
3021993004	Crystal River	4/8/1993	Shutdown	Plant Centered	1	E	16	E	136	C

Table A-7. (continued)

LER	Site	Date	Operational Mode	LOOP Category	Switchyard Restoration		Potential Bus Restoration		Actual Bus Restoration	
					Time	Certainty [a]	Time	Certainty [a]	Time	Certainty [a]
3461998006	Davis-Besse	6/24/1998	Power Ops	Weather Related	1364	C	1428	C	1495	C
3462000004	Davis-Besse	4/22/2000	Shutdown	Plant Centered	0	C	10	C	10	C
3462003009	Davis-Besse	8/14/2003	Shutdown	Grid Related	652	C	657	E	849	C
3231988008	Diablo Canyon	7/17/1988	Power Ops	Switchyard Centered	33	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	40	C	45	E	951	C
2752000004	Diablo Canyon	5/15/2000	Power Ops	Plant Centered	1901	C	1906	E	1996	C
2491989001	Dresden	3/25/1989	Power Ops	Switchyard Centered	45	E	50	E	50	E
2371990002	Dresden	1/16/1990	Decay Heat	Switchyard Centered	0	C	45	E	759	C
2492004003	Dresden	5/5/2004	Power Ops	Switchyard Centered	146	E	151	E	151	C
3311990007	Duane Arnold	7/9/1990	Shutdown	Switchyard Centered	0	C	37	C	37	C
3482000005	Farley	4/9/2000	Shutdown	Switchyard Centered	0	C	19	C	19	C
3412003002	Fermi	8/14/2003	Power Ops	Grid Related	379	C	384	E	582	C
3331988011	FitzPatrick-Nine Mile Pt. 1	10/31/1988	Shutdown	Weather Related	1	C	16	E	70	C
2201990023	FitzPatrick-Nine Mile Pt. 1	11/12/1990	Power Ops-No Trip	Switchyard Centered	355	C	360	E	360	E
2201993007	FitzPatrick-Nine Mile Pt. 1	8/31/1993	Power Ops-No Trip	Plant Centered	1	C	16	E	18	C
2202002001	FitzPatrick-Nine Mile Pt. 1	11/1/2002	Power Ops-No Trip	Switchyard Centered	0	C	15	E	482	C
3332003001 – 2202003002	FitzPatrick-Nine Mile Pt. 1	8/14/2003	Power Ops	Grid Related	137	C	142	E	431	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	0	C	14	C	14	C
2851998005	Fort Calhoun	5/20/1998	Shutdown	Switchyard Centered	104	E	109	E	109	C
2851999004	Fort Calhoun	10/26/1999	Shutdown	Plant Centered	2	C	2	C	2	C
2441988006	Ginna	7/16/1988	Power Ops-No Trip	Switchyard Centered	65	C	70	E	225	C
2442003002	Ginna	8/14/2003	Power Ops	Grid Related	49	C	54	E	297	C
4162003002	Grand Gulf	4/24/2003	Power Ops	Switchyard Centered	0	C	15	E	75	E
2131993009	Haddam Neck	6/22/1993	Shutdown	Plant Centered	12	C	27	E	35	C
2131993010	Haddam Neck	6/26/1993	Shutdown	Plant Centered	3	E	18	E	40	E
2471991006	Indian Point	3/20/1991	Shutdown	Switchyard Centered	0	C	15	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	40	E	132	C

Table A-7. (continued)

LER	Site	Date	Operational Mode	LOOP Category	Switchyard Restoration Time	Switchyard Restoration Certainty [a]	Potential Bus Restoration Time	Potential Bus Restoration Certainty [a]	Actual Bus Restoration Time	Actual Bus Restoration Certainty [a]
2861996002	Indian Point	1/20/1996	Shutdown	Switchyard Centered	30	E	40	E	145	C
2861997008	Indian Point	6/16/1997	Shutdown	Grid Related	37	E	42	C	42	C
2471998013	Indian Point	9/1/1998	Shutdown	Plant Centered	1	E	16	E	67	C
2471999015	Indian Point	8/31/1999	Decay Heat	Switchyard Centered	0	C	15	E	779	C
2862003005	Indian Point	8/14/2003	Power Ops	Grid Related	97	C	102	E	228	C
3731993015	La Salle	9/14/1993	Power Ops	Switchyard Centered	0	C	15	E	70	C
3091988006	Maine Yankee	8/13/1988	Power Ops	Switchyard Centered	14	C	15	E	15	C
3691987021	McGuire	9/16/1987	Shutdown	Plant Centered	0	C	6	C	6	C
3691988014	McGuire	6/24/1988	Shutdown	Switchyard Centered	8	C	8	C	8	C
3691991001	McGuire	2/11/1991	Power Ops	Plant Centered	0	C	40	C	60	E
3701993008	McGuire	12/27/1993	Power Ops	Switchyard Centered	96	C	101	E	131	C
3361986017	Millstone	11/5/1986	Shutdown	Switchyard Centered	(b)	U	(b)	U	(b)	U
3361988011	Millstone	10/25/1988	Power Ops	Plant Centered	19	E	29	E	29	E
2451989012	Millstone	4/29/1989	Shutdown	Switchyard Centered	0	C	15	E	75	E
4101988062	Nine Mile Pt. 2	12/26/1988	Shutdown	Switchyard Centered	9	C	24	E	54	C
4101992006	Nine Mile Pt. 2	3/23/1992	Shutdown	Plant Centered	20	C	30	E	50	E
4102003002	Nine Mile Pt. 2	8/14/2003	Power Ops	Grid Related	105	C	110	E	551	C
2871987002	Oconee	3/5/1987	Shutdown	Switchyard Centered	150	E	155	E	155	C
2701992004	Oconee	10/19/1992	Power Ops	Plant Centered	207	C	207	C	207	C
2191989015	Oyster Creek	5/18/1989	Power Ops	Plant Centered	1	E	16	E	54	C
2191992005	Oyster Creek	5/3/1992	Power Ops	Plant Centered	5	C	65	E	1029	C
2191997010	Oyster Creek	8/1/1997	Power Ops	Switchyard Centered	30	E	40	C	40	C
2551987024	Palisades	7/14/1987	Power Ops	Switchyard Centered	388	C	388	C	446	C
2551992032	Palisades	4/6/1992	Shutdown	Plant Centered	0	C	15	E	30	E
2551998013	Palisades	12/22/1998	Shutdown	Plant Centered	0	C	20	E	20	E
2552003003	Palisades	3/25/2003	Shutdown	Plant Centered	91	E	96	E	3261	C
5291989001	Palo Verde	1/3/1989	Power Ops-No Trip	Switchyard Centered	1138	C	1143	E	1266	C
5282004006	Palo Verde	6/14/2004	Power Ops	Grid Related	32	C	37	E	74	C
2771988020	Peach Bottom	7/29/1988	Shutdown	Switchyard Centered	9	E	24	C	125	C
2772003004	Peach Bottom	9/15/2003	Power Ops	Grid Related	1	C	16	E	72	C
4402003002	Perry	8/14/2003	Power Ops	Grid Related	82	C	87	E	123	C
2931986027	Pilgrim	11/19/1986	Shutdown	Weather Related	0	C	15	E	213	C

Table A-7. (continued)

LER	Site	Date	Operational Mode	LOOP Category	Switchyard Restoration		Potential Bus Restoration		Actual Bus Restoration	
					Time	Certainty [a]	Time	Certainty [a]	Time	Certainty [a]
2931986029	Pilgrim	12/23/1986	Shutdown	Switchyard Centered	0	C	1	E	1	C
2931987005	Pilgrim	3/31/1987	Shutdown	Weather Related	1	E	16	E	45	C
2931989010	Pilgrim	2/21/1989	Shutdown	Switchyard Centered	1	E	16	E	920	C
2931993004	Pilgrim	3/13/1993	Power Ops	Weather Related	30	E	40	E	298	C
2931993010	Pilgrim	5/19/1993	Shutdown	Switchyard Centered	36	C	37	C	37	C
2931993022	Pilgrim	9/10/1993	Power Ops	Switchyard Centered	10	C	25	E	200	C
2931997007	Pilgrim	4/1/1997	Shutdown	Weather Related	347	C	1200	C	1208	C
3011989002	Point Beach	3/29/1989	Power Ops	Switchyard Centered	90	E	95	E	202	C
2661992003	Point Beach	4/28/1992	Shutdown	Plant Centered	0	C	15	E	30	C
2661994010	Point Beach	9/27/1994	Shutdown	Plant Centered	0	C	15	E	15	E
2661998002	Point Beach	1/8/1998	Power Ops-No Trip	Switchyard Centered	337	E	342	C	557	C
2821996012	Prairie Island	6/29/1996	Power Ops	Weather Related	292	C	297	E	297	C
2651992011	Quad Cities	4/2/1992	Shutdown	Plant Centered	35	C	35	C	35	C
2652001001	Quad Cities	8/2/2001	Power Ops	Switchyard Centered	15	C	30	E	154	C
4581986002	River Bend	1/1/1986	Shutdown	Switchyard Centered	46	C	51	E	51	E
2611986005	Robinson	1/28/1986	Power Ops	Plant Centered	117	C	122	E	403	C
2611992017	Robinson	8/22/1992	Power Ops	Switchyard Centered	454	C	459	E	914	C
3111986007	Salem-Hope Creek	8/26/1986	Decay Heat	Plant Centered	0	C	15	E	75	E
3111994007	Salem-Hope Creek	4/11/1994	Power Ops-No Trip	Plant Centered	0	C	15	E	385	C
3111994014	Salem-Hope Creek	11/18/1994	Shutdown	Switchyard Centered	295	E	300	C	1675	C
2722003002	Salem-Hope Creek	7/29/2003	Power Ops	Switchyard Centered	30	E	40	E	480	C
4431991008	Seabrook	6/27/1991	Power Ops	Switchyard Centered	0	C	20	C	20	C
4432001002	Seabrook	3/5/2001	Power Ops	Weather Related	1	E	16	E	2122	C
3271992027	Sequoyah	12/31/1992	Power Ops	Switchyard Centered	96	C	101	E	116	E
3352004004	St. Lucie	9/25/2004	Shutdown	Weather Related	8	C	68	E	640	C
3951989012	Summer	7/11/1989	Decay Heat	Grid Related	95	C	100	E	120	C
2891997007	Three Mile Isl	6/21/1997	Power Ops	Switchyard Centered	85	E	90	C	90	C
2511991001	Turkey Point	3/13/1991	Shutdown	Plant Centered	62	E	67	C	67	C
2501991003	Turkey Point	7/24/1991	Shutdown	Switchyard Centered	0	C	11	C	11	C
2501992000	Turkey Point	8/24/1992	Shutdown	Weather Related	7916	E	7921	E	7921	C
2512000004	Turkey Point	10/21/2000	Shutdown	Switchyard Centered	1	E	16	E	111	C
2711987008	Vermont Yankee	8/17/1987	Shutdown	Grid Related	2	C	17	E	77	E

Table A-7. (continued)

					Switchyard Restoration		Potential Bus Restoration		Actual Bus Restoration	
LER	Site	Date	Operational Mode	LOOP Category	Time	Certainty [a]	Time	Certainty [a]	Time	Certainty [a]
2711991009	Vermont Yankee	4/23/1991	Power Ops	Plant Centered	277	C	282	E	822	C
4241990006	Vogtle	3/20/1990	Shutdown	Switchyard Centered	140	C	145	E	217	C
3902002005	Watts Bar	9/27/2002	Power Ops-No Trip	Grid Related	1	E	16	E	1003	C
4821987048	Wolf Creek	10/14/1987	Shutdown	Plant Centered	0	C	17	E	17	C
0291991002	Yankee-Rowe	6/15/1991	Power Ops	Switchyard Centered	24	C	25	C	25	C
3041991002	Zion	3/21/1991	Power Ops	Switchyard Centered	0	C	60	C	60	C
2951997007	Zion	3/11/1997	Shutdown	Switchyard Centered	235	E	240	E	240	C

a. 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.

b. The recovery/restoration times were unknown for this event.

Appendix B

Methods of Data Analysis

CONTENTS

FIGURES

Appendix B

Methods of Data Analysis

The LOOP database in Appendix A was analyzed to identify and summarize the behavior of the frequencies of occurrence of LOOPs and of their durations. In each case, the behavior of the data 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 analyze 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.

Three 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. S-PLUS [3] and @ Risk, Advanced Risk Analysis for Spreadsheets [4], provided checks for the 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 combining of frequencies and durations is explained.

B-1.1 Calculating Exposure Times

For each plant unit, hours of critical operation and of noncritical operation were obtained from the Monthly Operating Reports (MORP) submitted by the licensees to the NRC. The data from October 1986 forward are maintained in a Microsoft Access database at the Idaho National Laboratory for the Nuclear Regulatory Commission's "exAEOD" Performance Indicator Program. For each plant and month, shutdown operation times were obtained as "reporting hours" minus "critical hours."

Times for 1986 were obtained from an earlier "MORP1" data table that has not been modified since December of 1991.

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 1986–2004 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 an event tree or fault tree, affect the outcomes of the model leads to the need for a probability distribution for each occurrence rate. 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 exposure 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; 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 come from a 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, 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 the expression for the mean, 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 shaped like a backwards "J." 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 four 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 U.S.). 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. Another grouping variable was the season of each LOOP occurrence (May–September for summer, the rest of the year for nonsummer). 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 counts, normalized by the expected counts. 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 1997–2004 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 means, which in turn depend 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 can be 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 as 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 alternative 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 report, when an EB distribution was used in the calculation of an industry-level uncertainty distribution, the shape parameter (α) was 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 the same, 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 when the slope actually is zero, 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 has a chi-square distribution 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.

Because the GENMOD model is directly suited to the discrete nature of the frequency data, it was used if possible. More specifically, it was not rejected unless the goodness-of-fit p-value was less than 0.005 or greater than 0.995. With these conditions, it was not rejected at all.

Within each of the four LOOP categories, and for the data as a whole, frequency trends were studied separately for the 1986–1996 period (prior to deregulation) and the 1997–2004 period.

B-1.6 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 recovery 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 emergency diesel generators were running. The primary purpose for assessing these two times is to get bounds in particular events on the real time of interest in the station blackout scenario, 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 emergency diesel generator 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 1, and one site for Hope Creek and Salem (Nine Mile Point 2 remains as a single-unit site).

The statistical methods discussed below were applied for all three recovery times, but the PR times are the primary focus. Approximately 71% of these were estimated. For one event among 125 site-level LOOPs, all three times were unknown. This event was omitted from the duration study. Two salt water–related events at Pilgrim were also omitted (from both the durations and the frequencies), because the problem that caused these events has been permanently repaired. La Cross events were also totally omitted because of its atypical plant design. Therefore, 121 site-level LOOPs were analyzed.

B-1.7 Identifying Differences in Groupings of the Data

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

The SAS procedure NPAR1Way performs nonparametric 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 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-1.8 Fitting Exceedance Distributions

The complement of the EDF just described, abbreviated CEDF, is the probability of a recovery time being strictly greater than a specified value. Directly from the data, it is estimated as the number of sample values greater than a time of interest, 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.”

Risk assessments often need a smooth curve to describe the probability of long recovery times. 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 nonrecovery 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). Fitting selected types of CDFs to data is discussed further below.

In this report, two families of possible distribution functions are considered: lognormal and Weibull. The lognormal distribution is defined by the fact that, when a random quantity X is lognormal, the natural logarithm of X is normally-distributed (Gaussian). The Weibull distribution is defined by the fact that, when X is Weibull, the natural logarithm of X has a Type I (minimum) extreme value distribution. For both cases, specific distributions are fit to the data by the following process:

- Sort the data from small to large.
- Identify the logarithm of each recovery time and its EDF value (discussed above).
- Plot the logarithm of the times as a function of the EDF on both normal and extreme value probability paper. For the probability papers, the y axis is scaled according to the standard distribution being assessed. In the normal distribution case, the [0,1] interval is mapped with roughly the center 1/3 of the vertical axis representing the probabilities between 0.2 and 0.80. More space in the vertical axis is allocated to the tails of the distribution. More specifically, the vertical axis goes from nearly 0 to nearly 1 as $\Phi^{-1}(-3)$ goes smoothly to $\Phi^{-1}(+3)$, where Φ represents the standard normal cumulative distribution function. The normal distribution vertical axis is symmetric about the 50% line. On the other hand, the standard extreme value distribution favors smaller values and has a long tail only on the left. The top 1/3 of the axis covers the top 50% of the distribution and the lower 1/3 covers the lower 2% of the distribution. The figures below show the difference in the case of the overall LOOP potential bus recovery times.

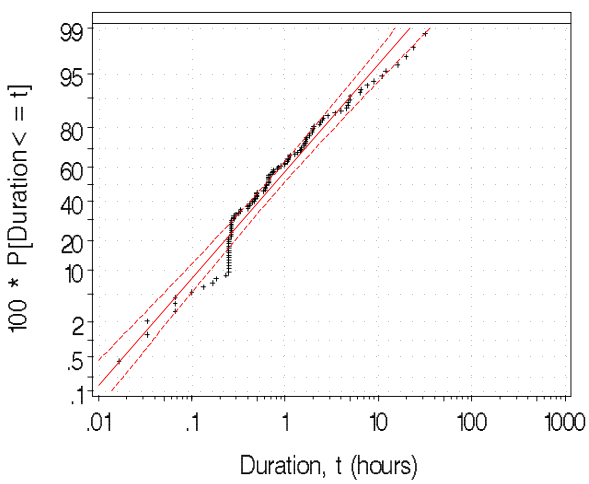


Figure B-1. Lognormal fit for overall LOOP data.

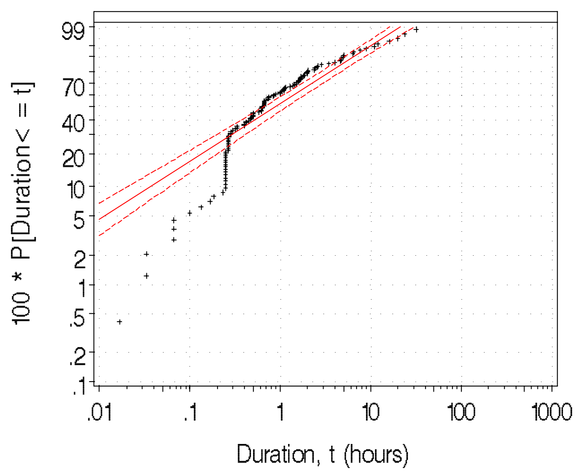


Figure B-2. Weibull fit for overall LOOP data.

