INL/RPT-22-68809

Analysis of Loss-of-Offsite-Power Events 2021 Update

August 2022

Nancy Johnson
Zhegang Ma

INL is a U.S. Department of Energy National Laboratory
operated by Battelle Energy Alliance, LLC

INL/RPT-22-68809

Analysis of Loss-of-Offsite-Power Events Update

Nancy Johnson
Zhegang Ma

August 2022

Idaho National Laboratory
Regulatory Support Department
Idaho Falls, Idaho 83415

http://www.inl.gov

Prepared for the
Division of Risk Assessment
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
NRC Agreement Number 31310019N0006
Task Order Number 31310019F0022

Page intentionally left blank

ABSTRACT

Loss-of-offsite power (LOOP) can have a negative impact on a nuclear power plant's ability to achieve and maintain safe shutdown conditions. LOOP frequencies and times required for subsequent restoration of offsite power are important inputs to plant probabilistic risk assessments. This report presents a statistical and engineering analysis of LOOP frequencies and durations at U.S. commercial nuclear power plants. The data used in this study were based on the operating experience during calendar years 1987–2021, while the most recent 15-year data (i.e., from 2007–2021) were used for most analyses in this report. LOOP events during critical operation that did not result in a reactor trip are not included. Frequencies and durations were determined for four LOOP event categories: plant-centered, switchyard-centered, grid-related, and weather-related. These categories (and the All-LOOPs group which contains all LOOP categories) could be further grouped by whether a LOOP event occurred during critical operation, during shutdown operation, or during all operations.

The following decreasing trends in the LOOP occurrence rates were identified for the most recent 10-year period (2012–2021): All-LOOPs during critical operation, switchyard-centered LOOPs during critical operation, and grid-related LOOPs during critical operation.

Adverse trends in LOOP durations continue for switchyard-centered LOOPs during all operations, All-LOOPs during all operations, and All-LOOPs during shutdown operation for the 1997–2021 period.

Statistical tests show the LOOP counts for the period of 2007–2021 are not uniformly distributed across the 12 months, and variation among the months exists for grid-related LOOPs during all operations, All-LOOPs during all operations, and All LOOPs during critical operation.

The engineering analysis of LOOP data showed for the period of 2007–2021, the equipment failure events were mostly caused by failures of relays and equipment in the "Other" subgroup; human errors have been less frequent and occurred primarily in maintenance and switching; and the leading natural disasters causing LOOP events from weather were tornadoes, lightning, and hurricane. Weather was the cause for 45% of

LOOPs for the last fifteen years (2007–2021), but for only 20% of LOOPs for the previous 20 years (1987–2006).

EXECUTIVE SUMMARY

Loss-of-offsite power (LOOP) can have a negative impact on a plant's ability to achieve and maintain safe shutdown conditions. Risk analyses have shown LOOP can represent most of the internal event risk at some plants.

The objectives of this study are (1) to summarize the frequency, duration, and other aspects of LOOP events at commercial nuclear plants in the U.S. through calendar years 2021; and (2) to provide operational experience insights and trend information. Since this study includes the most recent annual data, it provides a basis for input into Standardized Plant Analysis Risk (SPAR) and industry probabilistic risk assessments (PRAs). The parameters in the SPAR models employed by the staff, such as those related to LOOP are updated periodically so as to remain current, but not typically on the same schedule as these annual reports.

As in previous studies, the LOOP data were studied for four categories: plant-centered (PC), switchyard-centered (SC), grid-related (GR), and weather-related (WR). These categories (and the All-LOOPs group which contains all LOOP categories) could be further grouped by whether a LOOP event occurred during critical operation, during shutdown operation, or during all operations.

There was one new LOOP event in 2021, which occurred during shutdown operation and was weather-related.

The data used in this study included operating experience during calendar years 1987–2021, but the most recent 15-year data (i.e., from 2007–2021) were used for most analyses in this report.

Occurrence Rates. Industry-average LOOP frequencies were determined for calendar years 2007-2021. To characterize the variation in LOOP frequencies in each category for critical operation and shutdown operation, statistical tests were performed for each of the categories to see if there were significant differences across plant units. For the data that are not homogeneous (i.e., there are significant differences among the data groupings), Empirical Bayes (EB) gamma distributions were sought to describe any identified variation. The results show that weather-related LOOP for critical operation and overall LOOP data for critical and shutdown operation can be modeled using EB distributions showing variation between plants. For the remaining data groupings, the data appear homogeneous. In those cases, the Jeffreys noninformative prior was updated with industry-level data to obtain a posterior distribution. The results are presented in Table ES-1 and could be used in risk assessments as prior distributions to be updated with plant-specific data.

Table ES-1. Gamma distributions describing variation in LOOP frequencies across the U.S. NPP industry (2007–2021).

Mode	LOOP Category	Shape (α)	Scale (β)	5%	Median	95%	Gamma Mean	Notes
Critical Operation	LOOP-PC	6.50	1381.68	2.13E-03	4.47E-03	8.09E-03	4.70E-03	(a)
	LOOP-SC	9.50	1381.68	3.66E-03	6.64E-03	1.09E-02	6.88E-03	(a)
	LOOP-GR	7.50	1381.68	2.63E-03	5.19E-03	9.05E-03	5.43E-03	(a)
	LOOP-WR	0.69	94.30	1.17E-04	4.17E-03	2.49E-02	7.26E-03	(b)
	All-LOOPs	1.13	48.47	1.59E-03	1.69E-02	6.69E-02	2.33E-02	(b)
Shutdown Operation	LOOP-PC	2.50	124.52	4.60E-03	1.75E-02	4.45E-02	2.01E-02	(a)
	LOOP-SC	8.50	124.52	3.48E-02	6.56E-02	1.11E-01	6.83E-02	(a)
	LOOP-GR	2.50	124.52	4.60E-03	1.75E-02	4.45E-02	2.01E-02	(a)
	LOOP-WR	5.50	124.52	1.84E-02	4.15E-02	7.90E-02	4.42E-02	(a)
	All-LOOPs	0.63	4.35	1.67E-03	7.88E-02	5.12E-01	1.45E-01	(b)

[a] Homogeneous. The data rule out the possibility of wide variations among plants. The Jeffreys noninformative prior is used.
[b] EB method is used. There appears to be variability between plants.

An investigation of possible trends in the LOOP occurrence rates for the most recent 10 years was completed. The following decreasing trends were identified:

- all-LOOPs during critical operation (p-value=0.002)
- switchyard-centered LOOPs during critical operation (p-value=0.001)
- grid-related LOOPs during all operations (p-value = 0.017).

Recovery Times. To develop estimates of the probability of exceeding specified recovery time limits, the recovery times for each category were fit to lognormal distributions by matching moments for the underlying normal distributions. Unlike prior reports in this series, which used data since 1988, more recent data was used in this report. The most recent 15-year (i.e., 2007–2021) data was found not to fit a lognormal distribution. Instead, the data from 1997 through 2021 does fit the distribution and was used in the analysis. The results show grid-related LOOPs have the shortest recovery times with a mean value of 3.57 hours, while the weather-related LOOPs have the longest recovery times with a mean value of more than 44 hours.

A trend analysis of potential LOOP recovery times at the site level identified the following increasing trends:

- switchyard-centered LOOPs during all operations (p-value = 0.016)
- all-LOOPs during all operations (p-value = 0.018)

- all-LOOPs during shutdown operation (p-value = 0.003).

These increasing trends indicate it is taking longer to recover from the associated LOOP categories. There is no trend in the recovery times for plant-centered, grid-related, or weather-related events.

Seasonal Effects. To study monthly patterns in the LOOP occurrences, the 2007–2021 data were grouped and evaluated by month to see if the counts could be uniformly distributed. Statistical tests show the counts are not uniformly distributed across the 12 months, and variation among the months exist for:

- grid-related LOOPs during all operations (p-value = 0.021)
- all-LOOPs during all operations (p-value = 0.009)
- all-LOOPs during critical operation (p-value = 0.012).

Multi-Unit LOOPs. Data for LOOP events that affected multiple units at multi-unit sites were reviewed. No 2021 LOOP events affected multiple units. There were six occasions during 2007–2021 when more than one unit at a site was affected by the same incident. The six occasions contributed 13 of the 49 unit-level events during 2007–2021. When multiple units at a site experience a LOOP on the same day, the unit-level LOOP events may not be independent. While the analyses in this report treat the unit-level events independently for the most part, we also present an investigation of different approaches to address multi-unit LOOP events.

Consequential LOOPs. NUREG/CR-6890 (Eide, et al. 2005) provided an estimate of conditional probabilities of a consequential LOOP (CLOOP) given a reactor trip, 5.3E–3 for the period 1997–2004 and 3.0E–3 for the period 1986–1996. This study presents an update of the conditional probability using data from 2007–2021. The updated conditional probabilities of CLOOP given a reactor trip are found to be 1.76E-03, which represents a reduction of about 67% versus the value of 5.3E–3 from NUREG/CR-6890.

Engineering Analysis of LOOP Data. The engineering review of the LOOP data found that for the period of 2007–2021, the equipment failure events were mostly caused by failures of relays and equipment in the "Other" subgroup. Human errors have been much less frequent and occurred primarily in maintenance and switching. The leading natural disasters causing LOOP events from weather were tornadoes, lightning, and hurricane. Weather was the cause for 45% of LOOPs for the last fifteen years (2007– 2021), but for only 20% of LOOPs for the previous 20 years (1987–2006).

Page intentionally left blank

CONTENTS

FIGURES

TABLES

Page intentionally left blank

ACRONYMS

AC	alternating current
CLOOP	consequential loss-of-offsite power
EB	Empirical Bayes
EDG	emergency diesel generator
GR	grid-related
IE	initiating event
INL	Idaho National Laboratory
LER	licensee event report
LOCA	loss-of-coolant accident
LOOP	loss-of-offsite power
LOOP-GR	grid-related LOOP
LOOP-PC	plant-centered LOOP
LOOP-SC	switchyard-centered LOOP
LOOP-WR	weather-related LOOP
MLE	maximum likelihood estimator
NERC	North American Electric Reliability Council
NPP	nuclear power plant
NRC	Nuclear Regulatory Commission
PC	plant-centered
PLOOP	partial loss-of-offsite power
PRA	probabilistic risk assessment
rcry	reactor critical year
rsy	reactor shutdown year
SAPHIRE	Systems Analysis Programs for Hands-on Integrated Reliability Evaluations
SBO	station blackout
SC	switchyard-centered
SERC	Southeastern Electric Reliability Council
SPAR	Standardized Plant Analysis Risk
WR	weather-related

GLOSSARY[a]

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

Numerous definitions for LOOP exist. Although this definition provides clarity by "requiring all emergency power generators to start and supply power to the safety buses," for the purposes of this report and used as input to the SPAR models, the definition is extended so that an event in which all emergency power generators started yet did not load in response to a loss of offsite power to all safety buses is still classified as a LOOP event.

Another alternate definition of a LOOP event, similar to the above yet not employed here due to lack of emergency power mention, based on NUREG-2122 (Drouin et al. 2013)*, is "the loss of all AC power from the electrical grid to the plant safety buses."*

Partial LOOP (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).

Station blackout (SBO)—the complete loss of ac power to safety buses in a nuclear power plant (NPP) unit. Station blackout involves the LOOP concurrent with the failure of the onsite emergency ac power system. It does not *require* the loss of available ac power to safety buses fed by station batteries through inverters or successful high-pressure core spray operation *or station blackout power supplies (e.g., non-safety related SBO diesel generators or alternate offsite SBO feeds). For example, a LOOP concurrent with the failure of the onsite emergency ac power system is an SBO, even if SBO diesel generators are functional.*

Note the slight differences between the above SBO definition (based upon NUREG/CR-6890) and the definition in 10 CFR 50.2 and ASME/ANS RA-Sb-2013. For example, 10CFR 50.2 states that "Station blackout means the complete loss of alternating current (ac) electric power to the ***essential and non-essential switchgear buses*** *in a nuclear power plant (i.e., loss of offsite electric power system concurrent with turbine trip and unavailability of the onsite emergency ac power system)." The SBO definition in NUREG/CR-6890 and the following annual LOOP analyses do not include operation or failure of the non-essential buses (also referred to as non-safety buses, non-1E buses) for several reasons. For instance, non-essential buses are usually not modeled in probabilistic risk assessment (PRA), they are not used as a criterion in the state-of--practice identifying/classifying LOOP and SBO events, and successful performance of non-essential buses is generally not considered sufficient in leading PRA sequences to the safe and stable state.*

[a] This Glossary section uses the same definitions as those in NUREG/CR-6890. Additional notes or revisions are in *Italic font* for clarification, as needed.

Terms Related to LOOP Categories

Grid-related LOOP—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 *within* 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.

Plant-centered LOOP—a LOOP event in which the design and operational characteristics of the NPP unit itself play the major role in the LOOP cause and duration. 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 NPP main and station power transformers' high-voltage terminals.

Switchyard-centered LOOP—a LOOP event in which the equipment (or human-induced failures of equipment) in the switchyard plays 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 point where the transmission lines leave the switchyard*.

Weather-related LOOP—a LOOP event caused by severe or extreme weather. There are two subcategories:

Severe-weather-related LOOP—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 broad (beyond local) 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 result in widespread damage, just that the potential *existed*. 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.

Extreme-weather-related LOOP—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. *Extreme weather events are more impactful than severe weather events*.

Terms Related to LOOP Classifications

LOOP initiating event (LOOP-IE), or Functional 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 NUREG/CR-5750 (Poloski et al. 1999) definition of a functional-impact LOOP initiating event (as opposed to an initial plant fault LOOP initiating event). *LOOP-IE events are further subdivided into LOOP-IE-I, LOOP-IE-C, and LOOP-IE-NC (see below) and all three types are included in the critical operation LOOP frequency calculation.*

Initial plant fault LOOP-IE (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. NUREG/CR-5750 (Poloski et al. 1999) uses the term "initial plant fault" to distinguish these events from other "functional impact" events (LOOP-IE-C and LOOP-IE-NC).

Consequential LOOP-IE (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 (e.g., main generator tripping) after a unit trip from an unrelated cause. In this case, the LOOP would not have occurred if the unit remained operational. LOOP-IE-C is a subset of LOOP-IE events.

Nonconsequential LOOP-IE (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.

LOOP 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. *These LOOP events are not included in the analysis (neither in the LOOP frequency calculation nor in the LOOP event counts).*

LOOP shutdown event (LOOP-SD)—a LOOP occurring while a plant is shut down. *These LOOP events are included in the shutdown operation LOOP frequency calculation.*

Terms Related to Time Needed to Restore Offsite Power

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, *from the onset of the LOOP (time zero), until offsite power is restored* from the first available source to a safety bus.

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. *The determination of potential bus recovery time is based on engineering judgement (see Subsection 6.7 of NUREG/CR-6890).*

Switchyard restoration time—the duration, in minutes, from event initiation until offsite electrical power is restored (or could have been restored, whichever time is shorter) to the switchyard. Items, such as, absence of further interruptions to the switchyard, adequacy of the frequency and voltage levels to the switchyard, and absence of transients that could be disruptive to plant electrical equipment, should be considered in determining the time.

Page intentionally left blank

Analysis of Loss-of-Offsite-Power Events 2021 Update

1. INTRODUCTION

U.S. commercial nuclear power plants (NPPs) rely on alternating current (ac) power supplied through the electric grid for both routine operation and accident recovery. While emergency generating equipment is always available onsite, a loss-of-offsite power (LOOP) can have a major negative impact on a plant's ability to achieve and maintain safe shutdown conditions. Risk analyses have shown LOOP events can contribute significantly to the internal risk at many plants. Therefore, LOOP events and subsequent restoration of offsite power are important inputs to plant probabilistic risk assessments (PRAs). These inputs must reflect current industry performance so PRAs can accurately estimate the risk from LOOP-initiated scenarios.