- In each plot, fit a line through the data such that 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 lognormal or Weibull densities evaluated at each of the observed recovery times, regarded as a function of the slope and intercept of the lines described above. Each line leads to a particular lognormal or Weibull density, because of the following relationships:

  exp(normal paper line intercept) = median of fitted lognormal distribution

  exp(1.645*normal paper line slope) = error factor of fitted lognormal distribution exp(extreme value line intercept) = Weibull scale parameter

1/(extreme value line slope) = Weibull shape parameter.

An iterative search procedure is required to find the maximum likelihoods, at which the derivatives with regard to the parameters (intercept and slope) are zero. The estimates are called maximum likelihood estimates (MLE).

The process just described is performed by a number of software packages, such as Proc LifeReg in SAS, function CensorReg in S-PLUS, and the @ Risk plug-in to Excel. The plots above are often called "Q-Q" plots, because they relate the quantiles in the data (on the x axis) to the quantiles in the smooth distribution being sought.

For lognormal data, the exceedance probability for recovery exceeding a time, T, is

$$1 - \Phi([\log T - \{\text{underlying normal mean}\}] / \{ \text{underlying normal standard deviation}\}),$$

where Φ is the standard normal distribution cumulative distribution function, the intercept parameter in the fit above is the underlying normal mean, and the slope estimate in the fit above is the underlying normal distribution standard deviation. For Weibull data, the exceedance probability is

$$\exp(- T/ \{\text{Weibull scale}\})^{\{\text{Weibull shape}\}}.$$

For plots showing the switchyard recovery time, the recovery times for events in which power was lost in the switchyard were analyzed as described above. The resulting distributions provide conditional probabilities of recovery exceeding specified times, conditioned on the loss of that power. For unconditional exceedance probabilities, each conditional probability is multiplied by the probability of switchyard power loss. This probability was estimated from the fraction of events that did not lose switchyard power.

A number of goodness-of-fit tests exist to assess whether the lognormal or Weibull fit is better. The Kolmogorov-Smirnov test was discussed in Section B.2.1 above. While it looks at the maximum difference between the smooth fitted cumulative distribution function and the empirical distribution function, the Anderson-Darling test looks at *n* (the sample size) times the expected value (or average) of the squared difference with regard to the smooth curve, and the Cramér-von Mises test looks at *n* times a weighted average. For the latter, the weights are taken to be inversely proportional to the variance [F(x)*(1-F(x))], where F(x) is the smooth curve evaluated at the point "x." In all of these cases, the empirical distribution is being compared with a specific smooth distribution, namely, the one obtained by the MLE method described above. For each of these measures, the behavior of the difference has been tabulated for the case where the samples come from the fitted distributions. When the observed values of these statistics are large in comparison to the tabulated typical values, the statistics show lack of fit. Each statistic has a corresponding "p-value" showing the likelihood of seeing differences as large, or larger, than the observed difference, when the fits are perfect. Low p-values show lack of fit. Comparing Figures B-1 and B-2 shows that the lognormal fit is best for the overall data. The three statistics just described bear this out. In SAS, the statistics are computed in Proc Univariate.

Proc Univariate also can generate a histogram of the data, with the time axis divided into equally-spaced bins. The proportion of data lying in each bin can be compared with the theoretical proportion based on the smooth curve to form another goodness of fit test. The sum of the squares of the differences between the observed number of observations in each bin and the expected number based on the smooth curve, each divided by the expected count, follows a chi-square distribution as the sample size increases. The chi-squared goodness of fit test is most accurate when the expected count in each bin is at least 5.

The reference distribution has between (m-1) degrees of freedom, where m is the number of bins, and (m-3) degrees of freedom (depending on how one counts the number of estimated quantities).

All of the tests just described are discussed in HOPE, Section 6.6.2.3.

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 in the report). The p-values were also considered.

An alternative way of fitting a particular lognormal distribution to data is to identify the normal distribution whose mean and variance match the sample mean and variance of the logarithms of the observed recovery times. 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

Lognormal 5th percentile = lognormal median / EF.

This method does not lead to the same lognormal distribution as the one discussed above. The first method is preferable because it uses more of the information embedded in the sample data, and it facilitates the determination of which distribution, Weibull or lognormal, fits the data better.

An additional 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 do 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.

B-1.9 Assessing the Uncertainty of the Estimated CDF

From the calculations used to fit the lines in the Q-Q plots above, SAS, S-PLUS, and other software packages compute an estimate of the standard error of each intercept and slope. The standard errors reflect how well the associated parameter values are known. As the sample size increases, the parameter estimates are themselves approximately normally-distributed quantities with these standard deviations. In the lognormal case, the location and scale (slope) estimates are independent. In the Weibull case they are correlated, with a correlation coefficient of -0.3364. A natural way of observing the uncertainty in the exceedance probabilities is to simulate from a bivariate normal distribution with the specified mean and standard deviation for each of the two variables and the specified correlation coefficient. For each iteration in the simulation, exceedance probabilities are saved for selected recovery times from the resulting lognormal or Weibull distribution. The process is repeated many times (e.g., 5000 times), resulting in a matrix with 5000 rows and a column for each time of interest. The plots in the main text are based on collecting data for 23 time values. Then, within each column, report the average, 5th percentile, median, and 95th percentile. SAS procedure Univariate was used for these calculations. The resulting points, when connected across the domain of times of interest, produce smooth curves showing lower and upper bounds for the exceedance probabilities in addition to the median and mean. Note that each point along the 95th percentile line (for example) may have come from a different row in the matrix of simulated values.

Another observation worth noticing is that the medians and means may differ somewhat from the values that would be calculated directly from the curve fits. The simulation introduces additional variability, while the data calculated directly from the curve fits are “nominal” or “point values.”

In practice, the use of a bivariate normal distribution for the Weibull distribution (thus considering the effect of the correlation in the estimates), has not had a major impact on the results. Sensitivity studies have shown little difference. Therefore, two independent normal distribution samples have been used at each iteration.

The “plug-in” added to the Saphire reliability analysis package to study recovery times does not sample from the parameters of the underlying distributions (e.g., the normal and extreme value distributions). Instead, it samples from distributions for the parameters of the actual lognormal and Weibull distributions. For the lognormal distribution, this is no problem because the lognormal and normal parameters are related by simple exponential transformations. The plug-in uses a stated mean and error factor for the lognormal median, and a stated mean and error factor for the lognormal recovery time error factor. The same is true for the Weibull scale parameter—the Weibull scale parameter naturally has a lognormal distribution for its uncertainty.

However, the Weibull shape parameter is the reciprocal of the extreme value scale (slope) parameter, and reciprocals of normally-distributed quantities may not be normally-distributed. In order to get a lognormal distribution for the shape parameter, a sample of random extreme value scale parameters was generated, reciprocals were taken to obtain a sample of Weibull shape parameters, and the results were fit to a lognormal distribution. This latter fitting process was identical to the process used to fit a lognormal distribution to the recovery times. The MLE and standard deviation from the resulting curve fit were used to generate lognormal means and lognormal error factors for the Saphire plug-in for the Weibull shape parameter.

B-1.10 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. As with the frequencies, this analysis was performed separately for the 1986–1996 period and the 1997–2004 period.

Ordinary least squares regression was used to fit a line for the log recovery times, as a function of event date measured in days. For each time period, the dates were shifted to center the regression around 0. Each line was fit through a scatter plot of (date, log duration) pairs. To assess the adequacy of the models, 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 tests is a t-statistic that measures the statistical significance of the slopes.

B-1.11 Combining Frequencies and Durations

In this study, composite durations and frequencies for operations and for shutdown were obtained for use in situations where the LOOP category is not specified.

For durations, a frequency-weighted exceedance curve is created by a frequency-weighted pointwise average of the four separate exceedance curves. That is, at each time t, the plant-centered, switchyard-centered, grid-related, and weather-related exceedance values are averaged, using the frequencies associated with each category as weights. The sums of products of exceedance and frequency are normalized by dividing by the sum of the frequencies. This process forms an overall mixture distribution for the recovery time. In application, two distributions are formed, one using the frequencies from critical operations and another using the frequencies that pertain to shutdown operations.

The frequency-weighted average exceedance curves fit the data much better than fitting a lognormal or Weibull distribution for the critical operations data and for the shutdown data. The probability density functions for recovery time corresponding to the average curves can be multi-modal, with the possibility of a peak at the peak of each of the four lognormal (or Weibull) curves being combined.

For each LOOP category, and for a list of specified possible recovery times, the frequency of trip-associated LOOP occurrences during critical 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 four categories. Numerically, this calculation is the same as the frequency-weighted average exceedance except that it is not normalized. It retains the units of per reactor critical year.

The composite frequency of exceedance curve was also computed using the shutdown LOOP frequencies and the associated category-specific recovery curves.

B-2. ANALYSIS OF LOOP-RELATED PROBABILITIES

Selected probabilities were considered in the LOOP study. The probability of loss of power in the switchyard was considered. The probability of LOOP occurring during shutdown conditions or during critical operations was considered. Probabilities for LOOPs being directly or indirectly the result of reactor trips were studied. Probabilities were considered for LOOPs occurring during the summer (May–September) rather than nonsummer (the remaining seven months). Among weather-related and weather-caused events, the probability of abnormal conditions when the plant is shutdown was considered. 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-2.1 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 and β. 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 $[\alpha + n, \beta + (d\text{-}n)]$. 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 $(n+0.5,\ d\text{-}n+0.5)$. As in Section B.1.2 above, this distribution (for probabilities) will be called an updated Jeffreys noninformative distribution 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-2.2 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 nonoccurrence as well as the probability of the occurrence under study. Details are provided in HOPE, Section 6.3.3.

B-2.3 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 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 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 (4). HOPE, Section 6.3.2.5.4, provides further information.

B-2.4 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 recovery times are zero. Therefore, the fitted switchyard time distribution is a conditional distribution, given loss of power in the switchyard. Let p be the probability that the switchyard times are zero (e.g., no loss of power in the switchyard), and T be the switchyard recovery time. Then, from the definition of conditional probability, for any particular time, t, greater than zero

$P[T > t \mid \text{power lost}] = P[(T > t) \text{ AND } (\text{power lost})] / P[\text{power lost}]$.

If T is greater than t, then the switchyard power was lost, so the "AND" in the above expression adds nothing. Also, P[power lost] is 1-p. Thus,

$P[T > t \mid \text{power lost}] = P[(T > t)] / (1-p)$.

Rearranging these terms produces an unconditional probability:

$P[(T > t)] = P[(T > t) \mid \text{power lost}] * (1-p)$.

Thus, the unconditional switchyard recovery curves do not start at the (time, exceedance probability) point (0, 1) and drop towards (long times, 0). Instead, these curves start at (0, 1-p) and drop down towards (long times, 0).

B-3. 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 9.1. 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. *S-Plus 6 Guide to Statistics Vol. 1 and 2*, Insightful Corporation, Seattle, Washington, July 2001; and associated software.

4. *@Risk: Advanced Risk Analysis for Spreadsheet*s, 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

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FIGURES

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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.

In this report, the LOOP data were classified as plant centered, switchyard centered, grid related, or weather related. For comparison with previous reports, several of the tables herein also provide data for the case where plant-centered and switchyard-centered data are combined.

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. Summer and nonsummer data are shown. These are followed by the results of statistical tests for differences with respect to several other attributes of the plants, such as their locations in particular North American 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 1986–2004 and 1997–2004. For weather-related LOOPs, coastal plant results and inland plant results are shown separately. The results are also displayed separately for summer (May–September) and nonsummer (October–April) for each category.

The table shows extremely significant differences for plant-centered, switchyard-centered, and weather-related LOOPs. The differences persist in the recent time span and for both summer and nonsummer data for the first two of these categories. For weather-related LOOPs, the differences show for both coastal and inland 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-related category 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 1986–1996 and 1997–2004. 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 periods are of interest since deregulation occurred early in 1997.

Table C−1. Differences based on plant mode.

LOOP category	Total # of Events	Total Time (yr)	P-value for Plant Mode Differences	Summer			Nonsummer		
				Events	Time (yr)	P-value	Events	Time (yr)	P-value
Plant-centered LOOP freq. (1986–2004)	31	1984.7	**<0.00005**	13	828.0	**0.0021**	18	1156.8	**0.00005**
Plant-centered LOOP freq.(1997–2004)	6	828.9	**0.0002**	2	345.5	0.1837	4	483.4	**<0.00005**
Switchyard-centered LOOP freq. (1986–2004)	68	1984.7	**<0.00005**	29	828.0	**0.0012**	39	1156.8	**<0.00005**
Switchyard-centered LOOP freq.(1997–2004)	14	828.9	**0.0008**	7	345.5	1.00	7	483.4	**0.0001**
Grid-related LOOP freq. (1986–2004)	17	1984.7	1.00	17	828.0	1.00	0	1156.8	—
Grid-related LOOP freq.(1997–2004)	15	828.9	1.00	15	345.5	0.65	0	483.4	—
Weather-related LOOP freq. (1986–2004)	19	1984.7	**<0.00005**	9	828.0	**0.0082**	10	1156.8	**0.0001**
Weather-related LOOP freq. (1997–2004)	7	828.9	**0.0065**	5	345.5	**0.0077**	2	483.4	0.27
Weather-related LOOP freq.—coastal plants	14	795.5	**<0.00005**	5	332.0	**0.0035**	9	463.5	**0.0005**
Weather-related LOOP freq.—noncoastal plants	5	1189.3	0.25	4	496.0	1.00	1	693.3	—
Plant and switchyard combined (1986–2004)	99	1984.7	**<0.00005**	42	828.0	0.00001	57	1156.8	**<0.00005**
Plant and switchyard combined (1997–2004)	20	828.9	**<0.00005**	9	345.5	0.21	11	483.4	**<0.00005**

Table C−2. Differences based on time period (1986–1996 versus 1997–2004).

LOOP category and mode subset	1986–1996		1997–2004[a]		Total		P-value for time period differences	Summer[b]		Nonsummer[b]	
	Events	Time (yr)	Events	Time (yr)	Events	Time (yr)		Old/New Count	Time P-value	Old/New Count	Time P-value
Plant-centered	25	1984.7	6	829.9	31	1984.7	**0.0164**	11/2	0.0876	14/4	0.1005
Plant-centered trip	11	1601.5	**1**	**724.3**	12	1601.5	**0.0162**	5/1	0.2324	6/0	**0.0257**
Shutdown plant-centered	14	383.2	5	104.7	**19**	**383.2**	1.00	6/1	0.6901	8/4	0.7527
Switchyard-centered	54	1984.7	14	829.9	68	1984.7	**0.0005**	22/7	0.0604	32/7	**0.0029**
Switchyard-centered trip	23	1601.5	**7**	**724.3**	30	1601.5	**0.0167**	11/6	0.4732	12/1	**0.009**
Shutdown switchyard-centered	31	383.2	7	104.7	**38**	**383.2**	0.2754	11/1	0.3155	20/6	0.6663
Grid-related	2	1984.7	15	829.9	17	1984.7	**0.0001**	2/15	**0.0001**	0/0	—
Grid-related trip	1	1601.5	**13**	**724.3**	14	1601.5	**0.0003**	1/13	**0.0003**	0/0	—
Shutdown grid-related	1	383.2	2	104.7	**3**	**383.2**	0.183	1/2	0.1523	0/0	—
Weather-related	12	1984.7	7	829.9	19	1984.7	0.8172	4/5	0.5044	8/2	0.2094
Weather-related trip[c]	3	1601.5	**3**	**724.3**	6	1601.5	1.00	2/2	1.00	1/1	1.00
Shutdown weather-related	9	383.2	4	104.7	**13**	**383.2**	1.00	2/3	0.0998	7/1	0.4528
Plant and switchyard combined	79	1984.7	20	829.9	99	1984.7	**0.00001**	33/9	**0.0074**	46/11	**0.0006**
Plant and switchyard combined trip	34	1601.5	8	724.3	42	1601.5	**0.0009**	16/7	0.2087	18/1	**0.0003**
Shutdown plant and switchyard combined	45	383.2	12	104.7	57	383.2	0.3044	17/2	0.19	28/10	0.8585

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

b. The season-related 1986–1996 and 1997–2004 reactor year times are as follows. The time p-values are based on the expected count split between periods, as determined from the times, compared with the actual count split between the two time periods.

	1986–1996	1997–2004
Total summer years	482.5	345.5
Total nonsummer years	673.3	483.4
Critical operation summer yrs	380.5	312.2
Critical operation nonsummer years	496.7	412.1
Shutdown summer years	102.0	33.3
Shutdown nonsummer years	176.6	71.3

c. Use of 1997–2004 data is based on consistency with the other categories. The total data and the 1997–2004 data both give similar results.

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 for the plant-centered LOOP frequencies. For each of the four categories, these differences are not statistically significant for the shutdown data. There are no noticeable differences for the weather category. Further information on time differences is in the trend section below.

The seasonal data split the total time of 1984.7 years into 828.0 years of summer and 1156.7 years of nonsummer. Among critical operation time, the seasonal split divides the 1601.5 years into 692.7 summer years and 908.8 nonsummer years. Shutdown time is split with 135.3 years in the summer months and 247.9 years in the nonsummer months. Table C−2 shows how the total counts split for summer versus nonsummer for the two periods for each of the categories. It also gives the associated p-values for differences in the pre-deregulation and post-deregulation periods. The results are similar to the results with the seasons combined: differences are observed for one or both seasons for critical operation for all the LOOP categories except the weather-related category, and no significant differences are observed for shutdown operations.