The objectives of this study are (1) to summarize the frequency, duration, and other aspects of LOOP events at commercial nuclear plants in the U.S. through calendar year 2021; and (2) to provide operational experience insights and trend information. Since this study includes the most recent annual data, it provides a basis for input into Standardized Plant Analysis Risk (SPAR) and industry PRAs. The parameters in the SPAR models employed by the staff, such as those related to LOOP, are updated periodically so as to remain current, but not typically on the same schedule as these annual reports.

NUREG/CR-6890, Reevaluation of Station Blackout Risk at Nuclear Power Plants: Analysis of Loss-of-Offsite-Power Events (Eide et al. 2005) preceded the annual update studies such as those contained in this document which continues the work by covering data through 2021. As in the previous studies, the events are based on four LOOP categories: plant-centered (PC), switchyard-centered (SC), grid-related (GR), and weather-related (WR). See the Glossary for definitions of these and other related terms. These categories (and the All-LOOPs group which contains all LOOP categories) could be further grouped by whether a LOOP event occurred during critical operation, during shutdown operation, or during all operations.

The data used in this study included operating experience during calendar years 1987–2021. LOOP occurrence data from 1987 to the current update year are summarized in Subsection 2.3. Appendix A-1 of Appendix A lists the licensee event reports (LERs) as well as other event characteristics (including occurrence date, operating mode, LOOP category, LOOP restoration time, and event cause) associated with the LOOP events for 1987–2021 supporting this study. The operating mode designation used in the LOOP database and in this report is different from the term that is used in nuclear plant operations for Modes 1, 2, 3, etc. The operating modes in this report include Power-Ops (or Critical Operation) and Shutdown Operation.

The most recent 15-year data (i.e., from 2007–2021 for this update) were used in general in this report. The starting period of the data for most analyses in this report is January 1, 2007. In previous reports in this series, January 1, 1997, was often used as the starting period of the data for most analyses as it was regarded as the start of deregulation of the U.S. electrical industry. Furthermore, in the update reports prior to 2014, data from fiscal year 1988 (which includes some of calendar year 1987) were included for critical operation LOOPs-GR and for shutdown operation LOOPs other than SC. **However, as more time and data have accrued, the older data has been removed from analyses so that more recent data are used to represent**

current industry performance. Consistent with that, the most recent 15-year period was also selected in the 2020 LOOP update (Johnson and Ma 2021) as well as the 2020 PRA parameter update for component reliability, common-cause failure alpha factors, and initiating event frequencies (Ma, Wierman and Kvarfordt, November 2021), as it would provide sufficient operating experience for most analyses while excluding older data.

This report contains trending information as well as statistical distributions that describe variation in the data. Since the 2014 update, the frequency trends have been analyzed for the most recent 10 years. Consequently, the 2012–2021 period was used for the trending analysis in this update.

The other aspect of LOOP events that is a focal point of this report is their duration (or recovery time). Table A-2 of Appendix A lists the three durations and the uncertainties associated with the durations for each LOOP event from 1987–2021. Unlike the use of data from 1988 in previous reports in this series, only the more recent data has been used in this report. However, the most recent 15-year (i.e., 2007–2021) data did not fit the lognormal distribution that is used for the duration analysis. Instead, the data from 1997 through 2021 better fit the distribution and was used in the analysis. The same 1997–2021 period data was used in the trend analysis of the recovery times as well.

NUREG/CR-6890 also classifies LOOP events into (1) LOOP-IE, which occurs during critical operation and involve a plant trip; (2) LOOP-NT, which occurs during critical operation, but the plant can continue operation without a plant trip; and (3) LOOP-SD, which occurs during shut down. The LOOP-IE events are further divided into LOOP-IE-I, in which a LOOP event causes the reactor trip; LOOP-IE-C, in which an unrelated reactor trip causes a LOOP to occur; and LOOP-IE-NC, in which a reactor trip and LOOP occur during the same transient but are unrelated. Partial LOOP (PLOOP) events occur when some, but not all, offsite power is lost to unit safety buses. See the Glossary for definitions and Figure 1 for the classification.

The data covered in the annual update analysis includes LOOP initiating events (LOOP-IE) and LOOP shutdown events (LOOP-SD). LOOP no-trip events (LOOP-NT) and PLOOP events are not included in the analysis.

Since 2009, the annual LOOP updates have included a discussion of emergency diesel generator (EDG) repair times. Since 2018 these analyses have been moved to the EDG component study reports (Ma 2019, Ma 2022) and can be accessed at: https://nrcoe.inl.gov/resultsdb/CompPerf/.

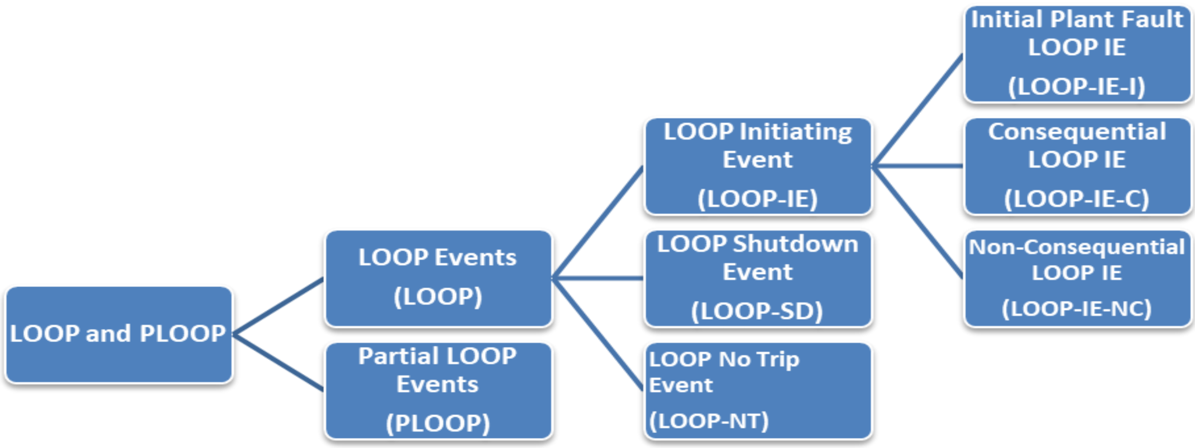


Figure 1. LOOP Classification.

1.1 Changes from Previous Years

Main changes in this update include:

- One new LOOP-WR event (LER 3822021002) occurred in 2021. The specific cause for this LER was a hurricane, and it occurred during shutdown operation.
- There was a recent change on the North American Electric Reliability Council (NERC) regional entities. After 2019, NERC encompasses six instead of seven regional entities. This change was incorporated in this study for the variation analysis in Subsection 2.2.2.
- As in the 2020 LOOP update report, the most recent 15-year data (i.e., from 2007–2021 for this update) were used for most analyses in this update report. Table 1 presents the data periods used in various LOOP analyses in this report.
- Table 2 and Table 3 contain changes after internal quality reviews of offsite power restoration times and their uncertainties earlier this year, which were not in time to be incorporated into 2020 LOOP update (Johnson and Ma 2021). Empty cells indicate that no change took place in those cells.

Table 1. LOOP analyses and the associated data periods.

LOOP Analysis	Section Number	Table/Figure Number	Period	Note
LOOP Frequency - MLE	Subsection 2.1.1	Table 4	2007–2021	(a)
LOOP Frequency Trending	Subsection 2.1.2	Figures 2 to 6	2012–2021	(b)
LOOP Frequency - Bayesian	Subsection 2.2	Tables 5 and 6	2007–2021	(a)
LOOP Event Count Data Summary	Subsection 2.3	Table 7	1987–2021	(c)
LOOP Recovery Time Analysis	Subsection 3	Tables 8 and 9	1997–2021	(d)
LOOP Seasonal Effects	Subsection 4.1	Tables 10 and 11	2007–2021	(a)
Multi-Unit LOOP	Subsection 4.2	Tables 13 to 14	2007–2021	(a)
Consequential LOOP	Subsection 4.3	Tables 16 to 17	2007–2021	(a)
Engineering Analysis of LOOP Data	Subsection 5	Figures 18 to 20	2007–2021	(a)

Note: (a) The most recent 15 years.
(b) The most recent 10 years, which has been used in the trending analyses for LOOP, initiating event, component performance, and system studies.
(c) The full LOOP database coverage
(d) The data from 2007–2021 did not have a lognormal distribution that typically is used in the LOOP recovery time analysis. Instead, the data from 1997–2021 fits the model and was used. 1997 has been historically used as the starting year for various LOOP associated analyses.