These evaluations resulted in the report's use of just the 1997–2004 data for plant, switchyard, and grid-related LOOP frequencies during critical operation. For consistency, the recent, post-deregulation data were also used for the weather-related LOOPs for critical operation. The entire period was used when considering shutdown operation. 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 Seasonal Effects

Table C−2 provides a complete breakdown of the summer and nonsummer LOOP counts with respect to both plant mode and the two periods for each category. A footnote supplies the corresponding time breakdown. Tabulating the LOOP occurrence rates separately by season within each of the selected category/mode/time period groupings is not directly useful, since a risk assessment using such frequencies needs to be applicable for an arbitrary point in time, but the data analysis did show two striking seasonal impacts. The first is that all of the grid-related events occurred in the summer. The 17 unit-level events occurred on just five separate dates. However, it is striking to note that all of those dates were summer dates. Also, during critical operation after deregulation, the time split between summer and nonsummer was 312.2 rcry to 412.1 rcyr, but the switchyard-centered event split was 6 summer, 1 nonsummer. These events occurred on separate dates and at different sites.

C-1.4 Effects of Other Groupings of the Data

The LOOP data were divided into four categories, due to differences in recovery durations (discussed in Section C.2). Within each of these categories, data were pooled by year, plant, site, 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

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

LOOP category	Source of variation	P-value for differences	Dist. Type[a]	Industry gamma uncertainty distribution 5th	Mean	95th	Shape (α)
Plant-centered trip (1997–2004)—1 event in 724.3 rcry							
	Sampling	—	UJNID	2.43E−04	2.07E−03	5.39E−03	1.50
	—	—	**CNID**	**8.14E−06**	**2.07E−03**	**7.96E−03**	**0.50**
	(no results for various sources of variation with only one event)						
Switchyard-centered trip (1997–2004)—7 events in 724.3 rcry							
	Sampling	—	UJNID	3.63E−03	8.74E−03	1.56E−02	5.50
	—	—	**CNID**	**3.44E−05**	**8.74E−03**	**3.36E−02**	**0.50**
	Year	0.5421	—	—	—	—	—
	Plant	0.5818	—	—	—	—	—
	Site	0.5560	—	—	—	—	—
	NERC subregion	0.5853	—	—	—	—	—
	NERC region	0.4544	—	—	—	—	—
	Interconnection	0.6230	—	—	—	—	—
	Coast	0.4509	—	—	—	—	—
	1032 design group	0.7723	—	—	—	—	—
Grid-related trip (1997–2004)—13 events in 724.3 rcry							
	Sampling	—	UJNID	1.12E−02	1.86E−02	2.77E−02	13.50
	—	—	**CNID**	**7.33E−05**	**1.86E−02**	**7.16E−02**	**0.50**
	Year	**<0.00005**	EB	3.56E−13	1.75E−02	1.00E−01	0.11
	Plant	0.8537	—				—
	Site	**0.0275**	EB	5.12E−08	1.76E−02	8.86E−02	0.22
	NERC subregion	**<0.00005**	EB	3.09E−09	2.09E−02	1.11E−01	0.18
	NERC region	**0.0005**	EB	3.16E−05	2.06E−02	8.38E−02	0.42
	Interconnection	0.104	—	—	—	—	—
	Coast	0.5802	—	—	—	—	—
	1032 design group	0.2831	—	—	—	—	—
Weather-related trip (1997–2004)—3 events in 724.3 rcry							
	Sampling	—	UJNID	1.50E−03	4.83E−03	9.71E−03	3.50
	—	—	**CNID**	**1.90E−05**	**4.83E−03**	**1.86E−02**	**0.50**
	Year	0.6631	—	—	—	—	—
	Plant	0.4044	—	—	—	—	—
	Site	**0.0184**	—	—	—	—	—
	NERC subregion	0.7817	—	—	—	—	—
	NERC region	0.7042	—	—	—	—	—
	Interconnection	0.8165	—	—	—	—	—
	Coast	0.5694	—	—	—	—	—
	1032 design group	0.7517	—	—	—	—	—

Table C-3 (continued)

LOOP category	Source of variation	P-value for differences	Dist. Type[a]	Industry gamma uncertainty distribution 5th	Mean	95th	Shape (α)
Weather-related trip (1986–2004)—6 events in 1601.5 ry [b]							
	Sampling	—	UJNID	1.84E−03	4.06E−03	6.98E−03	6.50
	—	—	CNID	1.60E−05	4.06E−03	1.56E−02	0.50
	Year	0.4364	—	—	—	—	—
	Plant	0.7157	—	—	—	—	—
	Site	**0.0293**	EB	1.66E−08	3.94E−03	1.97E−02	0.22
	NERC subregion	0.2625	EB	2.69E−04	3.84E−03	1.10E−02	1.14
	NERC region	0.1428	EB	9.68E−04	3.95E−03	8.59E−03	2.67
	Interconnection	0.6806	—	—	—	—	—
	Coast	0.6887	—	—	—	—	—
	1032 design group	0.8682	—	—	—	—	—
Plant- or switchyard-centered trip (1997–2004)—8 events in 724.3 rcry							
	Sampling	—	UJNID	5.99E−03	1.17E−02	1.90E−02	8.50
	—	—	CNID	4.61E−05	1.17E−02	4.51E−02	0.50
	Year	0.7409	—	—	—	—	—
	Plant	0.6325	—	—	—	—	—
	Site	0.6774	—	—	—	—	—
	NERC subregion	0.6194	—	—	—	—	—
	NERC region	0.5927	—	—	—	—	—
	Interconnection	0.763	—	—	—	—	—
	Coast	0.7223	—	—	—	—	—
	1032 design group	0.3898	—	—	—	—	—
	LOOP category	0.0703	EB	2.23E−03	1.10E−02	2.53E−02	2.23

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

b. These full-study-period data were not used in the main assessment, although the statistical tests did not show a difference between the 1986–1996 and 1997–2004 periods for weather-related LOOP events. The data are included to show that the use of the CNID from the more restricted, recent period covers the variation.

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 critical operations; in accordance with the selections in bold in Table C−2, the time span for the data is the recent period. Table C−4 provides evaluations for shutdown periods; the entire study period is used for these assessments. Since results differ for coastal plants for weather-related events in shutdown periods, the results for the coastal subset for weather-related LOOPs are also provided. Table C−5 applies to combined operations and shutdown data for the grid-related category (for which no statistical significance was found for the differing plant mode). Here, the entire time period of data 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−4. Industry uncertainty distributions for LOOP frequencies (/rsy) during shutdown periods.

				Industry gamma uncertainty distribution			
LOOP category	Source of variation	P-value for differences	Dist. type[a]	5th	Mean	95th	Shape (α)
Plant-centered, shutdown (1986–2004)—19 events in 383.2 rsy							
	Sampling	—	UJNID	3.35E−02	5.09E−02	7.12E−02	19.50
	—	—	CNID	2.00E−04	5.09E−02	1.95E−01	0.50
	Year	0.1136	EB	4.22E−03	5.06E−02	1.41E−01	1.24
	Plant	0.1988	EB	1.04E−04	4.79E−02	1.91E−01	0.45
	Site	**0.0033**	**EB**	**8.20E−05**	**5.25E−02**	**2.13E−01**	**0.43**
	NERC subregion	0.1532	—	—	—	—	—
	NERC region	0.0986	EB	1.73E−02	5.24E−02	1.03E−01	3.80
	Interconnection	0.2911	—	—	—	—	—
	Coast	1.00	—	—	—	—	—
	1032 design group	0.3758	—	—	—	—	—
Switchyard-centered, shutdown (1986–2004)—38 events in 383.2 rsy							
	Sampling	—	UJNID	7.54E−02	1.00E−01	1.28E−01	38.50
	—	—	CNID	3.95E−04	1.00E−01	3.86E−01	0.50
	Year	0.777	—	—	—	—	—
	Plant	**0.0052**	EB	8.55E−03	9.92E−02	2.74E−01	1.26
	Site	**0.0001**	**EB**	**7.88E−03**	**1.03E−01**	**2.92E−01**	**1.19**
	NERC subregion	0.1379	EB	6.02E−02	1.02E−01	1.54E−01	12.71
	NERC region	**0.0191**	EB	5.53E−02	1.03E−01	1.62E−01	9.80
	Interconnection	0.5797	—	—	—	—	—
	Coast	0.1394	—	—	—	—	—
	1032 design group	0.6116	—	—	—	—	—
Grid-related, shutdown (1986–2004)—3 events in 383.2 rsy							
	Sampling	—	UJNID	2.83E−03	9.13E−03	1.84E−02	3.50
	—	**—**	**CNID**	**3.59E−05**	**9.13E−03**	**3.51E−02**	**0.50**
	Year	0.4385	—	—	—	—	—
	Plant	0.8281	—	—	—	—	—
	Site	0.0782	—	—	—	—	—
	NERC subregion	0.9299	—	—	—	—	—
	NERC region	0.4983	EB	5.57E−04	7.72E−03	2.20E−02	1.16
	Interconnection	0.8229	—	—	—	—	—
	Coast	1.00	—	—	—	—	—
	1032 design group	0.0907	—	—	—	—	—

Table C-4 (continued)

LOOP category	Source of variation	P-value for differences	Dist. type[a]	Industry gamma uncertainty distribution 5th	Mean	95th	Shape (α)
Weather-related, shutdown (1986–2004)—13 events in 383.2 rsy							
	Sampling	—	UJNID	2.11E−02	3.52E−02	5.23E−02	13.50
	—	—	**CNID**	**1.39E−04**	**3.52E−02**	**1.35E−01**	**0.50**
	Year	**0.0231**	EB	3.88E−03	3.43E−02	8.99E−02	1.47
	Plant	0.0741	EB	2.52E−06	3.32E−02	1.54E−01	0.29
	Site	**<0.00005**	EB	8.63E−12	3.44E−02	1.95E−01	0.13
	NERC subregion	**<0.00005**	EB	2.42E−05	3.47E−02	1.47E−01	0.38
	NERC region	**<0.00005**	EB	1.07E−05	4.29E−02	1.90E−01	0.33
	Interconnection	0.4298	—	—	—	—	—
	Coast	**0.0015**	EB	4.18E−03	3.88E−02	1.03E−01	1.43
	1032 design group	0.2012	—	—	—	—	—
Weather-related (coast only), shutdown (1986–2004)—11 events in 155.6 rsy							
	Sampling	—	UJNID	4.21E−02	7.39E−02	1.13E−01	11.50
	—	—	CNID	2.91E−04	7.39E−02	2.84E−01	0.50
	Year	**0.0016**	EB	4.05E−04	7.43E−02	2.79E−01	0.53
	Plant	0.1805	EB	9.40E−04	6.95E−02	2.42E−01	0.66
	Site	**0.0022**	EB	1.91E−07	7.49E−02	3.79E−01	0.21
	NERC subregion	**0.0014**	EB	1.52E−04	6.83E−02	2.72E−01	0.45
	NERC region	**0.0002**	EB	1.67E−03	8.85E−02	2.99E−01	0.72
	Interconnection	0.4778	—	—	—	—	—
	1032 design group	0.1725	—	—	—	—	—
Weather-related (inland only), shutdown (1986–2004)—2 events in 227.6 rsy							
	Sampling	—	UJNID	2.52E−03	1.10E−02	2.43E−02	2.50
	—	—	CNID	4.32E−05	1.10E−02	4.22E−02	0.50
	Year	0.7643	—	—	—	—	—
	Plant	0.5657	—	—	—	—	—
	Site	0.8539	—	—	—	—	—
	NERC subregion	0.8806	—	—	—	—	—
	NERC region	0.6542	—	—	—	—	—
	Interconnection	0.8223	—	—	—	—	—
	1032 design group	0.8235	—	—	—	—	—
Plant- or switchyard-centered, shutdown (1986–2004)—57 events in 383.2 rsy							
	Sampling	—	UJNID	1.19E−01	1.50E−01	1.84E−01	57.50
	—	—	CNID	5.90E−04	1.50E−01	5.76E−01	0.50
	Year	0.6787	—	—	—	—	—
	Plant	**0.0005**	EB	1.21E−02	1.47E−01	4.09E−01	1.23
	Site	**<0.00005**	EB	7.98E−03	1.58E−01	4.73E−01	0.99
	NERC subregion	**0.023**	EB	6.92E−02	1.55E−01	2.69E−01	6.30
	NERC region	**0.0023**	EB	6.23E−02	1.61E−01	2.97E−01	4.85
	Interconnection	0.2751	—	—	—	—	—
	1032 design group	0.2245	—	—	—	—	—
	Coast	0.2245	—	—	—	—	—
	LOOP category	0.4853	EB	8.69E−02	1.49E−01	2.24E−01	12.50

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

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

LOOP category	Source of variation	P-value for differences	Dist. Type[a]	Industry gamma uncertainty distribution 5th	Mean	95th	Shape (α)
Grid-related (1986–2004)—17 events in 1984.7 ry							
	Sampling	—	UJNID	5.66E−03	8.82E−03	1.25E−02	17.50
	—	—	CNID	3.47E−05	8.82E−03	3.39E−02	0.50
	Year	**<0.00005**	EB	1.14E−10	8.65E−03	4.74E−02	0.15
	Plant	0.748	—	—	—	—	—
	Site	**0.0138**	EB	8.31E−07	8.69E−03	3.99E−02	0.30
	NERC subregion	**<0.00005**	EB	5.86E−06	9.50E−03	4.05E−02	0.37
	NERC region	**0.0008**	EB	1.84E−04	8.81E−03	2.94E−02	0.74
	Interconnection	0.3154	—	—	—	—	—
	Coast	0.8072	—	—	—	—	—
	1032 design group	0.1227	—	—	—	—	—

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

C-1.4.1 Differences with respect to year

Statistically significant year differences were shown in only two instances: grid-related LOOPs during operation, and weather-related LOOPs during shutdown. The grid results carry over to the overall results in Table C−5. Grid events that make grid-related frequencies differ by year include the August 14, 2003, grid blackout and the Palo Verde event in 2004 that affected all three units. The weather-related year differences are associated with storms that affected more than one plant. The effect is most pronounced among coastal plants.

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-1.4.2 Differences with respect to plant

Between-plant variation was identified in shutdown switchyard LOOPs. The difference carries over to the combined plant- and switchyard-centered grouping of shutdown LOOPs. The EB distribution for switchyard LOOP frequencies was not used in the study, however, because the p-value for site differences was more significant.

Plant differences were seen in the overall weather-related LOOP frequencies (p-value 0.0001), and in the overall coastal weather-related LOOP frequencies (p-value 0.0013). These do not show in Table C−3 through Table C−5 because the weather data is split according to plant operating mode. The weather-related distributions were also discounted due to dependence in the events and the high skewness of the fitted EB distributions.

C-1.4.3 Differences with respect to site

Where plant differences were seen, site differences were also seen. This is because almost half of the sites currently have single-unit plants. The EB distribution for shutdown, switchyard-related LOOPs 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. The differences also carry over to the combined plant- and switchyard-centered grouping.

Site differences are also shown in the shutdown and overall weather events, particularly for the coastal plants. As with the distributions based on variation in year, these were discounted because of the high degree of dependence among the events.

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 5th and 95th percentiles of the resulting gamma distribution were computed and tabulated.

C-1.4.4 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.

As shown in Table C−3 and Table C−4, site-level variations carry over into subregion variations for the grid-related category during critical operations and the weather-related category during shutdown operations. 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 a majority of the grid events occurred during operations, these findings also carry over in the total reactor-year-based rates in Table C−5.

C-1.4.5 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-related events during operations).

Switchyard-centered 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 four, five, and six events, respectively, and none with more, so statistically significant subregion differences were not observed.

C-1.4.6 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 than in the rest of the country, interconnection differences are not likely to be observed. None were.

C-1.4.7 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 and overall weather-related category. The data were too sparse to see any difference in operations. The Licensee Event Report data were reviewed to identify which plants shut down in anticipation of a storm or other weather event, and only one such event was found.

Table C−4 shows an evaluation of the coastal and inland plants separately for 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, site, subregion, and region. However, with highly-skewed EB distributions for site, subregion, and region variation, these results are influenced by the dependency in the data. The eleven events occurred at Brunswick (one 1993 salt spray event affecting the site), Crystal River 3 (two events in March 1993), Turkey Point (one 1992 event affecting the site), St. Lucie (one 2004 event affecting the site), and Pilgrim (3 separate events). The clustering of the events around particular years (1993), sites, and NERC subregions and councils is obvious. Crystal River, Turkey Point, and St. Lucie are all in Florida (a single NERC subregion/council).

C-1.4.8 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 1986–2004 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 258.1/633.7/709.7. 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 plant-centered data.

Among the grid- and weather-related shutdown data for the post-regulation period (1997–2004), two apparent differences with respect to 1032 electrical design class appear (with p-values of 0.0283 and 0.0327, respectively). For the 1997–2004 period, reactor shutdown time splits among the classes I1/I2/I3 as 22.9/43.1/38.6 sdy. In the grid case, two unrelated events (one in 1997 and the other in 2003) occurred, and both were at plants with the I1 design (which represents the least amount of time). In the weather case, four events occurred at three sites. The events were split among the design categories as, respectively, 0/0/4.

C-1.5 Frequency Trend Results

Figures 3−1 through 3−4 show yearly trends in the frequencies during operation for the four categories of LOOP events. Figure 3−5 is based on the critical operation data from all four categories combined. In each of these plots, the trends were examined separately for the 1986–1996 (pre-deregulation) and 1997–2004 (post-deregulation) periods. Statistical analyses for trends were performed for the overall period (1986–2004) as well. The trend lines were fitted using generalized linear models (Procedure GENMOD in SAS). They are annotated with the p-value for the significance of the slope for each section of time. The p-values show the likelihood of the fitted trend line under the assumption of no trend, and small p-values show trends. The vertical bars in the figures show the maximum likelihood estimates of the frequencies for each year (number of events divided by reactor critical years), together with a (5%, 95%) confidence interval on what the occurrence frequency might be if the data in a year were homogeneous with a constant occurrence rate. The figures also have simultaneous confidence bands that show, with 90% confidence, where the trend line is likely to be.

Table C−6 contains the yearly counts and reactor critical years that form the basis for the regressions in Figures 3−1 through 3−5 of the main report. Table C−7 provides additional information about these trend analyses. In the first section, the data on the left in each figure is described, and in the second section the post-deregulation data are described. A final section provides information about overall trends (not shown in the plots).