Table 2. Updated LOOP event restoration times.

LER	Plant Name	Date	Original Restoration Time (minutes)			Updated Restoration Time (minutes)		
			Switchyard Restoration Time	Potential Bus Restoration Time	Actual Bus Restoration Time	Switchyard Restoration Time	Potential Bus Restoration Time	Actual Bus Restoration Time
2592011001	Browns Ferry 2	4/27/2011		2			16	
2962012003	Browns Ferry 3	5/22/2012	0	101		86	91	
3252016001	Brunswick 1	2/7/2016	0	195		1	16	
3242006001	Brunswick 2	11/1/2006	0	30	1402	1	16	1456
4552018001	Byron 2	7/6/2018	0	90	2871	1	16	2896
3172015002	Calvert Cliffs 2	4/7/2015		20	20		29	29
4132006001	Catawba 1	5/20/2006	0			385		
4132006001	Catawba 2	5/20/2006	0			372		
4452013003	Comanche Peak 1	12/4/2013		1656	1656		1661	1661
4452013003	Comanche Peak 2	12/4/2013		1656	1656		1661	1661
3462000004	Davis-Besse	4/22/2000	0			5		
3482000005	Farley 1	4/9/2000	0			18		
4162003002	Grand Gulf	4/24/2003	0			1		
2471999015	Indian Point 2	8/31/1999	0			1		
2202002001	Nine Mile Pt. 1	11/1/2002	0			1		
2551998013	Palisades	12/22/1998	0	20		1	16	
2662011001	Point Beach 1	11/27/2011	0	334		1	16	
2512005005	Turkey Point 4	10/31/2005	0			1		

Note: The updated potential bus restoration times were used in this year's LOOP duration analysis (see Section 3).

Table 3. Updated LOOP event restoration time uncertainties.

LER	Plant Name	Date	Original Uncertainty: Switchyard Restoration Time	Original Uncertainty: Potential Bus Restoration Time	Original Uncertainty: Actual Bus Restoration Time	Updated Uncertainty: Switchyard Restoration Time	Updated Uncertainty: Potential Bus Restoration Time	Updated Uncertainty: Actual Bus Restoration Time
2592011001	Browns Ferry 2	4/27/2011	2			4		
2962012003	Browns Ferry 3	5/22/2012	1	1		4	4	
3252016001	Brunswick 1	2/7/2016	1			4		
3242006001	Brunswick 2	11/1/2006	1			4		
4552018001	Byron 2	7/6/2018	1	1		4	4	
3172015002	Calvert Cliffs 2	4/7/2015	2	2	2	4	4	4
4132006001	Catawba 1	5/20/2006	1			4		
4132006001	Catawba 2	5/20/2006	1			4		
4452013003	Comanche Peak 1	12/4/2013			2			4
4452013003	Comanche Peak 2	12/4/2013			2			4
3462000004	Davis-Besse	4/22/2000	1			4		
4162003002	Grand Gulf	4/24/2003	1			4		
2471999015	Indian Point 2	8/31/1999	1			4		
4232007002	Millstone 3	4/25/2007	2			4		
2202002001	Nine Mile Pt. 1	11/1/2002	1			4		
2551998013	Palisades	12/22/1998	1			4		
2662011001	Point Beach 1	11/27/2011	1			4		
2512005005	Turkey Point 4	10/31/2005	1			4		

Note: LOOP recovery time uncertainty: 1 = Certain; 2 = Unknown; 4 = Estimated.

2. INDUSTRY-WIDE LOOP FREQUENCIES

Industry-average LOOP frequencies were determined for calendar years 2007-2021. The 2007 start date for the data reflects the most recent 15-year's view of industry-wide LOOP frequencies. The values include critical and shutdown operations in four event categories: LOOP-PC, LOOP-SC, LOOP-GR, and LOOP-WR. Subsection 2.1 provides a frequentist analysis of LOOP frequencies covering the period 2007–2021 and annual data and trending analysis for the most recent 10 years. Subsection 2.2 provides Bayesian analysis of LOOP frequencies, which are more often used in PRA applications, covering the period2007–2021 and discusses variation in the frequencies between plants. It also provides an updated uncertainty distribution for critical operation LOOPs-GR for plants grouped by the new North American Electric Reliability Council (NERC) regional entities. Subsection 2.3 presents a summary of all LOOP data for 1987–2021 for reference.

2.1 Frequentist Analysis of LOOP Frequencies and Trend

2.1.1 LOOP Frequencies – Maximum Likelihood Estimate

Table 4 reports the observed event counts and reactor years with the latter one from the Nuclear Regulatory Commission (NRC) Reactor Operational Experience Results and Databases website Operating Time webpage, https://nrcoe.inl.gov/resultsdb/ReactorYears. The simplest statistic that comes from the counts and exposure time is the maximum likelihood estimate (MLE) of the occurrence rate. It is computed as event count divided by the corresponding exposure time. This estimate is the value that maximizes the probability of seeing the observed data, assuming a constant LOOP occurrence rate across the industry for each LOOP category/operating mode.

Table 4. LOOP events and maximum likelihood estimate of frequencies for 2007–2021.

Mode	LOOP Category	Events	Reactor Critical or Shutdown Years	MLE (Events/Years)	Percent
Critical Operation[a]	LOOP-PC	6	1381.68	4.34E-03	19%
	LOOP-SC	9	1381.68	6.51E-03	28%
	LOOP-GR	7	1381.68	5.07E-03	22%
	LOOP-WR	10	1381.68	7.24E-03	31%
	All-LOOPs	32	1381.68	2.32E-02	100%
Shutdown Operation[b]	LOOP-PC	2	124.52	1.61E-02	12%
	LOOP-SC	8	124.52	6.42E-02	47%
	LOOP-GR	2	124.52	1.61E-02	12%
	LOOP-WR	5	124.52	4.02E-02	29%
	All-LOOPs	17	124.52	1.37E-01	100.00%

[a]The frequency units for critical operation are events per reactor critical year (/rcry)

[b]The frequency units for shutdown operation are events per reactor shutdown year (/rsy).

For critical operation, LOOP-WR events contribute 31%, followed by LOOP-SC (28%), to the total critical operation LOOP frequency. For shutdown operation, LOOP-SC events contribute 47% and LOOP-WR contributes 29% to the total shutdown operation LOOP frequency. It is interesting to note that LOOP-SC and LOOP-WR are the most common type of LOOPs, contributing over 65% to the totals for critical and shutdown operations.

2.1.2 Plots of Annual Data and 10-year Trends

The performance trends provided in this subsection are intended to be representative of current operating conditions. The amount of historical data to be included in the trend period requires judgement on what constitutes current trends, considered to be the most recent 10 years in the study. To provide perspective, the plots include data since 2007 to reflect the most recent fifteen year's insight to industry-wide performance.

Figure 2–Figure 6 show the annual estimated overall and sub-category LOOP frequencies from 2007–2021 and the trend for the most recent 10 years (2012–2021) during critical operation, respectively. The 90% confidence intervals of the LOOP frequency (plotted vertically) are confidence intervals for the estimated rate associated with each individual year's data. The 90% confidence band of the trend for the most recent 10 years is a simultaneous band, intended to cover 90% of the possible trend lines that might underlie the data. Each regression is analyzed as a generalized linear model, with Poisson data in each year and a trend from year to year postulated for the logarithm of the occurrence rate.

The following trends were identified for the most recent 10 years (2012–2021):

- A highly statistically significant[b] decreasing trend was identified for All-LOOPs during critical operation (p-value = 0.002) as seen in Figure 2.
- A highly statistically significant decreasing trend was identified for LOOP-SC during critical operation (p-value = 0.001) as seen in Figure 4.
- A statistically significant decreasing trend was identified for LOOP-GR during critical operation (p-value = 0.017) as seen in Figure 5.

There were no statistically significant trends identified for LOOP-PC and LOOP-WR during critical operation for the most recent 10 years (2012–2021).

[b] Statistical significance is defined in terms of the 'p-value.' A p-value is a probability indicating whether to accept or reject the null hypothesis that there is no trend in the data. P-values of less than or equal to 0.05 indicate that we are 95% confident there is a trend in the data (reject the null hypothesis of no trend.) By convention, we use the "Michelin Guide" scale: p-value < 0.05 (statistically significant), p-value < 0.01 (highly statistically significant); p-value < 0.001 (extremely statistically significant)

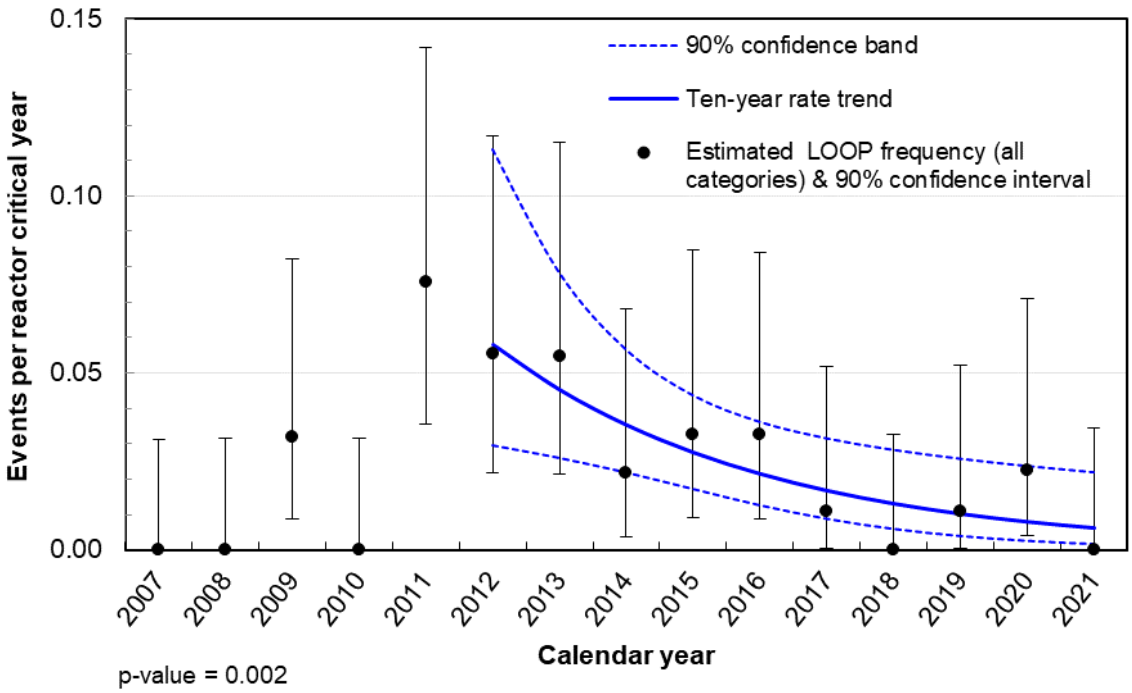


Figure 2. Estimated LOOP frequencies (all categories) and 10-year trend during critical operation.

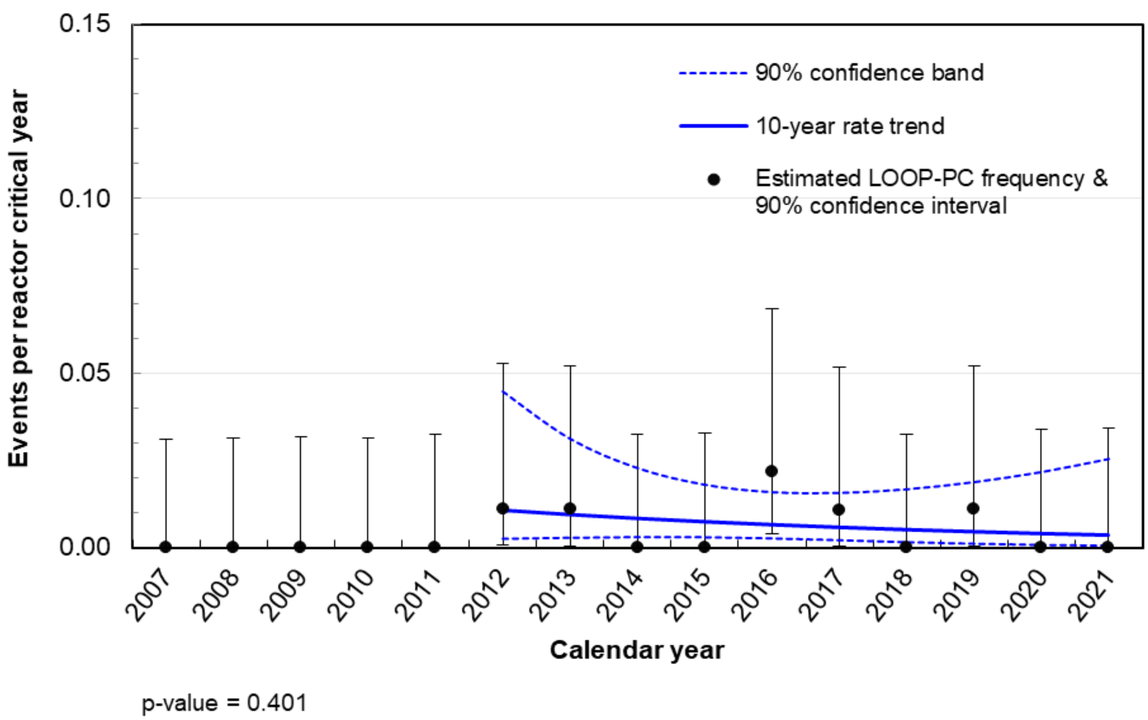


Figure 3. Estimated LOOP-PC frequency and 10-year trend during critical operation.

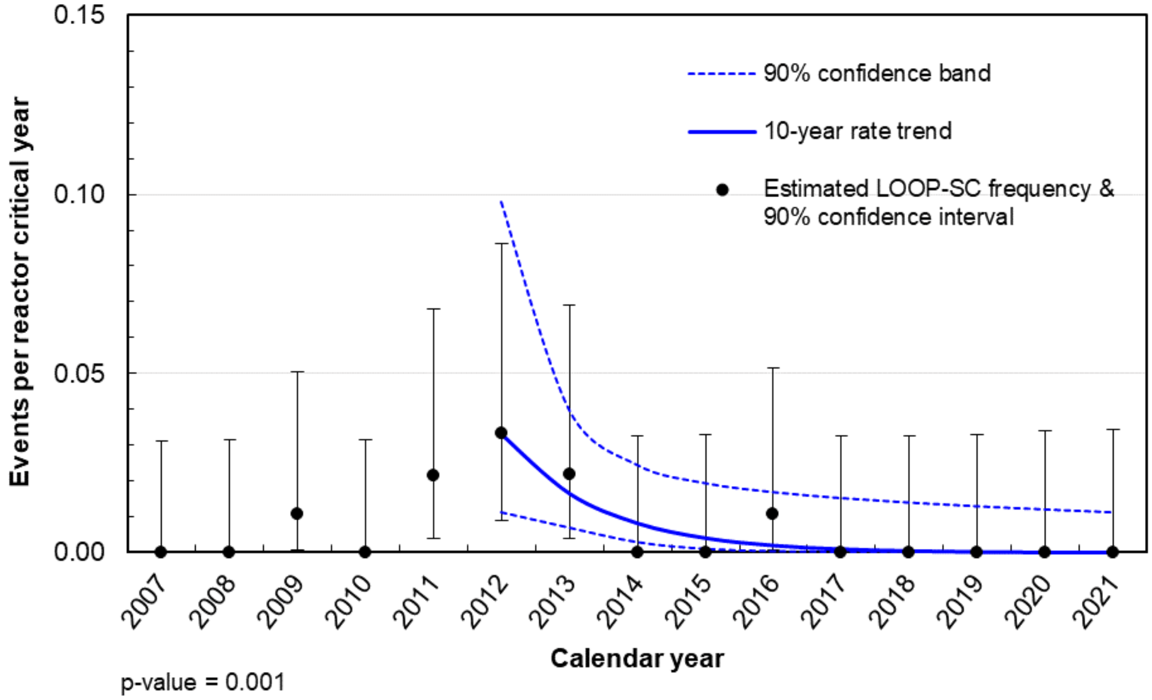


Figure 4. Estimated LOOP-SC frequency and 10-year trend during critical operation.