In each section, the slope of the log of the LOOP critical operation frequency is given. When a trend is significant, this slope shows whether it is increasing or decreasing. The second column shows the estimated standard deviation of the slope. A slope can be "statistically significant" at the 5% confidence level only if its absolute value divided by its standard error is greater than 1.96 (the square root of the 95th percentile of the chi-squared distribution with one degree of freedom). The p-value in the last column indicates if this tail probability is large enough to show a departure from the status quo assumption of no trend. Slope p-values that are less than 0.05 are in bold in the table.

Table C−6. Data for critical operations LOOP frequency trend plots.

	Unit LOOP event counts by LOOP category					
Year	Plant centered	Switchyard centered	Grid related	Weather related	Reactor critical years	Total trip LOOP events
Pre-deregulation period (1986–1996)						
1986	3	0	0	0	62.519	3
1987	0	5	0	0	70.224	5
1988	1	3	0	0	75.757	4
1989	1	3	1	0	75.998	5
1990	0	1	0	0	80.653	1
1991	3	3	0	0	83.916	6
1992	3	3	0	0	83.590	6
1993	0	4	0	1	82.892	5
1994	0	0	0	0	85.774	0
1995	0	0	0	0	88.823	0
1996	0	1	0	2	87.097	3
Post-deregulation period (1997–2004)						
1997	0	2	0	0	79.919	2
1998	0	0	0	1	84.356	1
1999	0	1	0	0	90.705	1
2000	1	0	0	0	92.919	1
2001	0	1	0	1	93.952	2
2002	0	0	0	0	94.874	0
2003	0	2	10	0	92.599	12
2004	0	1	3	1	94.937	5

Table C−7. Summary of LOOP frequency trend tests for 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
Pre-deregulation period (1986–1996)					
Plant-centered trip	−0.197	0.105	**0.0489**	**0.0488**	0.0604
Switchyard-centered trip	−0.12	0.069	0.1779	**0.0449**	0.0806
Grid-related trip	−0.255	0.369	0.5601	0.8879	0.4892
Weather-related trip	0.677	0.416	0.8251	0.8699	0.1037
Overall (all trip events, per rcry)	−0.103	0.053	0.1196	**0.0251**	0.0522
Post-deregulation period (1997–2004)					
Plant-centered trip (only one event)	−0.12	0.449	0.368	0.6721	0.7887
Switchyard-centered trip	−0.008	0.167	0.4298	0.265	0.9637
Grid-related trip	0.817	0.244	**0.0029**	**0.007**	**0.0008**
Weather-related trip	0.077	0.259	0.5346	0.4497	0.7661
Overall (all trip events, per rcry)	0.312	0.105	**0.0086**	**0.0068**	**0.0031**
Total period (1986–2004) (not plotted)					
Plant-centered trip	−0.21	0.07	0.1365	0.2217	**0.0029**
Switchyard-centered trip	−0.104	0.036	0.3314	0.0885	**0.0039**
Grid-related trip	0.432	0.121	**<0.00005**	**0.0257**	**0.0004**
Weather-related trip	0.092	0.083	0.3923	0.616	0.2677
Overall (all trip events, per rcry)	−0.057	1.746	**<0.00005**	—	0.1681

However, the validity of the p-value for trend in the last column depends on the two previous columns, which show whether the data fit the Poisson model used in the regression analysis. The hypothesis is that the data in each year are independent and occurring with a constant rate, and that the mean for each year follows the regression line. The goodness of fit tests show poor fit if their values are near zero (in which case, there is too much scatter in the data for the Poisson condition that the mean and variance are equal), or if their values are near 1.0. In the latter case, there is too little scatter in the data for the Poisson model and the model is said to overfit the data. Goodness-of-fit p-values showing poor fits are also in bold in Table C−7.

The data show that the plant-centered LOOP frequencies did not fit the model well for 1986–1996. However, having a p-value near 0.05 is not uncommon when many tests are being performed; the 5% confidence level allows a 1-in-20 chance of error in the statistical test. So the plant-centered data may fit the Poisson assumptions adequately. On a couple of other rows in the early period part of the table, only one of the goodness-of-fit tests shows poor fit. The fit is worse as the p-values get closer to zero and as both of them indicate a problem with the model. The data in the early period thus fit the model reasonably well. They show weak decreasing trends for plant-centered, switchyard-centered, and overall trip LOOP occurrences.

The 1997–2004 period shows a clear lack of fit for the grid-related LOOP models. The data consist of five years of zeros, the August 14, 2003, event, two other multiple-unit events in 2003, and one three-unit event in 2004. This might be indicating a distinctive increasing trend in grid events, but, on the other hand, only two years show this increase. The Poisson model does not fit, and other types of log-based models require adjustments for the years with no events. This lack of fit carries over in the overall trend modeling for the recent period. When the last two years are omitted in the grid data model, there is nothing left to analyze (no events). When they are omitted in the overall model, the p-value for the trend is 0.35. More data is needed to assess the critical operation LOOP trends, especially for grid events.

Table C−8 and Table C−9 show the possibility of LOOP trends for successive summer periods, and for successive nonsummer periods, respectively. The nonsummer times in each year are January–April and October–December. The p-values in these tables are not as likely as Table C−7 to show trends, since less data is present for each table. On the other hand, trends for a LOOP critical operation occurrence rate that were increasing over the summers and decreasing over the nonsummers would not show in Table C−7, but might in Table C−8 and Table C−9. For the LOOP critical operation data, no such seasonal shifts were observed.

The seasonal trend tables also may provide further insights for Table C−7. With a reduced set of data, there is less likelihood of extra-Poisson variation. Fewer of the goodness-of-fit statistics are highlighted in these tables than in Table C−7. For example, the pre-deregulation period's nearly significant plant-centered LOOP occurrence trend in the first row of Table C−7 is difficult to interpret because the goodness-of-fit statistics show extra-Poisson variation. Viewing the corresponding rows in Table C−8 and Table C−9 shows that most of the decrease occurred during the successive summers.

Table C−8. Summary of LOOP frequency trend tests for critical operation in summer.

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
Pre-deregulation period (1986–1996)					
Plant-centered trip	−0.287	0.172	0.6465	0.5159	0.0949
Switchyard-centered trip	−0.177	0.104	0.3818	0.1932	0.0868
Grid-related trip (only one event)	−0.258	0.372	0.582	0.8915	0.4869
Weather-related trip	0.056	0.68	**0.9002**	—	0.1909
Post-deregulation period (1997–2004)					
Plant-centered trip (only one event)	−0.12	0.449	0.3698	0.6727	0.7893
Switchyard-centered trip	−0.087	0.182	0.6246	0.3955	0.6334
Grid-related trip	0.815	0.243	**0.0027**	**0.0068**	**0.0008**
Weather-related trip	0.077	0.317	0.3888	0.478	0.8076
Total summer period (1986–2004)					
Plant-centered trip	−0.191	0.096	0.4988	0.7545	**0.046**
Switchyard-centered trip	−0.074	0.046	0.5817	0.2742	0.1088
Grid-related trip	0.432	0.121	**<0.00005**	**0.0256**	**0.0004**
Weather-related trip	0.114	0.105	0.153	0.6983	0.2805

Table C−9. Summary of LOOP frequency trend tests for critical operation in nonsummer.

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
Pre-deregulation period (1986–1996)					
Plant-centered trip	−0.133	0.135	0.1906	0.2104	0.3243
Switchyard-centered trip	−0.071	0.093	0.7328	0.4757	0.4439
Grid-related trip (no events)	—	—	—	—	—
Weather-related trip (only one event)	0.196	0.366	0.533	0.8834	0.5929
Post-deregulation period (1997–2004)					
Plant-centered trip (no events)	—	—	—	—	—
Switchyard-centered trip (only 1 event)	0.668	0.746	0.8056	0.8352	0.3706
Grid-related trip (no events)	—	—	—	—	—
Weather-related trip (only 1 event)	0.077	0.449	0.3607	0.6695	0.8638
Total nonsummer period (1986–2004)					
Plant-centered trip	−0.23	0.104	0.4554	0.6998	**0.0278**
Switchyard-centered trip	−0.147	0.059	0.6917	0.5901	**0.0125**
Grid-related trip (no events)	—	—	—	—	**—**
Weather-related trip	0.053	0.136	0.5153	**0.9502**	0.6987

C-2. ANALYSIS OF LOOP DURATIONS

Switchyard restoration times, potential bus recovery times, and actual LOOP restoration times were all analyzed in this study. As in NUREG/CR-5496, averages were used for each event that affected more than one unit at a site. This choice reduces the dependence among the events, since recovery times at multiple units at a site tend to be similar. In fact, the switchyard and potential bus recovery times were virtually identical for 10 of the 13 events for which more than one unit at a site experienced a LOOP. The largest potential bus recovery time difference for two units at a site was slightly over 5 h.

Results are presented here for the time of primary interest in station blackout scenarios, the potential bus recovery time. Unless otherwise stated, "duration" in this section applies to this potential recovery time.

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 lognormal distribution fits are noted in the main text (Table 4−1). Weibull distribution fits were also considered. They are briefly described here, for comparison.

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.

C-2.1 Differences in the Four LOOP Categories

Table C−10 provides an overview of the durations. First, it gives counts of the events by LOOP category, plant mode, time period, and season. The duration counts are not the same as the counts for the

LOOP frequency categories because of the site-level treatment of the events. One event with no recovery time information was excluded from the duration study. A total of 121 site-level events were included.

The second and third sections of the table provide average durations and maximum durations, respectively. The averages are at a season level. The table shows an increase in the magnitude of the durations as the category changes from plant centered to switchyard centered, grid related, and weather related, particularly when the two unusually long times marked in bold are ignored. Since the number of site LOOPs in the category, mode, time period, and season associated with each of these long observations is one, the average time for the category/mode/time period level associated with excluding these potential outliers is the average for the other season.

Table C−10. Potential bus recovery counts, averages, and maximums.

LOOP category	Mode	Summer/nonsummer 1986–1996	Summer/nonsummer 1997–2004
Counts[a]			
Plant-centered	Critical operation	5/6	1/0
	Shutdown operation	6/8	1/4
Switchyard-centered	Critical operation	10/11	6/1
	Shutdown operation	10/18	1/6
Grid-related	Critical operation	1/0	8/0
	Shutdown operation	1/0	2/0
Weather-related	Critical operation	1/1	2/1
	Shutdown operation	1/6	2/1
Average durations (hours)			
Plant-centered[b]	Critical operation	0.4/2.0	**31.8**/—
	Shutdown operation	0.4/0.4	0.3/0.5
Switchyard-centered	Critical operation	2.0/1.1	1.0/0.3
	Shutdown operation	1.6/1.2	1.8/1.7
Grid-related	Critical operation	1.7/—	1.9/—
	Shutdown operation	0.3/—	5.8/—
Weather-related	Critical operation	5.0/0.7	13.3/0.3
	Shutdown operation	**132.0**/3.1	5.0/20.0
Maximum durations (hours)			
Plant-centered	Critical operation	1.1/4.7	**31.8**/—
	Shutdown operation	1.0/1.1	0.3/1.6
Switchyard-centered	Critical operation	7.7/2.0	2.5/0.3
	Shutdown operation	12.0/5.0	1.8/4.6
Grid-related	Critical operation	1.7/—	6.4/—
	Shutdown operation	0.3/—	11.0/—
Weather-related	Critical operation	5.0/0.7	23.8/0.3
	Shutdown operation	**132.0**/16.2	8.9/20.0

a. In each row, the number before the slash describes summer durations, while the number after the slash describes durations that occurred in January through April and October through December.
b. The recovery times in bold are outliers in the sense that they are at least 5 times longer than next shorter time in the same LOOP category.

Table C−11 provides details for the statistical tests for differences in the site-average potential bus recovery times among the four LOOP categories. The top line in the table has the most significant p-values, and justifies the separation of the LOOP events into categories having generally different recovery times. The second row in the table shows a rather weak difference in the plant- and switchyard-centered restoration durations (the p-values are less than 0.1 but greater than 0.05). The switchyard events tend to require a longer recovery time, especially when a plant is shut down. The presence of the long duration for a plant-centered, critical operation event in 1992 influences the ability of the statistical tests to see differences. With plant mode, time periods, and seasons combined, the geometric mean for the recovery time is 0.5 h for plant-centered (P) events, and 0.67 h for switchyard-centered (S) events, 1.4 h for grid-related (G) events, and 2.2 h for weather-related (W) events. From small to large, the overall mean durations are in the order {S, P, G, W}; the overall empirical median durations are in the order {P, S, W, G}. In all of these assessments, the grid- and weather-related times tend to be longer than the plant- and switchyard-centered recovery times. The LOOP category distinction is important in studying the recovery times.

Table C−11. Overall tests of differences in groups of LOOP potential bus recovery times.

Grouping variable	Time period	Plant Mode	LOOP category[a]	Number of groups	No. of durations	Kruskal-Wallis p-value	K-S p-value[b]
LOOP category	1986–2004	All	All	4	121	**0.01**	**<0.01**
		All	P vs. S	2	94	0.075	0.075
		Operational	All	4	54	0.3184	NS
		Shutdown	All	4	67	0.0588	**0.0326**
		Operational	P vs. S	2	40	0.9528	0.7833
		Shutdown	P vs. S	2	54	**0.0432**	0.052
	1997–2004	Operational	All	4	19	0.1555	—[c]
		Shutdown	All	4	17	0.0634	—[c]
		Operational	P vs. S	2	8	0.1221	0.3457
		Shutdown	P vs. S	2	12	0.0735	0.4234
Time[d]	1986–2004	All	All	2	121	**0.0244**	0.1396
		Operational	All	2	54	0.3228	0.8551
		Shutdown	All	2	67	0.0713	0.2343
	1986–2004	All	Plant	2	31	0.8408	0.9153
			Switchyard	2	63	0.6254	0.9794
			Grid	2	12	0.3902	0.7990
			Weather	2	15	0.2365	0.6476
Plant mode	1986–2004	All	All	2	121	**0.021**	0.0698
	1986–1996		All	2	85	**0.0235**	0.1162
	1997–2004		All	2	36	0.70	0.9889
	1986–2004	All	Plant	2	31	0.0506	0.1822
			Switchyard	2	63	0.3572	0.7952
			Grid	2	12	0.7815	0.7658
			Weather	2	15	0.7121	0.9993

a. P. vs. S: plant-centered durations compared with switchyard-centered. In the bottom sections of the table, "Plant" refers to plant-centered, "Switchyard" refers to switchyard-centered, "Grid" refers to grid-related, and "Weather," to weather-related.
b. K-S: Kolmogorov-Smirnov test. NS, not significant. The SAS procedure quantifies the p-value only when the number of groups is two, in which case it compares the two empirical distribution functions. With more levels, each level is compared to the composite of all. In this latter case, the reference distribution for the test is not as clearly defined, and the reported p-values are not as reliable in controlling the probability of inferring differences that do not really exist. When there are more than two levels being compared, the K-S p-values are cited here only if the number of durations is greater than 30.
c. There can be no statistical test with only one group. Also, more than one observation per group is required for the K-S test statistic. There was just one plant-centered, critical operations LOOP event in the 1997–2004 period.
d. These test compare durations in the 1986–1996 period with those in the 1997–2004 period.

For the 1997–2004, post-deregulation, data in the next four lines of Table C−11, fewer total events occurred and the category differences are not statistically significant. However, during shutdown periods, when most of the weather events occur, the times tend to be somewhat longer. The Kruskal-Wallis test is almost statistically significant (at 0.06 and 0.07) for these scenarios.

The issue of splitting the durations based on time, and thus focusing on the 1997–2004 data, is considered in the second section of the table. The first line there indicates a statistically significant difference. The 36 1997–2004 events took somewhat longer for potential recovery of power to the bus, on average, than the 85 1986–1996 events (with p-value 0.0244). The averages are, respectively, 3.8 h and 2.9 h. The differences are seen primarily in the shutdown data.

Even these differences can be associated with the LOOP categories. The longer times clearly are associated with the grid- and weather-related events, and the longest times tend to be from weather-related events. Empirically, the weather events are found most in the shutdown data, for which there is proportionally less reactor time (rsy) in 1997–2004. Shorter times in 1997–2004 could thus be associated with the fact that, although this period has had more critical operation site-level grid events than the pre-deregulation period, it has had fewer shutdown operation site-level weather-related events.

In any case, the time period effect on the duration times is seen clearly only when considering the all the data grouped together. The idea of grouping all the data together is rejected as shown in the data in the first line of the table.

Table C−11 shows that, within the separate categories, no statistically significant difference is seen in the recovery times for the two periods. Another reason not to split the data and focus only on 1997–2004 is that no time trends were observed in the data (see Section C.2.4).

In the final section of the table, plant mode is considered. The Kruskal-Wallis statistical test sees mode differences in the durations in the overall data and in the 1986–1996 data, but no detectible difference in the 1997–2004 data. When the overall empirical distributions are examined, variations are seen but there is no consistent pattern. The lack of a pattern can be observed in Figure 4−6 in the main text, where the two empirical exceedance curves cross each other several times. The mean duration is higher for shutdown operations, but the median and geometric mean are higher for critical operations. None of these differences are very large. At the 75th percentile, the critical operation recovery is 2.0 h while the shutdown operation recovery is 1.13 h. At the 95th percentile, on the other hand, the shutdown recovery time is 12 h and the critical operations recovery time is 7.65 h. Among all the plant-centered events, the critical operation recoveries tend to be a little bit longer than the shutdown operation recoveries. However, (1) the p-value (0.0506) is not quite statistically significant, (2) the 31.8-h outlier among the plant-centered data occurred during critical operation, and (3) the more the data are partitioned the less data are available for estimating smooth curves to characterize the probability of seeing longer or shorter recovery times.

As with the time period differences, the LOOP category evaluations took priority over the plant mode differences. For each separate LOOP category, the data provided insufficient evidence to reject the null hypothesis that the times could be the same.

In summary, 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 mean 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, and finally weather-related. (Notice that the medians there differ from the category medians cited above because they come from the smooth curves fitted to the potential bus recovery time distributions.)

C-2.2 Seasonal Differences

The issue of whether recovery times are longer in the summer is fairly easy to assess and might be of interest. In current applications, it is not likely to be used, because the initiating event frequencies and other probabilistic data have not been partitioned by season. Probabilistic risk assessments have sought an estimate for the annual frequency of core damage with the idea that an initiating event could occur at any time.

For the LOOP durations, it is interesting to note that all the grid events have been in the summer (May–September), and both of the “outlier” times in bold in Table C−10 occurred in the summer.

The Kruskal-Wallis p-value for differences in the durations of weather-related events according to season is 0.0331. The summer recoveries tend to take longer. The mean potential bus recovery time for summer, weather-related LOOPs is 28.9 h and the median is 6.9 h. For the other parts of the year, the mean is 4.4 h and the median is 0.27 h.

Overall, the mean for summer recoveries is 4.9 h and the median is 40 min. The corresponding figure for nonsummer periods is 1.6 h and the median is 35 min. This difference is not statistically significant (p-value 0.30). The mean for the summer period is definitely influenced by the one 132-h recovery time.

C-2.3 Differences for Other Groupings of the Data

Table C−12 provides a summary of potential bus recovery 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 center section of Table C−11, and because a separate trend analysis was performed.

Kruskal-Wallis P-values that are less than 0.05 are highlighted in the table. The instances of statistically significant differences for the more reliable Kruskal-Wallis test are all in the switchyard-related category, which is the category having the most data (63 observations, compared with 31 plant-centered, 15 weather-related, and 12 grid-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 in the top section of Table C-13. The council acronyms are defined in the acronym list. The data show a variety of restoration times, with the means ranging from approximately 0.4 h to over 2.4 h. With regard to switchyard-centered LOOPs and plant location near the coast, the data show longer potential bus recovery times for the inland plants (see the middle section of Table C−13). Cause is highlighted among the grid recovery times (last section of Table C−13) because the 8/14/2003 LOOPs generally had longer potential bus recovery times than the other grid-related events.

Table C−12. Tests of differences in groupings of LOOP potential bus recovery times, by category.

Grouping variable	No. of levels / No. of durations	Kruskal-Wallis p-value	K-S p-value[a]	No. of levels / No. of durations	Kruskal-Wallis p-value	K-S p-value[a]
	Plant-centered			Switchyard-centered		
Site	21/31	0.4020	HS	40/63	0.3587	HS
NERC subregion	10/31	0.4983	0.0329	13/63	**0.0406**	HS
NERC region	9/31	0.4063	0.0329	8/63	**0.0128**	HS
Interconnection	2/31	0.0922	0.2878	2/63	0.7778	0.9916
Coast	2/31	0.8738	0.7751	2/63	**0.0372**	0.0442
Cause[b]	3/31	0.3427	NS	3/63	0.0803	0.0281
1032 design group	3/31	0.5114	NS	3/63	0.5885	NS
	Grid-related			Weather-related		
Site	11/12	0.4074	No test	10/15	0.4359	No test
NERC subregion	6/12	0.1960	No test	7/15	0.5125	No test
NERC region	5/12	0.2298	No test	6/15	0.4007	No test
Interconnection	2/12	0.3106	0.5715	1/15	—	—
Coast	2/12	0.3082	0.5176	2/15	0.3586	0.5161
Cause[b]	3/12	**0.0414**	No test	1/15	—	—
1032 design group	3/12	0.4037	No test	3/15	0.2787	No test
	Combined plant- and switchyard-centered					
Site	45/94	0.2658	HS			
NERC subregion	14/94	0.1259	HS			
NERC region	9/94	0.0717	HS			
Interconnection	2/94	0.1967	0.5651			
Coast	2/94	0.0831	0.1540			
Cause[b]	3/94	0.0740	0.0158			
1032 design group	3/94	0.6207	NS			

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). The actual p-value was not quantified. The SAS procedure quantifies the p-value only when the number of groups is two, in which case it compares the two empirical distribution functions. With more levels, each level is compared to the composite of all. In this latter case, the reference distribution for the test is not as clearly defined, and the reported p-values (based on an interpolation of the reported K-S statistic in a table of ordinary K-S distributions) are not as reliable in controlling the probability of a Type I error (i.e., of inferring differences that do not really exist). When there are more than two levels being compared, the K-S p-values are cited here only if the number of durations is greater than 30. No K-S p-values are in bold in this table.

b. Cause: human, equipment, external, other, or weather. All instances of “Other cause” are grid-related LOOPs caused by load reductions (brownouts). “External” is not used as a cause within the grid LOOP category. All weather-related events are caused by weather, and occurred in the eastern interconnection.

Table C−13. Significant potential bus recovery time differences among groupings of LOOPs.

	# of obs.	Minimum	5th	25th	50th	Mean	Geometric mean	75th	95th	Maximum
Switchyard-centered durations (h) grouped by NERC Council										
ECAR	4	0.067	0.067	0.267	0.917	2.092	0.724	3.917	6.467	6.467
FRCC	5	0.033	0.033	0.183	0.267	0.407	0.242	0.467	1.083	1.083
MAAC	6	0.400	0.400	0.667	1.083	1.700	1.174	1.967	5.000	5.000
MAIN	13	0.250	0.250	0.750	1.050	2.408	1.322	2.517	12.000	12.000
MAPP	5	0.067	0.067	0.233	0.617	0.673	0.406	0.633	1.817	1.817
NPCC	13	0.017	0.017	0.250	0.333	0.369	0.292	0.417	0.667	0.667
SERC	13	0.133	0.133	0.500	1.500	1.715	1.023	2.000	7.650	7.650
WECC	4	0.250	0.250	0.442	0.692	1.596	0.867	2.750	4.750	4.750
Switchyard-centered durations (h) grouped by plant location										
Inland	35	0.067	0.067	0.417	0.833	1.730	0.898	1.967	6.467	12.000
Coast	28	0.017	0.033	0.250	0.442	1.007	0.475	0.758	5.000	7.650
Grid-related durations (h) grouped by cause										
Equipment	4	0.267	0.267	0.275	0.450	0.708	0.528	1.142	1.667	1.667
Human error	1	0.700	0.700	0.700	0.700	0.700	0.700	0.700	0.700	0.700
Load reductions	7	0.900	0.900	1.450	1.833	3.657	2.536	6.400	10.950	10.950

C-2.4 Exceedance Distributions

To fit smooth distributions for the potential bus recovery times (measured in hours), the data were grouped according to LOOP category. As discussed in Section C.2.1, further breakdowns of the data were judged unnecessary. Even such ideas as breaking the switchyard times according to NERC council (as discussed in the previous section) are not beneficial for obtaining exceedance curves because some of the councils have no LOOP events and others have only four or five events. Having a larger sample size produces a more detailed, and thus more informative, empirical distribution function to use as a basis for finding a smooth curve.

Curve-fitting was performed as described in Appendix B for each LOOP category, and for the case of plant- and switchyard-centered events combined, with both lognormal and Weibull distribution "templates." The density and distribution functions for the lognormal fits are given in the main text; for the Weibull, they are as follows:

$f(t) = (\alpha/t)\,(t/\beta)^{\alpha} \exp[-((t/\beta)^{\alpha})]$ and $F(t) = 1 - \exp[-((t/\beta)^{\alpha})]$,

where α is the shape parameter of the distribution and β is the scale parameter.

The results of the curve fitting are summarized in Table C−14. Many of the lognormal results carry over into Table 4−1 in the main report. In addition to displaying the parameters for the curve fits, medians, means, and selected percentiles, the table provides two measures of goodness of fit. Both show adequate fits when the p-values are not close to zero. The Shapiro-Wilk test is only applicable to the lognormal fits since it tests whether the logarithms of the times could be normally distributed. Further details of the goodness-of-fit tests are in Appendix B.

Table C−14. Duration distribution parameters.

LOOP category	Distribution	Parameter #1 [a]	Parameter #2 [b]	Duration (hours) 5th percentile	Median	Mean	95th percentile	Anderson-Darling p-value	Shapiro-Wilk p-value
Plant-centered (31 observations)									
	Actual Data	—	—	0.067	0.30	1.74	4.7	—	—
	Lognormal	-0.760	1.287	0.056	0.47	1.07	3.9	>0.25	0.0097
	Weibull	0.618	0.945	0.008	0.52	1.37	5.6	**0.0541**	—
Switchyard-centered (63 observations)									
	Actual Data	—	—	0.067	0.67	1.41	5.0	—	—
	Lognormal	-0.391	1.256	0.086	0.68	1.49	5.3	>0.25	0.322
	Weibull	0.833	1.257	0.036	0.81	1.38	4.7	>0.25	—
Grid-related (12 observations)									
	Actual Data	—	—	0.267	1.56	2.43	11.0	—	—
	Lognormal	0.300	1.064	0.234	1.35	2.38	7.8	>0.25	0.7035
	Weibull	0.929	2.332	0.095	1.57	2.41	7.6	>0.25	—
Weather-related (15 observations)									
	Actual Data	—	—	0.250	1.28	14.21	132.0	—	—
	Lognormal	0.793	1.982	0.085	2.21	15.77	57.6	>0.25	0.0883
	Weibull	0.4985	6.174	0.016	2.96	12.42	55.8	>0.25	—
Plant- and switchyard-centered (94 observations)									
	Actual Data	—	—	0.067	0.50	1.52	5.0	—	—
	Lognormal	-0.512	1.278	0.073	0.60	1.36	4.9	>0.25	0.0534
	Weibull	0.728	1.1509	0.019	0.70	1.41	5.2	**0.0269**	—

a. For lognormal, Parameter #1 is the mean of the underlying normal distribution (the mean of the natural logarithm of the potential restoration times). For Weibull, it is the shape parameter.
b. For lognormal, Parameter #2 is the standard deviation of the underlying normal distribution (the standard deviation of the natural logarithm of the potential restoration times). For Weibull, it is the scale parameter.

The table shows that the data set with the worst fit to either distribution is the plant-centered data. Although the Anderson-Darling test statistic shows an adequate fit, the natural logarithm of the 31.8-h maximum duration remains an outlier that does not fit in the underlying normal distribution. However, the Anderson-Darling statistic shows that the Weibull fit is worse. The medians and 95^{th} percentiles of the lognormal distributions tend to fit the actual data somewhat better than the Weibull distribution in most cases. In particular, the lognormal fit is better for the weather-related LOOP durations.

Figure C−1 through Figure C−4 show the Weibull curve fits in the same format as Figures 4−1 through 4−4 show lognormal fits in the main report. A comparison of these figures shows further evidence that the lognormal fits were better for the LOOP durations.

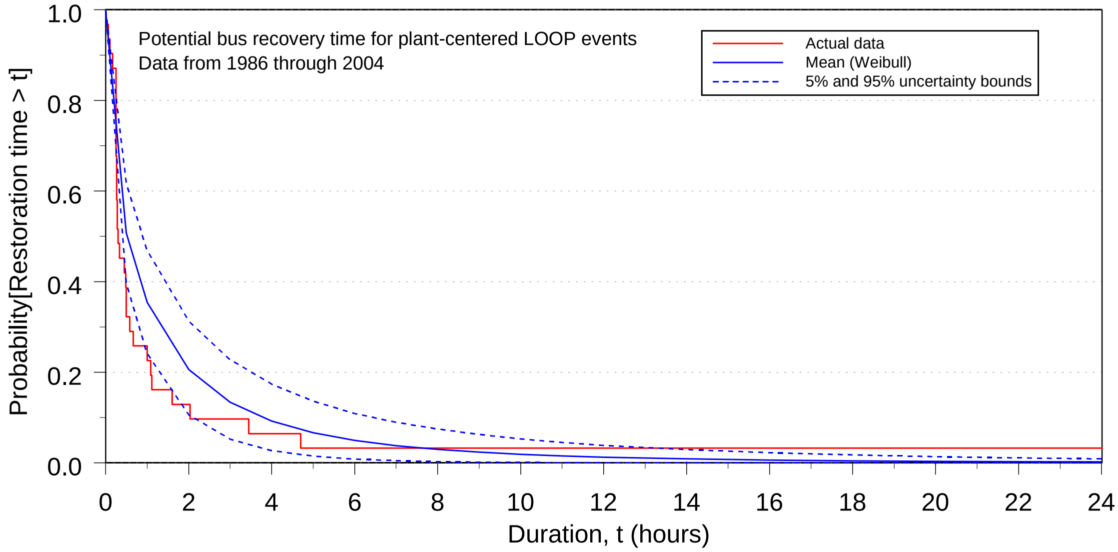

Figure C−1. Weibull fit for plant-centered LOOP durations.

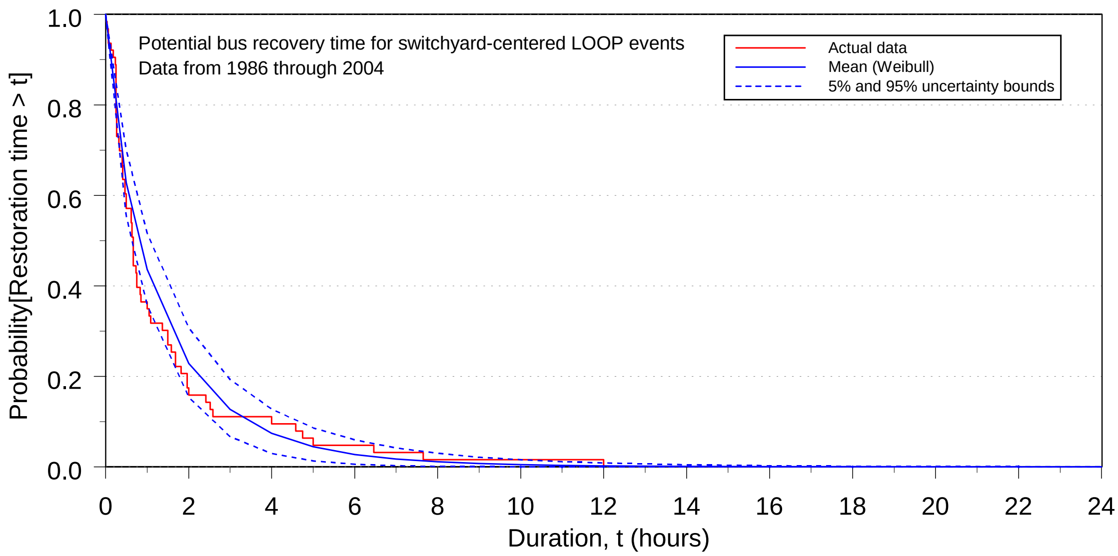

Figure C−2. Weibull fit for switchyard-centered LOOP durations.

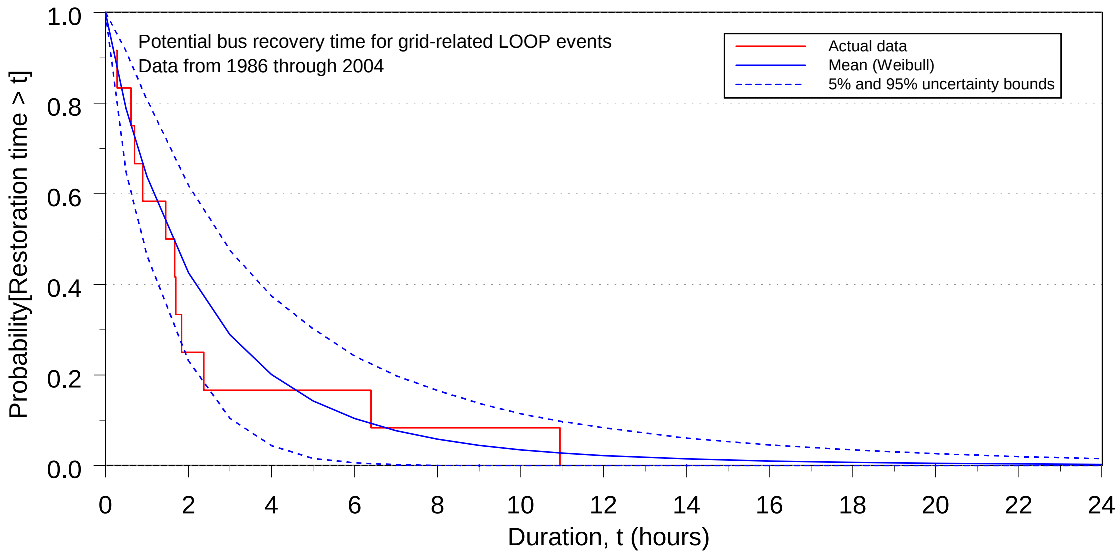

Figure C−3. Weibull fit for grid-related LOOP durations.

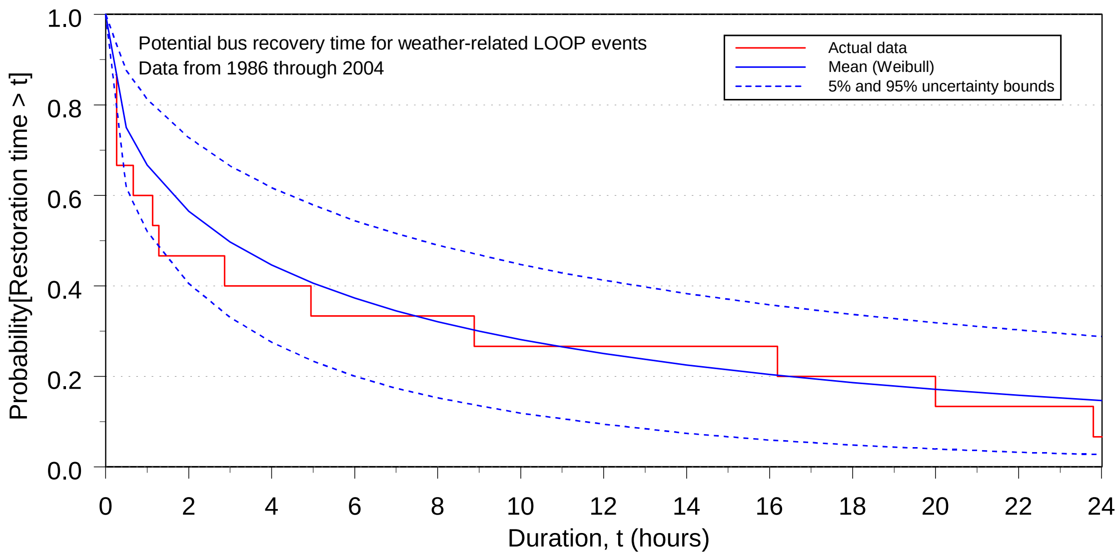

Figure C−4. Weibull fit for weather-related LOOP durations.