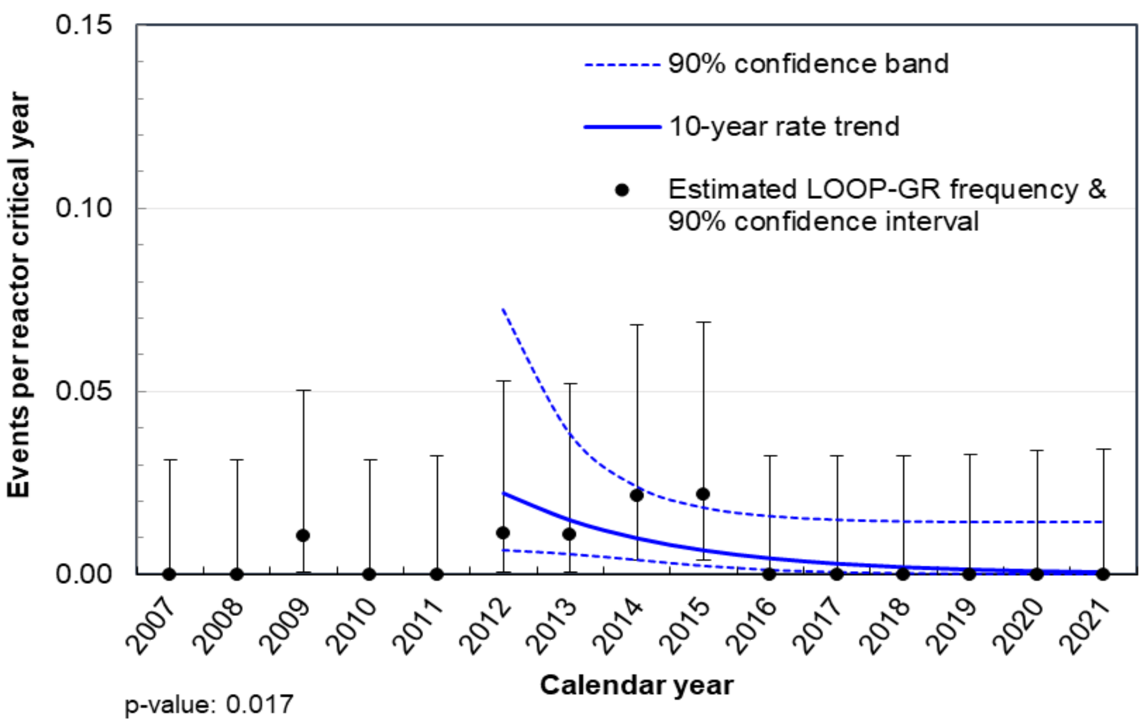


Figure 5. Estimated LOOP-GR frequency and 10-year trend during critical operation.

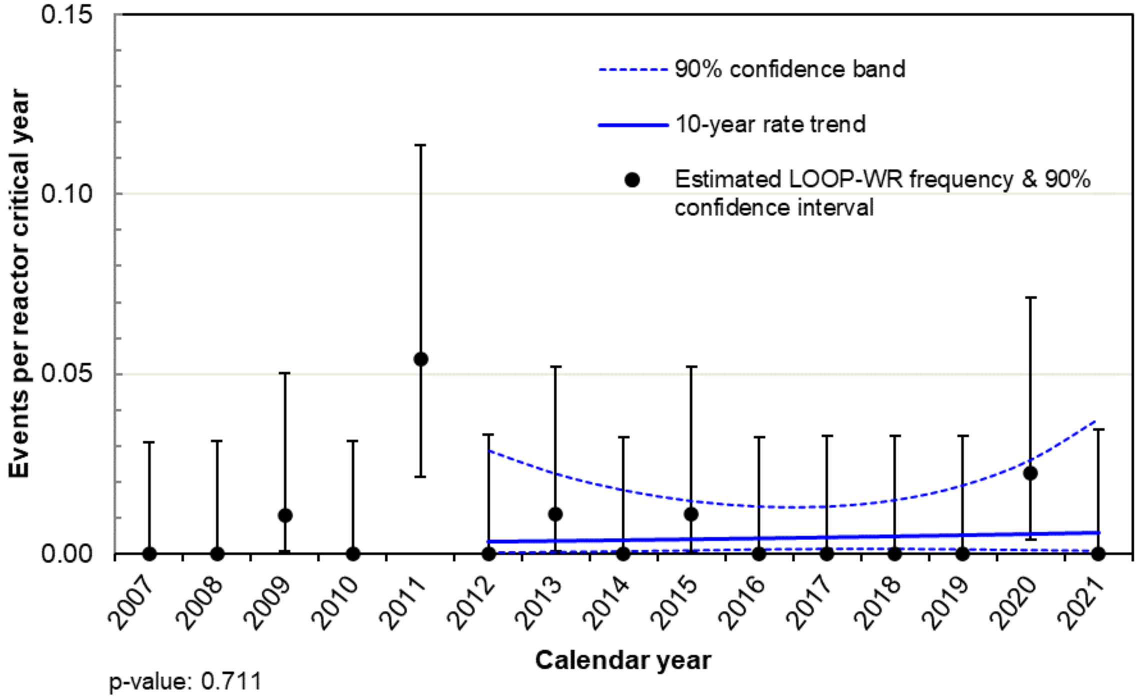


Figure 6. Estimated LOOP-WR frequency and 10-year trend during critical operation.

2.2 Bayesian Analysis of LOOP Frequencies

2.2.1 LOOP Frequencies – Uncertainty Distribution

When developing parameter estimates for use in PRA applications, the question arises as to whether all plants are comparable or if there are significant plant-to-plant variations in performance. Other factors might also account for differences in plant performance, such as electrical grid, power pool, plant-operating mode, and time (calendar years). In this subsection Bayesian methods are used to derive distributions describing industry-level occurrence rates for use in PRAs. The methods account for uncertainties coming from the random nature of the data and from between-group variation. The methods start by searching for variability in the data after grouping (pooling) the data based on a particular factor. The chi-squared test is used to determine equality of LOOP frequency estimate groupings, then parameter estimates are updated using Empirical Bayes (EB) analyses (Atwood et al. 2003).

When the statistical tests detect variation, an EB distribution can be obtained representing that variation. EB distribution results are reported in Table 5. If the tests for variation indicate the data appear homogeneous for each grouping, a Jeffreys noninformative prior is used to construct the industry estimate. The Jeffreys noninformative prior results in a posterior distribution with the event count plus 0.5, divided by the exposure time, as the mean. For each distribution, the 5th, 50th, and 95th percentiles, the mean, and the distribution parameters were tabulated.

The LOOP data were split by whether plant is in critical operation or shutdown operation for all LOOP categories because of different plant-operating conditions and demands on the emergency power system associated with the two operating modes.

Table 5. Gamma distributions describing variation in LOOP frequencies across the U. S. NPP industry (2007–2021).