C-2.5 Trend Results

The 122 site-level durations for 1986–2004 (Appendix A, Table A−5) were trended in a manner similar to the frequencies, i.e. the period from 1986 to 1996 was considered separately from the post-deregulation period. Since times occur on a continuum and are not discrete, ordinary least squares methods were used for the trending (SAS proc REG). The log models fit better than the linear ones. Selected statistics related to the tests are Table C−15. A very slight increasing trend in the durations was observed for the switchyard-centered LOOPs during the earlier period (see Figure C−5). This trend is influenced by the fact that the longest such duration occurred just at the end of 1996. There were no statistically significant trends in 1997–2004. For the main report, the overall data were trended together (Figure 4−11). These results (see the last line in each section of Table C−15) were dominated by the switchyard results, since over half of the site-level observations were in that LOOP category.

Table C−15. Summary of potential bus recovery time trend tests.

LOOP Category	Slope of log of duration	Standard error of slope	P-value for normality of residuals	P-value for homogeneity of variances	P-value for slope
1986–1996					
Plant-centered	1.87E−05	9.91E−05	0.0586	0.6332	0.8521
Switchyard-centered	1.868E−05	7.78E−05	0.7895	0.2956	**0.0210**
Grid-related (insufficient data)	—	—	—	—	—
Weather-related	4.32E−04	2.64E−04	0.1302	0.2684	0.1459
Combined	1.83E−04	6.25E−05	0.0116	0.8967	**0.0044**
1997–2004					
Plant-centered	5.94E−04	8.07E−04	0.3211	0.3024	0.5028
Switchyard-centered	-1.47E−04	1.36E−04	0.1488	0.8468	0.3009
Grid-related	1.31E−04	2.27E−04	0.8628	0.4161	0.5800
Weather-related	-4.24E−04	2.42E−04	**0.0299**	0.4777	0.1547
Combined	-2.38E−05	1.19E−04	0.4420	0.0578	0.8433

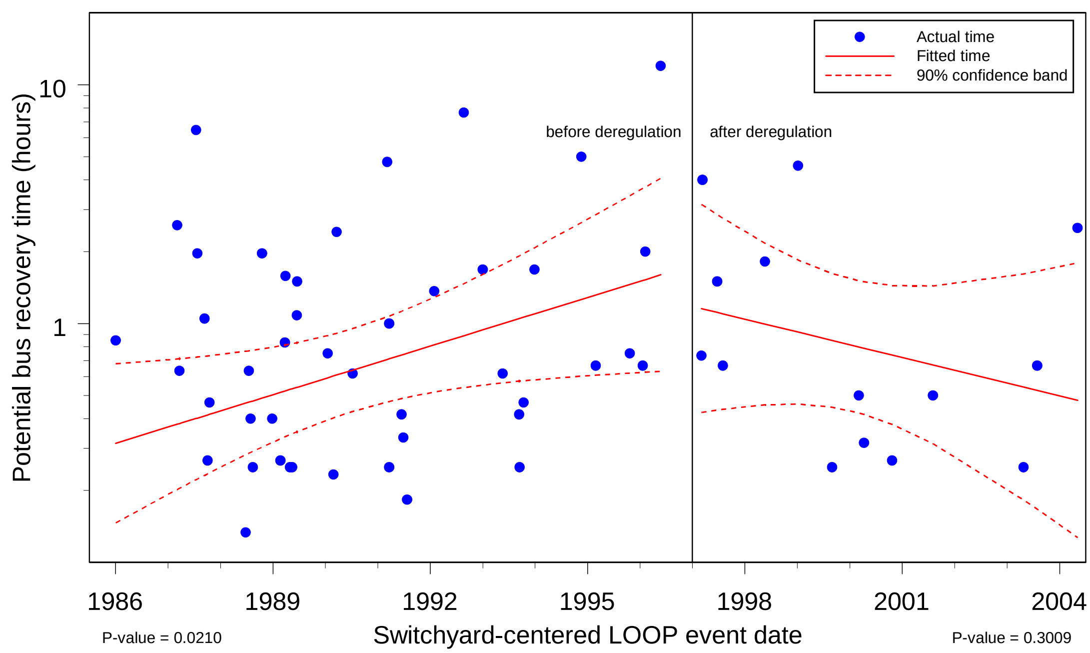

Figure C−5. Switchyard-center LOOP duration trends before and after deregulation.

C-3. ANALYSIS OF LOOP-RELATED PROBABILITIES

The LOOP-related probability that was studied in the most detail is the probability of multiple units being affected in a LOOP event. Among the 135 unit-level LOOP events considered in this study (spanning 1986–2004, and either associated with a trip or occurring when the unit was shut down), twelve involved multiple units on the same day. These events are listed in chronological order in Table 6−3 in the main report. Eleven involved both units at two-unit sites, while one (on 6/14/2004) involved all three units at the site. The remaining 110 events were single-unit events: 56 at single-unit sites, 46 at two-unit sites, and 8 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 6−3.

Table C−16 summarizes the site-level LOOP experience with respect to site size. In the two "Total" rows of Table C−16, 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 1.00). 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.

Table C−16. LOOP site event counts tabulated by site size.

	1-unit sites	2-unit sites	3-unit sites	Totals
Total number of sites[a]	34[a]	32	5	71
Number of single-unit events	56	46	8	110
Number of 2-unit events	—	11	0	11
Number of 3-unit events	—	—	1	1
Total number of site-level events	56	57	9	122
Number of sites with no events	9	8	1	18
Number of sites represented among 1-unit events	25	19	3	47
Number of sites represented among 2-unit events	—	10	—	10
Number of sites represented among 3-unit events	—	—	1	1

a. Nine Mile Point 2 is considered a single-unit site.

Among the 32 two-unit sites, eight had no events, 10 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: one of five had no events, one had an event affecting all three units, and (by subtraction), three 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 two-unit events at three-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=1.00).

The pooled data show that, with 66 of the site events at multiple-unit sites, 12 affected multiple units. After a Jeffreys prior update, these data correspond to an overall probability of 0.187 for more than one unit being affected by a LOOP at a multiple-unit site.

A study of the variation in the multi-unit data shows that total-site LOOPs are more likely for plants in certain reliability councils (p-value 0.039). Among the councils, for example, the estimated probability of multiple LOOPs given a LOOP at any unit is over three times higher for MAAC, with three of the 12 events, than for MAIN, which had no multiple-unit events among 16 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 switchyard-centered events.

For each LOOP category, other sources of possible variation in the probability of multiple-unit events were 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 four 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 six opportunities and MAIN had 12 opportunities for multiple-unit events.

One other finding of the multiple-unit study is that all twelve 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.

Probabilistic risk assessments (PRAs) consider whether other units at a multiple-unit site are available to support a unit that has experienced a LOOP. For this application, the relevant set of data is the set for which the unit being analyzed experienced a LOOP. The conditional probability needed for the PRA is conditioned on the LOOP postulated for the particular unit being modeled. The needed estimate is:

P[LOOP at other units] = count of events with LOOPs at all units / count of events with LOOPs at the unit under study.

Therefore, the set of events that form the denominator for an estimate of this probability is smaller than the total set of events at multiple-unit sites. More specifically, half of the single-unit LOOPs at two-unit sites are relevant, one-third of the single-unit events at three-unit sites are relevant, and two-thirds of the two-unit events at three-unit sites are relevant (if there were any). Of course, all the events that affected all units at a site are relevant for the denominator. For an estimate of the failure probability, i.e. that no unit is available to help the particular unit under consideration, the numerator is the number of instances where all units at the site experienced a LOOP. Overall, the numerator is 12 events. Table C−17 summarizes the calculation for the denominator. The estimate of the overall probability of no unit being able to provide offsite power for the unit being analyzed, using a Jeffrey's prior, is 0.323.

Table C−17. Counts of events at multi-unit sites with a LOOP at a specified, particular unit.

	2-unit sites	3-unit sites	Total
Number of single-unit events	46/2=23	8/3=2.667	25.667
Number of 2-unit events	11	2/3*0=0	11
Number of 3-unit events	—	1	1
Total number of relevant site-level events	34	3.667	37.667

Note: The sum of the shaded numbers is the number of relevant events that contribute to the numerator of the estimated probability that no other unit at the site will have offsite power available. The grand total acts like the total number of demands, in the denominator.

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 = 1.6E−5). Table C−18 is an expansion of Table C−17 at a LOOP category level. The shaded cells represent failures, where no other unit with offsite power was available. The grand totals in each section are the demands. Note that noninteger demands can be processed using the beta-binomial techniques discussed in Appendix B for processing probability estimates.

Table C−18. Counts of events at multi-unit sites with a LOOP at a specified, particular unit, by LOOP category.

	2-unit sites	3-unit sites	Total
Plant-centered LOOPs			
Number of single-unit events	6	1.333	7.333
Number of 2-unit events	0	0	0
Number of 3-unit events	0	0	0
Total number of relevant site-level events	6	1.333	7.333
Switchyard-centered LOOPs			
Number of single-unit events	15	1.333	16.333
Number of 2-unit events	4	0	4
Number of 3-unit events	0	0	0
Total number of relevant site-level events	19	1.333	20.333
Grid-related LOOPs			
Number of single-unit events	0.5	0	0.5
Number of 2-unit events	3	0	3
Number of 3-unit events	0	1	1
Total number of relevant site-level events	3.5	1	4.5
Weather-related LOOPs			
Number of single-unit events	1.5	0	1.5
Number of 2-unit events	4	0	4
Number of 3-unit events	0	0	0
Total number of relevant site-level events	5.5	0	5.5

Note: The sum of the shaded numbers is the number of relevant events that contribute to the numerator of the estimated probability that no other unit at the site will have offsite power available. The grand total acts like the total number of demands, in the denominator.

Table C−19 summarizes the relevant data from Table C−17 and Table C−18. It provides CNID-based estimates of the failure probability from the overall data and the data for each class. Each row is a separate fitting of the beta CNID distribution constrained to have a mean equal to the number of events affecting all sites, plus 0.5, divided by the number of relevant site events. The CNID distribution was chosen to reflect the uncertainty associated with a small data set. The higher probabilities associated with grid- and weather-related events are not surprising.

Table C−19. Probability that the remaining units at a multiple-unit site have a LOOP given a LOOP at a particular unit.

LOOP Category	# of relevant site events at multiple-unit sites	# of site events at multiple-unit sites affecting all the units	Beta distribution (CNID)				
			5th percentile	Mean	95th percentile	Alpha	Beta
All	37.667	12	4.34E−04	3.23E−01	9.37E−01	0.371	0.776
Plant-centered	7.333	0	6.71E−05	6.00E−02	2.43E−01	0.398	6.235
Switchyard-centered	20.333	4	8.00E−05	2.11E−01	7.80E−01	0.327	1.222
Grid-related	4.5	4	2.92E−01	8.18E−01	1.00E+00	1.447	0.322
Weather-related	5.5	4	7.55E−02	6.92E−01	1.00E+00	0.816	0.363

The first row in Table C−19 is based on fitting the CNID distribution to the pooled data across the four LOOP categories. Because the probabilities differ significantly between the categories, a frequency-weighted approach (rather than pooling) is recommended for combining data across LOOP categories. Since the frequencies are provided separately for critical operations and shutdown operations in Table 3−1 in the main text, separate estimates based on plant operating mode are calculated below. The data for the mode-specific frequencies also appear in bold in Table C−2.

Separate probabilities calculated directly from the site-level data, like those in Table C−19, are not derived based on plant mode because the data are too sparse to try to split up the site event counts by LOOP category and mode. With this sparsity, no statistically-significant differences were found between plant modes for the probability of multiple events being experienced at a multi-unit site.

The separate mode-specific frequencies for the categories given in Table 3−1 in the main text are based on all the sites, not just the multiple-unit sites. Frequency-weighted probability averages for critical operations and for shutdown operations, using the total data and just the multi-unit data, are shown in Table C−20. For each section of the table, the frequency weights are also the same weights one obtains using the counts, since the operating times are constant across the LOOP classes. Footnotes in Table C−20 provide further details on the calculations.

Table C−20 shows that the total data and multi-unit data give similar results for the frequency of LOOP events in the various categories. The weighting for critical operations and shutdown operations differs considerably, however. The 0.58 probability of failure of the other units during critical operations is due to the impact of the LOOP grid category, for which most of the events occurred during critical operations.

For PRA applications, an uncertainty distribution is needed for the frequency-weighted probabilities in Table C−20. The weighted average probabilities in Table C−20 are just point estimates. Simulation was used to get a distribution for critical operations and a distribution for shutdown operations. Gamma uncertainty distributions for the overall frequencies are given in Table 3−3 in the main text. Since use of the overall data for frequencies gives nearly the same weighted probability estimates as use of frequency data restricted to multi-unit sites, the overall frequency distributions from Table 3−3 were used in the simulations. For the probabilities, the LOOP category-specific beta distributions in Table C−19 were used. In each iteration, four frequencies and four probabilities were sampled from their respective distributions. The weighted average probability was computed and stored. This process was repeated 10,000 times. The entire process was repeated twice, once for critical operations and once for shutdown operations. Table C−20 shows observed percentiles from the resulting samples and also the percentiles of beta distributions fit to the means and variances. The beta distributions are suitable for use in PRAs when the category of the LOOP is not postulated in the event tree.

Table C−20. Frequency-weighted averages of probability that the remaining units at a multiple-unit site have a LOOP given a LOOP at a particular unit.

LOOP Category	Failure Probability (Table C−19)	All Sites[a]		Multi-unit Sites	
		Events	Weight[b]	Events	Weight
Critical operations					
Plant-centered	6.00E−02	1	0.0577	1	0.0882
Switchyard-centered	2.11E−01	7	0.2885	4	0.2648
Grid-related	8.18E−01	13	0.5192	9	0.5588
Weather-related	6.92E−01	3	0.1346	1	0.0882
Weighted average probability:		5.82E−01		5.79E−01	
Shutdown operations					
Plant-centered	6.00E−02	19	0.26	8	0.2073
Switchyard-centered	2.11E−01	38	0.5133	22	0.5488
Grid-related	8.18E−01	3	0.0467	1	0.0366
Weather-related	6.92E−01	13	0.18	8	0.2073
Weighted average probability:		2.87E−01		3.02E−01	

a. Operating times are as follows: critical operations (1997–2004), all sites, 724.3 rcyr; multi-unit sites, 526.8 rcyr; shutdown operations (1986–2004), all sites, 383.2 sdy; multi-unit sites, 273.9 sdy.

b. In accordance with the Jeffreys prior update used in modeling the frequencies, the weights are based on 0.5 being added to each event count.

Table C−21. Uncertainty distribution for frequency-weighted averages of probability that the remaining units at a multiple-unit site have a LOOP, given a LOOP at a particular unit.

Plant mode	Distribution	Beta Distribution		Probability of other unit LOOPs			
		Alpha	Beta	5th percentile	Median	Mean	95th percentile
Critical operations							
	Simulated data	—	—	1.07E−01	5.60E−01	5.46E−01	9.29E−01
	Fitted beta	1.512	1.255	1.15E−01	5.59E−01	5.46E−01	9.36E−01
Shutdown operations							
	Simulated data	—	—	3.65E−02	2.57E−01	3.05E−01	7.34E−01
	Fitted beta	1.056	2.402	2.51E−02	2.65E−01	3.05E−01	7.22E−01

Appendix D

Plant-Specific LOOP Frequencies

CONTENTS

TABLES

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 four categories of LOOPs (plant centered, switchyard centered, grid related, and weather related) as well as all LOOPs for both critical operation (Table D-1) and shutdown operation (Table D-2).

The plant-specific LOOP frequencies were estimated by performing Bayesian updates on each of the individual LOOP categories using the industry frequencies (Table 3-3 in the report) as priors and plant-specific data over the period 1997–2004. Industry priors were used rather than the regional priors (Table 3-6 in the report) because the regional priors for grid-related LOOPs are heavily influenced by the single grid blackout event on August 14, 2003. In addition, plant-specific data over 1997–2004 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 approximate midpoint of the period 1997–2004).

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

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

where

α = prior gamma distribution shape parameter (Table 3-3 in the report)

β = prior gamma distribution scale parameter (Table 3-3 in the report)

n = number of LOOP events at the plant in question (1997–2004)

T = number of reactor critical years or reactor shutdown years (1997–2004).

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 four 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. In addition, 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 eight 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, 1997–2004.

Plant	Plant-Specific Mean Frequencies for Critical Operation (/rcry)					LOOP IEs During Critical Operation				Time[a]		
	Plant Centered	Switchyard Centered	Grid Related	Weather Related	Combined	Plant Centered	Switchyard Centered	Grid Related	Weather Related	rcry	rsy	rcy
Arkansas 1	2.01E−03	8.99E−03	1.46E−02	3.83E−03	2.95E−02	—	—	—	—	7.32	0.68	8.00
Arkansas 2	2.01E−03	9.01E−03	1.47E−02	3.83E−03	2.95E−02	—	—	—	—	7.21	0.79	8.00
Beaver Valley 1	2.02E−03	9.15E−03	1.51E−02	3.86E−03	3.01E−02	—	—	—	—	6.33	1.67	8.00
Beaver Valley 2	2.02E−03	9.09E−03	1.49E−02	3.85E−03	2.99E−02	—	—	—	—	6.69	1.31	8.00
Braidwood 1	2.01E−03	8.97E−03	1.46E−02	3.83E−03	2.94E−02	—	—	—	—	7.44	0.56	8.00
Braidwood 2	2.01E−03	8.95E−03	1.45E−02	3.82E−03	2.93E−02	—	—	—	—	7.58	0.42	8.00
Browns Ferry 2	2.01E−03	8.95E−03	1.45E−02	3.82E−03	2.93E−02	—	—	—	—	7.58	0.42	8.00
Browns Ferry 3	2.01E−03	8.94E−03	1.45E−02	3.82E−03	2.93E−02	—	—	—	—	7.65	0.35	8.00
Brunswick 1	2.01E−03	8.95E−03	1.45E−02	1.15E−02	3.69E−02	—	—	—	1	7.59	0.41	8.00
Brunswick 2	2.01E−03	8.95E−03	1.45E−02	3.82E−03	2.93E−02	—	—	—	—	7.56	0.44	8.00
Byron 1	2.01E−03	8.99E−03	1.46E−02	3.83E−03	2.95E−02	—	—	—	—	7.35	0.65	8.00
Byron 2	2.01E−03	8.94E−03	1.45E−02	3.82E−03	2.93E−02	—	—	—	—	7.63	0.37	8.00
Callaway	2.01E−03	9.00E−03	1.47E−02	3.83E−03	2.95E−02	—	—	—	—	7.28	0.72	8.00
Calvert Cliffs 1	2.01E−03	9.02E−03	1.47E−02	3.84E−03	2.96E−02	—	—	—	—	7.17	0.83	8.00
Calvert Cliffs 2	2.01E−03	9.00E−03	1.47E−02	3.83E−03	2.95E−02	—	—	—	—	7.26	0.74	8.00
Catawba 1	2.01E−03	8.98E−03	1.46E−02	3.83E−03	2.94E−02	—	—	—	—	7.42	0.58	8.00
Catawba 2	2.01E−03	9.01E−03	1.47E−02	3.83E−03	2.95E−02	—	—	—	—	7.22	0.78	8.00
Clinton 1	2.03E−03	9.33E−03	1.56E−02	3.89E−03	3.08E−02	—	—	—	—	5.32	2.68	8.00
Columbia 2	2.01E−03	9.08E−03	1.49E−02	3.85E−03	2.98E−02	—	—	—	—	6.76	1.24	8.00
Comanche Peak 1	2.01E−03	8.98E−03	1.46E−02	3.83E−03	2.94E−02	—	—	—	—	7.42	0.58	8.00
Comanche Peak 2	2.01E−03	8.97E−03	1.46E−02	3.83E−03	2.94E−02	—	—	—	—	7.44	0.57	8.00
Cook 1	2.04E−03	9.54E−03	1.62E−02	3.93E−03	3.17E−02	—	—	—	—	4.10	3.90	8.00
Cook 2	2.03E−03	9.47E−03	1.59E−02	3.91E−03	3.14E−02	—	—	—	—	4.53	3.47	8.00
Cooper	2.01E−03	9.07E−03	1.49E−02	3.85E−03	2.98E−02	—	—	—	—	6.81	1.19	8.00
Crystal River 3	2.02E−03	9.12E−03	1.50E−02	3.85E−03	3.00E−02	—	—	—	—	6.54	1.46	8.00
Davis-Besse	2.02E−03	9.29E−03	1.55E−02	1.17E−02	3.84E−02	—	—	—	1	5.51	2.49	8.00
Diablo Canyon 1	6.03E−03	9.01E−03	1.47E−02	3.83E−03	3.36E−02	1	—	—	—	7.20	0.80	8.00
Diablo Canyon 2	2.01E−03	8.99E−03	1.46E−02	3.83E−03	2.95E−02	—	—	—	—	7.35	0.65	8.00
Dresden 2	2.01E−03	8.98E−03	1.46E−02	3.83E−03	2.94E−02	—	—	—	—	7.37	0.63	8.00
Dresden 3	2.01E−03	2.70E−02	1.47E−02	3.83E−03	4.76E−02	—	1	—	—	7.20	0.80	8.00
Duane Arnold	2.01E−03	9.00E−03	1.47E−02	3.83E−03	2.95E−02	—	—	—	—	7.28	0.72	8.00
Farley 1	2.01E−03	9.05E−03	1.48E−02	3.84E−03	2.97E−02	—	—	—	—	6.98	1.02	8.00
Farley 2	2.01E−03	9.00E−03	1.47E−02	3.83E−03	2.95E−02	—	—	—	—	7.28	0.72	8.00
Fermi 2	2.01E−03	9.04E−03	4.43E−02	3.84E−03	5.92E−02	—	—	1	—	7.00	1.00	8.00
FitzPatrick	2.01E−03	8.98E−03	4.38E−02	3.83E−03	5.86E−02	—	—	1	—	7.41	0.59	8.00
Fort Calhoun	2.01E−03	9.00E−03	1.47E−02	3.83E−03	2.95E−02	—	—	—	—	7.24	0.76	8.00
Ginna	2.01E−03	8.96E−03	4.37E−02	3.83E−03	5.85E−02	—	—	1	—	7.51	0.49	8.00

Table D-1. (continued)

	Plant-Specific Mean Frequencies for Critical Operation (/rcry)					LOOP IEs During Critical Operation				Time[a]		
Plant	Plant Centered	Switchyard Centered	Grid Related	Weather Related	Combined	Plant Centered	Switchyard Centered	Grid Related	Weather Related	rcry	rsy	rcy
Grand Gulf	2.01E−03	2.69E−02	1.46E−02	3.83E−03	4.73E−02	—	1	—	—	7.47	0.53	8.00
Harris	2.01E−03	9.02E−03	1.47E−02	3.84E−03	2.96E−02	—	—	—	—	7.15	0.85	8.00
Hatch 1	2.01E−03	8.98E−03	1.46E−02	3.83E−03	2.94E−02	—	—	—	—	7.39	0.61	8.00
Hatch 2	2.01E−03	8.99E−03	1.46E−02	3.83E−03	2.95E−02	—	—	—	—	7.33	0.67	8.00
Hope Creek	2.01E−03	9.05E−03	1.48E−02	3.84E−03	2.97E−02	—	—	—	—	6.97	1.03	8.00
Indian Point 2	2.02E−03	2.79E−02	4.63E−02	3.88E−03	8.01E−02	—	1	1	—	5.55	2.45	8.00
Indian Point 3	2.01E−03	9.01E−03	4.41E−02	3.83E−03	5.89E−02	—	—	1	—	7.20	0.81	8.00
Kewaunee	2.01E−03	9.07E−03	1.49E−02	3.85E−03	2.98E−02	—	—	—	—	6.82	1.18	8.00
La Salle 1	2.02E−03	9.19E−03	1.52E−02	3.87E−03	3.02E−02	—	—	—	—	6.13	1.87	8.00
La Salle 2	2.03E−03	9.30E−03	1.55E−02	3.89E−03	3.07E−02	—	—	—	—	5.48	2.53	8.00
Limerick 1	2.01E−03	8.94E−03	1.45E−02	3.82E−03	2.93E−02	—	—	—	—	7.63	0.37	8.00
Limerick 2	2.01E−03	8.94E−03	1.45E−02	3.82E−03	2.93E−02	—	—	—	—	7.66	0.34	8.00
McGuire 1	2.01E−03	9.02E−03	1.47E−02	3.84E−03	2.96E−02	—	—	—	—	7.16	0.84	8.00
McGuire 2	2.01E−03	8.99E−03	1.46E−02	3.83E−03	2.95E−02	—	—	—	—	7.34	0.67	8.00
Millstone 2	2.03E−03	9.36E−03	1.57E−02	3.90E−03	3.09E−02	—	—	—	—	5.11	2.89	8.00
Millstone 3	2.02E−03	9.22E−03	1.53E−02	3.87E−03	3.04E−02	—	—	—	—	5.93	2.07	8.00
Monticello	2.01E−03	9.03E−03	1.47E−02	3.84E−03	2.96E−02	—	—	—	—	7.10	0.90	8.00
Nine Mile Pt. 1	2.01E−03	9.09E−03	4.47E−02	3.85E−03	5.97E−02	—	—	1	—	6.72	1.28	8.00
Nine Mile Pt. 2	2.01E−03	9.02E−03	4.41E−02	3.84E−03	5.90E−02	—	—	1	—	7.17	0.83	8.00
North Anna 1	2.01E−03	8.97E−03	1.46E−02	3.83E−03	2.94E−02	—	—	—	—	7.43	0.57	8.00
North Anna 2	2.01E−03	9.02E−03	1.47E−02	3.84E−03	2.96E−02	—	—	—	—	7.15	0.85	8.00
Oconee 1	2.02E−03	9.10E−03	1.49E−02	3.85E−03	2.99E−02	—	—	—	—	6.64	1.36	8.00
Oconee 2	2.01E−03	9.04E−03	1.48E−02	3.84E−03	2.97E−02	—	—	—	—	7.03	0.97	8.00
Oconee 3	2.01E−03	9.08E−03	1.49E−02	3.85E−03	2.98E−02	—	—	—	—	6.76	1.24	8.00
Oyster Creek	2.01E−03	2.69E−02	1.46E−02	3.83E−03	4.74E−02	—	1	—	—	7.41	0.59	8.00
Palisades	2.02E−03	9.13E−03	1.50E−02	3.86E−03	3.00E−02	—	—	—	—	6.46	1.54	8.00
Palo Verde 1	2.01E−03	8.97E−03	4.38E−02	3.83E−03	5.86E−02	—	—	1	—	7.44	0.56	8.00
Palo Verde 2	2.01E−03	9.01E−03	4.41E−02	3.83E−03	5.89E−02	—	—	1	—	7.22	0.78	8.00
Palo Verde 3	2.01E−03	9.01E−03	4.40E−02	3.83E−03	5.89E−02	—	—	1	—	7.23	0.77	8.00
Peach Bottom 2	2.01E−03	8.94E−03	4.35E−02	3.82E−03	5.83E−02	—	—	1	—	7.65	0.35	8.00
Peach Bottom 3	2.01E−03	8.94E−03	4.35E−02	3.82E−03	5.83E−02	—	—	1	—	7.66	0.35	8.00
Perry	2.01E−03	9.00E−03	4.40E−02	3.83E−03	5.89E−02	—	—	1	—	7.25	0.75	8.00
Pilgrim	2.01E−03	8.98E−03	1.46E−02	3.83E−03	2.94E−02	—	—	—	—	7.42	0.58	8.00
Point Beach 1	2.02E−03	9.17E−03	1.51E−02	3.86E−03	3.02E−02	—	—	—	—	6.22	1.78	8.00
Point Beach 2	2.02E−03	9.14E−03	1.51E−02	3.86E−03	3.01E−02	—	—	—	—	6.39	1.61	8.00
Prairie Island 1	2.01E−03	9.03E−03	1.47E−02	3.84E−03	2.96E−02	—	—	—	—	7.11	0.89	8.00
Prairie Island 2	2.01E−03	9.00E−03	1.47E−02	3.83E−03	2.95E−02	—	—	—	—	7.24	0.76	8.00

Table D-1. (continued)

	Plant-Specific Mean Frequencies for Critical Operation (/rcry)					LOOP IEs During Critical Operation				Time[a]		
Plant	Plant Centered	Switchyard Centered	Grid Related	Weather Related	Combined	Plant Centered	Switchyard Centered	Grid Related	Weather Related	rcry	rsy	rcy
Quad Cities 1	2.01E−03	9.03E−03	1.47E−02	3.84E−03	2.96E−02	—	—	—	—	7.08	0.92	8.00
Quad Cities 2	2.02E−03	2.73E−02	1.49E−02	3.85E−03	4.81E−02	—	1	—	—	6.62	1.38	8.00
River Bend	2.01E−03	9.01E−03	1.47E−02	3.83E−03	2.95E−02	—	—	—	—	7.23	0.77	8.00
Robinson 2	2.01E−03	8.96E−03	1.46E−02	3.83E−03	2.94E−02	—	—	—	—	7.51	0.49	8.00
Salem 1	2.02E−03	2.76E−02	1.52E−02	3.87E−03	4.87E−02	—	1	—	—	6.08	1.92	8.00
Salem 2	2.02E−03	9.11E−03	1.50E−02	3.85E−03	2.99E−02	—	—	—	—	6.60	1.40	8.00
San Onofre 2	2.01E−03	9.03E−03	1.48E−02	3.84E−03	2.96E−02	—	—	—	—	7.05	0.95	8.00
San Onofre 3	2.01E−03	9.08E−03	1.49E−02	3.85E−03	2.98E−02	—	—	—	—	6.79	1.21	8.00
Seabrook	2.01E−03	9.03E−03	1.47E−02	1.15E−02	3.73E−02	—	—	—	1	7.07	0.93	8.00
Sequoyah 1	2.01E−03	9.02E−03	1.47E−02	3.84E−03	2.96E−02	—	—	—	—	7.16	0.84	8.00
Sequoyah 2	2.01E−03	8.97E−03	1.46E−02	3.83E−03	2.94E−02	—	—	—	—	7.48	0.52	8.00
South Texas 1	2.01E−03	9.02E−03	1.47E−02	3.84E−03	2.96E−02	—	—	—	—	7.17	0.83	8.00
South Texas 2	2.01E−03	9.01E−03	1.47E−02	3.83E−03	2.95E−02	—	—	—	—	7.22	0.78	8.00
St. Lucie 1	2.01E−03	8.99E−03	1.46E−02	3.83E−03	2.94E−02	—	—	—	—	7.36	0.64	8.00
St. Lucie 2	2.01E−03	8.98E−03	1.46E−02	3.83E−03	2.94E−02	—	—	—	—	7.38	0.62	8.00
Summer	2.01E−03	9.03E−03	1.47E−02	3.84E−03	2.96E−02	—	—	—	—	7.10	0.90	8.00
Surry 1	2.01E−03	9.02E−03	1.47E−02	3.84E−03	2.96E−02	—	—	—	—	7.14	0.86	8.00
Surry 2	2.01E−03	8.98E−03	1.46E−02	3.83E−03	2.94E−02	—	—	—	—	7.36	0.64	8.00
Susquehanna 1	2.01E−03	8.99E−03	1.46E−02	3.83E−03	2.95E−02	—	—	—	—	7.31	0.69	8.00
Susquehanna 2	2.01E−03	8.99E−03	1.46E−02	3.83E−03	2.95E−02	—	—	—	—	7.34	0.66	8.00
Three Mile Isl 1	2.01E−03	2.69E−02	1.46E−02	3.83E−03	4.73E−02	—	1	—	—	7.46	0.54	8.00
Turkey Point 3	2.01E−03	8.99E−03	1.46E−02	3.83E−03	2.95E−02	—	—	—	—	7.32	0.68	8.00
Turkey Point 4	2.01E−03	8.94E−03	1.45E−02	3.82E−03	2.93E−02	—	—	—	—	7.61	0.39	8.00
Vermont Yankee	2.01E−03	8.98E−03	1.46E−02	3.83E−03	2.94E−02	—	—	—	—	7.36	0.64	8.00
Vogtle 1	2.01E−03	8.97E−03	1.46E−02	3.83E−03	2.94E−02	—	—	—	—	7.46	0.54	8.00
Vogtle 2	2.01E−03	8.98E−03	1.46E−02	3.83E−03	2.94E−02	—	—	—	—	7.40	0.60	8.00
Waterford 3	2.01E−03	9.02E−03	1.47E−02	3.84E−03	2.96E−02	—	—	—	—	7.15	0.85	8.00
Watts Bar 1	2.01E−03	8.98E−03	1.46E−02	3.83E−03	2.94E−02	—	—	—	—	7.38	0.62	8.00
Wolf Creek	2.01E−03	8.98E−03	1.46E−02	3.83E−03	2.94E−02	—	—	—	—	7.39	0.61	8.00
	Statistics					Totals						
Max	6.03E−03	2.79E−02	4.63E−02	1.17E−02	8.01E−02	1	7	13	3	724.12	99.92	824.04
95%	2.03E−03	2.69E−02	4.41E−02	3.90E−03	5.89E−02	—	—	—	—	—	—	—
Mean	2.05E−03	1.03E−02	1.85E−02	4.06E−03	3.49E−02	—	—	—	—	—	—	—
50%	2.01E−03	9.01E−03	1.47E−02	3.83E−03	2.96E−02	—	—	—	—	—	—	—
5%	2.01E−03	8.94E−03	1.45E−02	3.82E−03	2.93E−02	—	—	—	—	—	—	—
Min	2.01E−03	8.94E−03	1.45E−02	3.82E−03	2.93E−02	—	—	—	—	—	—	—

a. rcry—reactor critical year, rsy—reactor shutdown year, rcy—reactor calendar year

Table D-2. Plant specific LOOP frequencies for shutdown operation, 1997–2004.