Mode	LOOP Category	Shape (α)	Scale (β)	5%	Median	95%	Gamma Mean	Notes
Critical Operation	LOOP-PC	6.50	1381.68	2.13E-03	4.47E-03	8.09E-03	4.70E-03	(a)
	LOOP-SC	9.50	1381.68	3.66E-03	6.64E-03	1.09E-02	6.88E-03	(a)
	LOOP-GR	7.50	1381.68	2.63E-03	5.19E-03	9.05E-03	5.43E-03	(a)
	LOOP-WR	0.69	94.30	1.17E-04	4.17E-03	2.49E-02	7.26E-03	(b)
	All-LOOPs	1.13	48.47	1.59E-03	1.69E-02	6.69E-02	2.33E-02	(b)
Shutdown Operation	LOOP-PC	2.50	124.52	4.60E-03	1.75E-02	4.45E-02	2.01E-02	(a)
	LOOP-SC	8.50	124.52	3.48E-02	6.56E-02	1.11E-01	6.83E-02	(a)
	LOOP-GR	2.50	124.52	4.60E-03	1.75E-02	4.45E-02	2.01E-02	(a)
	LOOP-WR	5.50	124.52	1.84E-02	4.15E-02	7.90E-02	4.42E-02	(a)
	All-LOOPs	0.63	4.35	1.67E-03	7.88E-02	5.12E-01	1.45E-01	(b)

[a] Homogeneous. The data rule out the possibility of wide variations among plants. The Jeffreys noninformative prior is used.
[b] EB method was used There appears to be variability between plants.

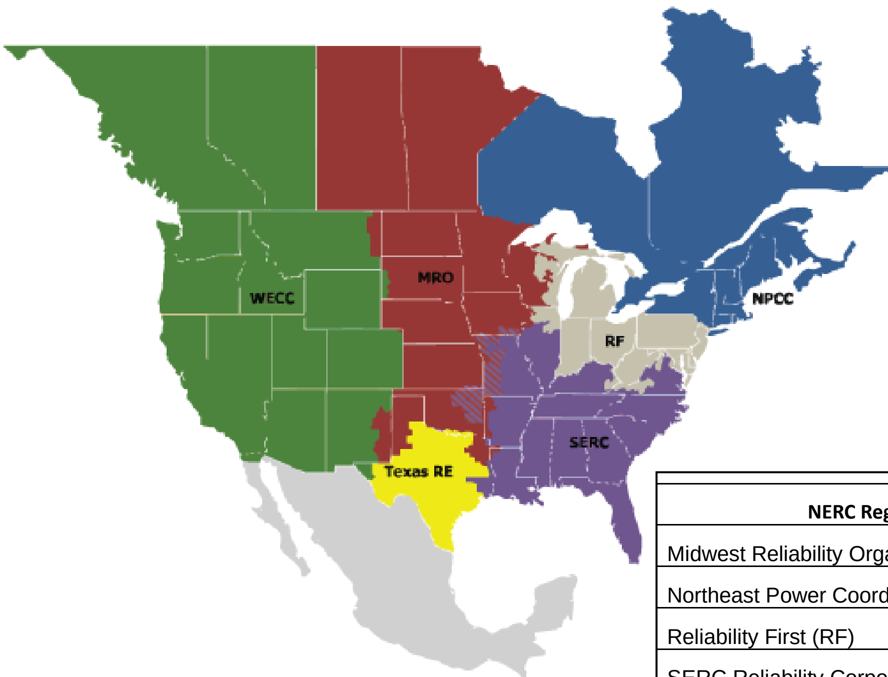
The results show that the LOOP-WR data for critical operation, the combined critical operation data, and the combined shutdown operation data can each be modeled using EB distributions with variation between plants. In the remaining data groupings, the data appear homogeneous (i.e., the variations among the plants are small). In those cases, the Jeffreys noninformative prior was updated with industry-level data to obtain a distribution. These distributions could be used in risk assessments and any PRA applications as prior distributions to be updated with plant-specific data.

2.2.2 Variations over NERC Regions

In principle, it is possible to group the data in any number of ways (by season, year, site, state, proximity to the coast, or NERC regional entities) and to characterize how much variation exists among the subgroups. Such variations may exist—rolling blackouts in California, hurricanes along the Gulf Coast, and ice storms in the Northeast have occurred in recent years. Attempting to detect and model all such variations is beyond the scope of this report. However, because of the significance of grid events that may affect multiple units at different sites, the critical operation LOOP-GR data have been grouped according to the NERC regional entities containing each plant to examine the variation in previous LOOP studies. Note that the NERC regional council names and boundaries are subject to change over the time. The original NERC regions used in NUREG/CR-6890 (Eide et al. 2005) were applied in the subsequent LOOP studies until INL/EXT-18-45359, *Analysis of Loss-of-Offsite-Power Events: 1987–2017* (Johnson, Ma and Schroeder 2018). The new NERC entities were incorporated to the regional variation analysis since the 2018 LOOP study. See INL/EXT-19-54699, *Analysis of Loss-of-Offsite-Power Events: 1987–2018* (Johnson and Ma 2019).

A more recent change on the NERC regional entities was that the Florida regional entity member (or FRCC) was dissolved, and all entity members were transitioned to the Southeastern Electric Reliability Council (SERC) by July 1, 2019. NERC now encompasses six instead of seven regional entities. Further information on the regional entities can be obtained from https://www.nerc.com/AboutNERC/keyplayers/Pages/default.aspx. This change was incorporated in this study for the variation analysis. Figure 7 shows the new NERC regional entity map with six regions. Figure 8 presents the map showing the previous NERC regional entities.[c]

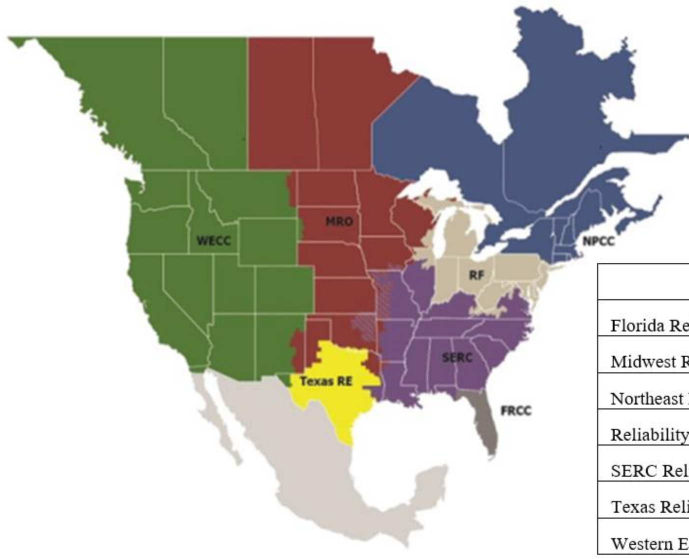
With the newest NERC regions, the analysis results derived from the EB method had the 5th percentile being more than three orders of magnitude lower than the mean of the distribution and, therefore, that approach is not recommended for use. Instead, a Bayesian Update with Jeffreys noninformative prior was performed to provide a homogenous posterior distribution, as provided in Table 6. The simple MLE (with event count divided by exposure time) values are included in the table for reference only.



NERC Regional Entity	Short Name
Midwest Reliability Organization (MRO)	Midwest
Northeast Power Coordinating Council (NPCC)	North East
Reliability First (RF)	Central East
SERC Reliability Corporation (SERC)	South East
Texas Reliability Entity (Texas RE)	Texas
Western Electricity Coordinating Council (WECC)	West

Figure 7. New NERC Regional Entities.

[c] It is noted that there was another NERC territory change in 2019 that the Florida regional entity (or FRCC) was removed out and merged to the South East regional entity (or SERC). The change may be adopted in the future regional variation analysis.



NERC Regional Entity	Short Name
Florida Reliability Coordinating Council (FRCC)	Florida
Midwest Reliability Organization (MRO)	Midwest
Northeast Power Coordinating Council (NPCC)	North East
Reliability First (RF)	Central East
SERC Reliability Corporation (SERC)	South East
Texas Reliability Entity (Texas RE)	Texas
Western Electricity Coordinating Council (WECC)	West

Figure 8. Previous NERC Regional Entities.

Table 6. Estimated LOOP-GR frequencies by NERC regional entities during critical operation (2007–2021).