Plant	Plant-Specific Mean Frequencies for Critical Operation (/rcry)					LOOP IEs During Critical Operation				Time[a]		
	Plant Centered	Switchyard Centered	Grid Related	Weather Related	Combined	Plant Centered	Switchyard Centered[b]	Grid Related	Weather Related	rcry	rsy	rcy
Arkansas 1	4.71E−02	9.51E−02	9.02E−03	3.36E−02	1.85E−01	—	—	—	—	7.32	0.68	8.00
Arkansas 2	4.65E−02	9.42E−02	9.00E−03	3.34E−02	1.83E−01	—	—	—	—	7.21	0.79	8.00
Beaver Valley 1	4.25E−02	8.81E−02	8.86E−03	3.15E−02	1.71E−01	—	—	—	—	6.33	1.67	8.00
Beaver Valley 2	4.41E−02	9.05E−02	8.92E−03	3.23E−02	1.76E−01	—	—	—	—	6.69	1.31	8.00
Braidwood 1	4.77E−02	9.59E−02	9.04E−03	1.02E−01	2.54E−01	—	—	—	1	7.44	0.56	8.00
Braidwood 2	4.85E−02	9.71E−02	9.06E−03	3.42E−02	1.89E−01	—	—	—	—	7.58	0.42	8.00
Browns Ferry 2	4.85E−02	9.70E−02	9.06E−03	3.42E−02	1.89E−01	—	—	—	—	7.58	0.42	8.00
Browns Ferry 3	4.89E−02	1.80E−01	9.08E−03	3.44E−02	2.72E−01	—	1	—	—	7.65	0.35	8.00
Brunswick 1	4.85E−02	1.79E−01	9.07E−03	3.43E−02	2.71E−01	—	1	—	—	7.59	0.41	8.00
Brunswick 2	4.84E−02	9.69E−02	9.06E−03	3.42E−02	1.88E−01	—	—	—	—	7.56	0.44	8.00
Byron 1	4.72E−02	9.53E−02	9.03E−03	3.37E−02	1.85E−01	—	—	—	—	7.35	0.65	8.00
Byron 2	4.87E−02	9.74E−02	9.07E−03	3.43E−02	1.90E−01	—	—	—	—	7.63	0.37	8.00
Callaway	4.69E−02	9.48E−02	9.02E−03	3.35E−02	1.84E−01	—	—	—	—	7.28	0.72	8.00
Calvert Cliffs 1	4.63E−02	9.39E−02	9.00E−03	3.33E−02	1.83E−01	—	—	—	—	7.17	0.83	8.00
Calvert Cliffs 2	4.68E−02	9.46E−02	9.01E−03	3.35E−02	1.84E−01	—	—	—	—	7.26	0.74	8.00
Catawba 1	4.76E−02	9.58E−02	9.04E−03	3.39E−02	1.86E−01	—	—	—	—	7.42	0.58	8.00
Catawba 2	4.66E−02	9.43E−02	9.01E−03	3.34E−02	1.83E−01	—	—	—	—	7.22	0.78	8.00
Clinton 1	3.86E−02	1.51E−01	8.71E−03	2.96E−02	2.28E−01	—	1	—	—	5.32	2.68	8.00
Columbia 2	4.44E−02	9.10E−02	8.93E−03	3.24E−02	1.77E−01	—	—	—	—	6.76	1.24	8.00
Comanche Peak 1	4.76E−02	9.58E−02	9.04E−03	3.39E−02	1.86E−01	—	—	—	—	7.42	0.58	8.00
Comanche Peak 2	4.77E−02	9.59E−02	9.04E−03	3.39E−02	1.87E−01	—	—	—	—	7.44	0.57	8.00
Cook 1	3.48E−02	7.56E−02	8.53E−03	2.76E−02	1.47E−01	—	—	—	—	4.10	3.90	8.00
Cook 2	3.61E−02	7.77E−02	8.59E−03	2.83E−02	1.51E−01	—	—	—	—	4.53	3.47	8.00
Cooper	4.46E−02	9.14E−02	8.94E−03	3.25E−02	1.77E−01	—	—	—	—	6.81	1.19	8.00
Crystal River 3	4.34E−02	8.95E−02	8.90E−03	3.19E−02	1.74E−01	—	—	—	—	6.54	1.46	8.00
Davis-Besse	1.31E−01	8.30E−02	2.62E−02	3.00E−02	2.70E−01	1	—	1	—	5.51	2.49	8.00
Diablo Canyon 1	4.65E−02	9.41E−02	9.00E−03	3.34E−02	1.83E−01	—	—	—	—	7.20	0.80	8.00
Diablo Canyon 2	4.73E−02	9.53E−02	9.03E−03	3.37E−02	1.85E−01	—	—	—	—	7.35	0.65	8.00
Dresden 2	4.74E−02	9.54E−02	9.03E−03	3.37E−02	1.86E−01	—	—	—	—	7.37	0.63	8.00
Dresden 3	4.65E−02	9.42E−02	9.00E−03	3.34E−02	1.83E−01	—	—	—	—	7.20	0.80	8.00
Duane Arnold	4.69E−02	9.48E−02	9.02E−03	3.35E−02	1.84E−01	—	—	—	—	7.28	0.72	8.00
Farley 1	4.54E−02	1.70E−01	8.97E−03	3.29E−02	2.58E−01	—	1	—	—	6.98	1.02	8.00
Farley 2	4.69E−02	9.47E−02	9.01E−03	3.35E−02	1.84E−01	—	—	—	—	7.28	0.72	8.00
Fermi 2	4.55E−02	9.27E−02	8.97E−03	3.29E−02	1.80E−01	—	—	—	—	7.00	1.00	8.00
FitzPatrick	4.75E−02	9.57E−02	9.04E−03	3.38E−02	1.86E−01	—	—	—	—	7.41	0.59	8.00
Fort Calhoun	1.55E−01	1.74E−01	9.01E−03	3.34E−02	3.71E−01	1	1	—	—	7.24	0.76	8.00
Ginna	4.81E−02	9.65E−02	9.05E−03	3.41E−02	1.88E−01	—	—	—	—	7.51	0.49	8.00
Grand Gulf	4.79E−02	9.62E−02	9.05E−03	3.40E−02	1.87E−01	—	—	—	—	7.47	0.53	8.00
Harris	4.62E−02	9.38E−02	8.99E−03	3.32E−02	1.82E−01	—	—	—	—	7.15	0.85	8.00
Hatch 1	4.75E−02	9.56E−02	9.03E−03	3.38E−02	1.86E−01	—	—	—	—	7.39	0.61	8.00
Hatch 2	4.71E−02	9.51E−02	9.02E−03	3.36E−02	1.85E−01	—	—	—	—	7.33	0.67	8.00
Hope Creek	4.54E−02	9.25E−02	8.97E−03	3.29E−02	1.80E−01	—	—	—	—	6.97	1.03	8.00
Indian Point 2	1.31E−01	8.33E−02	8.74E−03	3.00E−02	2.53E−01	1	—	—	—	5.55	2.45	8.00
Indian Point 3	4.64E−02	9.41E−02	2.70E−02	3.33E−02	2.01E−01	—	—	1	—	7.20	0.81	8.00
Kewaunee	4.47E−02	9.14E−02	8.94E−03	3.25E−02	1.78E−01	—	—	—	—	6.82	1.18	8.00
La Salle 1	4.17E−02	8.68E−02	8.83E−03	3.11E−02	1.68E−01	—	—	—	—	6.13	1.87	8.00

Table D-2. (continued)

Plant	Plant-Specific Mean Frequencies for Critical Operation (/rcry)					LOOP IEs During Critical Operation				Time[a]		
	Plant Centered	Switchyard Centered	Grid Related	Weather Related	Combined	Plant Centered	Switchyard Centered[b]	Grid Related	Weather Related	rcry	rsy	rcy
La Salle 2	3.92E−02	8.28E−02	8.73E−03	2.99E−02	1.61E−01	—	—	—	—	5.48	2.53	8.00
Limerick 1	4.87E−02	9.74E−02	9.07E−03	3.43E−02	1.90E−01	—	—	—	—	7.63	0.37	8.00
Limerick 2	4.89E−02	9.77E−02	9.08E−03	3.44E−02	1.90E−01	—	—	—	—	7.66	0.34	8.00
McGuire 1	4.63E−02	9.38E−02	9.00E−03	3.33E−02	1.82E−01	—	—	—	—	7.16	0.84	8.00
McGuire 2	4.72E−02	9.52E−02	9.02E−03	3.37E−02	1.85E−01	—	—	—	—	7.34	0.67	8.00
Millstone 2	3.79E−02	8.08E−02	8.68E−03	2.93E−02	1.57E−01	—	—	—	—	5.11	2.89	8.00
Millstone 3	4.09E−02	8.56E−02	8.80E−03	3.08E−02	1.66E−01	—	—	—	—	5.93	2.07	8.00
Monticello	4.60E−02	9.34E−02	8.99E−03	3.31E−02	1.81E−01	—	—	—	—	7.10	0.90	8.00
Nine Mile Pt. 1	4.42E−02	9.07E−02	8.93E−03	3.23E−02	1.76E−01	—	—	—	—	6.72	1.28	8.00
Nine Mile Pt. 2	4.63E−02	9.39E−02	9.00E−03	3.33E−02	1.82E−01	—	—	—	—	7.17	0.83	8.00
North Anna 1	4.77E−02	9.59E−02	9.04E−03	3.39E−02	1.87E−01	—	—	—	—	7.43	0.57	8.00
North Anna 2	4.62E−02	9.38E−02	8.99E−03	3.32E−02	1.82E−01	—	—	—	—	7.15	0.85	8.00
Oconee 1	4.38E−02	9.01E−02	8.91E−03	3.22E−02	1.75E−01	—	—	—	—	6.64	1.36	8.00
Oconee 2	4.56E−02	9.29E−02	8.97E−03	3.30E−02	1.80E−01	—	—	—	—	7.03	0.97	8.00
Oconee 3	4.44E−02	9.10E−02	8.93E−03	3.24E−02	1.77E−01	—	—	—	—	6.76	1.24	8.00
Oyster Creek	4.76E−02	9.57E−02	9.04E−03	3.38E−02	1.86E−01	—	—	—	—	7.41	0.59	8.00
Palisades	2.43E−01	8.89E−02	8.88E−03	3.18E−02	3.73E−01	2	—	—	—	6.46	1.54	8.00
Palo Verde 1	4.77E−02	9.60E−02	9.04E−03	3.39E−02	1.87E−01	—	—	—	—	7.44	0.56	8.00
Palo Verde 2	4.66E−02	9.43E−02	9.01E−03	3.34E−02	1.83E−01	—	—	—	—	7.22	0.78	8.00
Palo Verde 3	4.66E−02	9.44E−02	9.01E−03	3.34E−02	1.83E−01	—	—	—	—	7.23	0.77	8.00
Peach Bottom 2	4.88E−02	9.76E−02	9.08E−03	3.44E−02	1.90E−01	—	—	—	—	7.65	0.35	8.00
Peach Bottom 3	4.89E−02	9.76E−02	9.08E−03	3.44E−02	1.90E−01	—	—	—	—	7.66	0.35	8.00
Perry	4.68E−02	9.46E−02	9.01E−03	3.35E−02	1.84E−01	—	—	—	—	7.25	0.75	8.00
Pilgrim	4.76E−02	9.58E−02	9.04E−03	1.02E−01	2.54E−01	—	—	—	1	7.42	0.58	8.00
Point Beach 1	4.20E−02	8.74E−02	8.85E−03	3.13E−02	1.70E−01	—	—	—	—	6.22	1.78	8.00
Point Beach 2	4.27E−02	8.85E−02	8.87E−03	3.16E−02	1.72E−01	—	—	—	—	6.39	1.61	8.00
Prairie Island 1	4.60E−02	9.35E−02	8.99E−03	3.32E−02	1.82E−01	—	—	—	—	7.11	0.89	8.00
Prairie Island 2	4.67E−02	9.45E−02	9.01E−03	3.35E−02	1.84E−01	—	—	—	—	7.24	0.76	8.00
Quad Cities 1	4.59E−02	9.32E−02	8.98E−03	3.31E−02	1.81E−01	—	—	—	—	7.08	0.92	8.00
Quad Cities 2	4.38E−02	9.00E−02	8.91E−03	3.21E−02	1.75E−01	—	—	—	—	6.62	1.38	8.00
River Bend	4.66E−02	9.43E−02	9.01E−03	3.34E−02	1.83E−01	—	—	—	—	7.23	0.77	8.00
Robinson 2	4.81E−02	9.65E−02	9.05E−03	3.41E−02	1.88E−01	—	—	—	—	7.51	0.49	8.00
Salem 1	4.15E−02	8.65E−02	8.82E−03	3.10E−02	1.68E−01	—	—	—	—	6.08	1.92	8.00
Salem 2	4.37E−02	8.99E−02	8.91E−03	3.21E−02	1.75E−01	—	—	—	—	6.60	1.40	8.00
San Onofre 2	4.58E−02	9.31E−02	8.98E−03	3.30E−02	1.81E−01	—	—	—	—	7.05	0.95	8.00
San Onofre 3	4.45E−02	9.12E−02	8.94E−03	3.25E−02	1.77E−01	—	—	—	—	6.79	1.21	8.00
Seabrook	4.58E−02	9.32E−02	8.98E−03	3.31E−02	1.81E−01	—	—	—	—	7.07	0.93	8.00
Sequoyah 1	4.63E−02	9.39E−02	9.00E−03	3.33E−02	1.82E−01	—	—	—	—	7.16	0.84	8.00
Sequoyah 2	4.79E−02	9.63E−02	9.05E−03	3.40E−02	1.87E−01	—	—	—	—	7.48	0.52	8.00
South Texas 1	4.63E−02	9.39E−02	9.00E−03	3.33E−02	1.83E−01	—	—	—	—	7.17	0.83	8.00
South Texas 2	4.66E−02	9.43E−02	9.01E−03	3.34E−02	1.83E−01	—	—	—	—	7.22	0.78	8.00
St. Lucie 1	4.73E−02	9.53E−02	9.03E−03	1.01E−01	2.53E−01	—	—	—	1	7.36	0.64	8.00
St. Lucie 2	4.74E−02	9.55E−02	9.03E−03	1.01E−01	2.53E−01	—	—	—	1	7.38	0.62	8.00
Summer	4.60E−02	9.34E−02	8.99E−03	3.31E−02	1.82E−01	—	—	—	—	7.10	0.90	8.00
Surry 1	4.62E−02	9.37E−02	8.99E−03	3.32E−02	1.82E−01	—	—	—	—	7.14	0.86	8.00
Surry 2	4.73E−02	9.54E−02	9.03E−03	3.37E−02	1.85E−01	—	—	—	—	7.36	0.64	8.00
Susquehanna 1	4.70E−02	9.49E−02	9.02E−03	3.36E−02	1.85E−01	—	—	—	—	7.31	0.69	8.00

Table D-2. (continued)

Plant	Plant-Specific Mean Frequencies for Critical Operation (/rcry): Plant Centered	Switchyard Centered	Grid Related	Weather Related	Combined	LOOP IEs During Critical Operation: Plant Centered	Switchyard Centered[b]	Grid Related	Weather Related	Time[a]: rcry	rsy	rcy
Susquehanna 2	4.72E−02	9.52E−02	9.02E−03	3.37E−02	1.85E−01	—	—	—	—	7.34	0.66	8.00
Three Mile Isl 1	4.78E−02	9.61E−02	9.04E−03	3.39E−02	1.87E−01	—	—	—	—	7.46	0.54	8.00
Turkey Point 3	4.71E−02	9.51E−02	9.02E−03	3.36E−02	1.85E−01	—	—	—	—	7.32	0.68	8.00
Turkey Point 4	4.87E−02	1.79E−01	9.07E−03	3.43E−02	2.71E−01	—	1	—	—	7.61	0.39	8.00
Vermont Yankee	4.73E−02	9.54E−02	9.03E−03	3.37E−02	1.85E−01	—	—	—	—	7.36	0.64	8.00
Vogtle 1	4.78E−02	9.61E−02	9.04E−03	3.39E−02	1.87E−01	—	—	—	—	7.46	0.54	8.00
Vogtle 2	4.75E−02	9.57E−02	9.04E−03	3.38E−02	1.86E−01	—	—	—	—	7.40	0.60	8.00
Waterford 3	4.62E−02	9.38E−02	8.99E−03	3.32E−02	1.82E−01	—	—	—	—	7.15	0.85	8.00
Watts Bar 1	4.74E−02	9.55E−02	9.03E−03	3.38E−02	1.86E−01	—	—	—	—	7.38	0.62	8.00
Wolf Creek	4.74E−02	9.56E−02	9.03E−03	3.38E−02	1.86E−01	—	—	—	—	7.39	0.61	8.00
	Statistics					Total						
Max	2.43E−01	1.80E−01	2.70E−02	1.02E−01	3.73E−01	5	6	2	4	724.12	99.92	824.04
95%	4.89E−02	1.46E−01	9.08E−03	3.44E−02	2.69E−01	—	—	—	—	—	—	—
Mean	5.06E−02	9.77E−02	9.32E−03	3.57E−02	1.93E−01	—	—	—	—	—	—	—
50%	4.68E−02	9.45E−02	9.01E−03	3.34E−02	1.84E−01	—	—	—	—	—	—	—
5%	4.09E−02	8.35E−02	8.75E−03	3.00E−02	1.68E−01	—	—	—	—	—	—	—
Min	3.48E−02	7.56E−02	8.53E−03	2.76E−02	1.47E−01	—	—	—	—	—	—	—

a. rcry—reactor critical year, rsy—reactor shutdown year, rcy—reactor calendar year

b. The Zion switchyard-centered LOOP is not included because it is not one of the 103 currently operating nuclear power plants.

NRC FORM 335 (2-89)
NRCM 1102, 3201. 3202

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

(See Instructions on the reverse)

1. REPORT NUMBER (Assigned by NRC, Add Vol., Supp., Rev., and Addendum Numbers, if any.)
NUREG/CR-6890
INL/EXT-05-00501

2. TITLE AND SUBTITLE
Reevaluation of Station Blackout Risk at Nuclear Power Plants

3. DATE REPORT PUBLISHED

MONTH	YEAR
December	2005

4. FIN OR GRANT NUMBER
Y6546

5. AUTHOR(S)
S.A. Eide, INL; C.D. Gentillon, INL; T.E. Wierman, INL; D.M. Rasmuson, NRC

6. TYPE OF REPORT
Technical

7. PERIOD COVERED (Inclusive Dates)
01/01/1986 – 12/31/2004

8. PERFORMING ORGANIZAITON - NAME AND ADDRESS (If NRC, provide Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address; if contractor, provide name and mailing address.)
Idaho National Laboratory
Risk, Reliability & NRC Programs Department
P.O. Box 1625
Idaho Falls, ID 83415-3850

9. SPONSORING ORGANIZATION – NAME AND ADDRESS (If NRC, type "Same as above"; If contractor, provide NRC Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address.)
Division of Risk Analysis and Applications
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

10. SUPPLEMENTARY NOTES
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11. ABSTRACT (200 words or less)
This report is an update of previous reports analyzing loss of offsite power (LOOP) events and the associated station blackout (SBO) core damage risk at U.S. commercial nuclear power plants. LOOP data over the period 1986–2004 were collected and analyzed. Frequency and duration estimates for critical and shutdown operations were generated for four categories of LOOPs: plant centered, switchyard centered, grid related, and weather related. Overall, LOOP frequencies during critical operation have decreased significantly in recent years, while LOOP durations have increased. To obtain SBO results, updated LOOP frequencies and offsite power nonrecovery curves were input into standardized plant analysis risk (SPAR) models covering the 103 operating commercial nuclear power plants. Core damage frequency results indicating contributions from SBO and other LOOP-initiated scenarios are presented for each of the 103 plants, along with plant class and industry averages. In addition, a comprehensive review of emergency diesel generator performance was performed to obtain current estimates for the SPAR models. Overall SPAR results indicate that core damage frequencies for LOOP and SBO are lower than previous estimates. Improvements in emergency diesel generator performance contribute to this risk reduction.

12. KEY WORDS/DESCRIPTORS (List words or phrases that will assist researchers in locating the report.)
Loss of offsite power, LOOP, station blackout, SBO, probabilistic risk assessment, PRA, core damage frequency, CDF

13. AVAILABILITY STATEMENT
Unlimited

14. SECURITY CLASSIFICATION
(This page)
Unclassified
(This report)
Unclassified

15. NUMBER OF PAGES

16. PRICE