NERC Regional Entities	LOOP Events	Critical Years	Shape (α)	Scale (β)	5%	Median	95%	Gamma Mean	Simple MLE
Central East	4	343.72	4.5	343.72	4.84E-03	1.21E-02	2.46E-02	1.31E-02	1.16E-02
Midwest	0	127.27	0.5	127.27	1.54E-05	1.79E-03	1.51E-02	3.93E-03	0.00E+00
North East	3	143.03	3.5	143.03	7.58E-03	2.22E-02	4.92E-02	2.45E-02	2.10E-02
South East	0	622.20	0.5	622.20	3.16E-06	3.66E-04	3.09E-03	8.04E-04	0.00E+00
Texas	0	55.12	0.5	55.12	3.57E-05	4.13E-03	3.48E-02	9.07E-03	0.00E+00
West	0	90.35	0.5	90.35	2.18E-05	2.52E-03	2.13E-02	5.53E-03	0.00E+00

2.3 Summary of LOOP Event Count Data

Table 7 Table 7. Summary of all U.S. NPP LOOP Event Count Data 1987–2021.shows a summary of LOOP data for 1987–2021, including reactor years and LOOP counts by plant status and LOOP category. From this table, a 53% decrease in the number of LOOPs from 1987–2006 to 2007–2021 can be calculated. This shows an overall improvement in LOOP events.

Figure 9–Figure 15 illustrate the above LOOP data in various charts. These LOOP data show the following:

- Shutdown periods over the years continue to show a decrease while shutdown operation LOOP events[d] remained steady for the last 15 years (2007–2021). From 1987–2006, NPPs averaged 82% critical operation. For 2007–2021, NPPs averaged 92% critical operation (Figure 9).

[d] Assuming each LOOP is an independent event—an assumption that may not be true (see Section 4.2).

- There were 76 shutdown operation LOOP events occurring during the 20-year period from 1987–2006, while 17 shutdown operation LOOP events occurred during the 15-year period from 2007–2021 (Figure 10).
- There were more shutdown operation LOOP events (76) than critical operation events (64) from 1987–2006, but more critical operation LOOP events (32) than shutdown operation events (17) since 2007 (Figure 10). The only year without any LOOP events during the whole period from 1987–2021 was 2010.
- Of all the LOOP categories during all operations from 1987–2006 (Figure 11), LOOP-SC (69 out of 140, or 49%) has the most event counts followed by LOOP-PC (32, or 23%), LOOP-WR (22, or 16%), and LOOP-GR (17 or 12%). For 2007–2021, LOOP-SC (17 out of 49, or 35%) has the highest event counts followed LOOP-WR (15, or 31%), LOOP-GR (9, or 18%), and LOOP-PC (8, or 16%)
- There were more LOOP-PC shutdown operation events (23) than critical operation events (9) from 1987–2006, but more LOOP-PC critical operation events (6) than shutdown operation events (2) since 2007 (Figure 12).
- No LOOP-SC shutdown operation events have occurred since 2015, and no LOOP-SC events have occurred since 2017 (Figure 13).
- No LOOP-GR shutdown operation events have occurred since 2008, and no LOOP-GR events have occurred since 2016 (Figure 14). The northeast blackout of August 2003 that affected eight plants simultaneously has a large influence on the LOOP-GR critical operational event counts.
- There were more LOOP-WR shutdown events (16) than LOOP-WR critical operation events (6) from 1987–2006 (Figure 15), but more critical operation events (10) than shutdown operation events (4) from 2007–2021.
- All LOOP events since 2017 have been either LOOP-PC or LOOP-WR.

Table 7. Summary of all U.S. NPP LOOP Event Count Data 1987–2021.

Calendar	Reactor Years			Critical Operation				Shutdown Operation				Total by Operating Status		Total by Type				
Year	Critical	Shutdown	Total	PC	SC	GR	WR	PC	SC	GR	WR	Up	Down	PC	SC	GR	WR	Total
1987	70.56	30.23	100.80	0	5	0	0	2	5	1	2	5	10	2	10	1	2	15
1988	76.19	30.77	106.96	1	3	0	0	1	4	0	1	4	6	2	7	0	1	10
1989	76.42	33.08	109.50	2	4	0	0	0	4	0	0	6	4	2	8	0	0	10
1990	80.66	29.23	109.88	0	1	0	0	0	3	0	0	1	3	0	4	0	0	4
1991	83.94	25.67	109.61	3	3	0	0	4	3	0	1	6	8	7	6	0	1	14
1992	83.61	24.64	108.25	2	3	1	0	4	1	0	2	6	7	6	4	1	2	13
1993	82.90	24.26	107.16	0	4	0	1	3	2	0	4	5	9	3	6	0	5	14
1994	85.80	21.20	107.00	0	0	0	0	2	1	0	0	0	3	2	1	0	0	3
1995	88.84	18.42	107.26	0	0	0	0	0	2	0	0	0	2	0	2	0	0	2
1996	87.09	21.91	109.00	0	1	0	2	0	2	0	0	3	2	0	3	0	2	5
1997	79.93	28.15	108.08	0	2	0	0	1	2	1	1	2	5	1	4	1	1	7
1998	84.39	21.61	106.00	0	0	0	1	2	1	0	1	1	4	2	1	0	2	5
1999	90.73	15.10	105.83	0	1	0	0	1	1	0	0	1	2	1	2	0	0	3
2000	92.92	10.08	103.00	1	0	0	0	1	3	0	0	1	4	2	3	0	0	5
2001	93.96	9.04	103.00	0	1	0	1	0	0	0	0	2	0	0	1	0	1	2
2002	94.88	8.12	103.00	0	1	0	0	0	0	0	0	1	0	0	1	0	0	1
2003	92.61	10.39	103.00	0	2	10	0	1	0	1	0	12	2	1	2	11	0	14
2004	94.94	8.06	103.00	0	1	3	1	0	0	0	2	5	2	0	1	3	3	7
2005	93.92	9.08	103.00	0	0	0	0	0	0	0	2	0	2	0	0	0	2	2
2006	94.34	8.66	103.00	0	3	0	0	1	0	0	0	3	1	1	3	0	0	4
2007	96.16	7.45	103.61	0	0	0	0	0	0	2	1	0	3	0	0	2	1	3
2008	95.43	8.57	104.00	0	0	0	0	0	3	0	0	0	3	0	3	0	0	3
2009	94.34	9.66	104.00	0	1	1	1	0	0	0	0	3	0	0	1	1	1	3
2010	95.44	8.56	104.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2011	92.61	11.39	104.00	0	2	0	5	0	1	0	0	7	1	0	3	0	5	8
2012	90.02	13.98	104.00	1	3	1	0	0	2	0	1	5	3	1	5	1	1	8

Table 5. (continued).

Calendar	Reactor Years			Critical Operation				Shutdown Operation				Total by Operating Status		Total by Type				
Year	**Critical**	**Shutdown**	**Total**	**PC**	**SC**	**GR**	**WR**	**PC**	**SC**	**GR**	**WR**	**Up**	**Down**	**PC**	**SC**	**GR**	**WR**	**Total**
2013	91.23	10.34	101.57	1	2	1	1	1	1	0	0	5	2	2	3	1	1	7
2014	92.44	7.56	100.00	0	0	2	0	0	1	0	0	2	1	0	1	2	0	3
2015	91.44	7.56	99.00	0	0	2	1	0	0	0	0	3	0	0	0	2	1	3
2016	92.18	6.77	98.95	2	1	0	0	0	0	0	1	3	1	2	1	0	1	4
2017	91.87	7.13	99.00	1	0	0	0	0	0	0	0	1	0	1	0	0	0	1
2018	91.89	6.86	98.75	0	0	0	0	1	0	0	1	0	2	1	0	0	1	2
2019	90.97	6.02	96.99	1	0	0	0	0	0	0	0	1	0	1	0	0	0	1
2020	88.50	6.58	95.08	0	0	0	2	0	0	0	0	2	0	0	0	0	2	2
2021	6.18	93.33	87.15	0	0	0	0	0	0	0	1	0	1	0	0	0	1	1
Totals	**3110.32**	**512.22**	**3622.53**	**15**	**44**	**21**	**16**	**25**	**42**	**5**	**21**	**96**	**93**	**40**	**86**	**26**	**37**	**189**

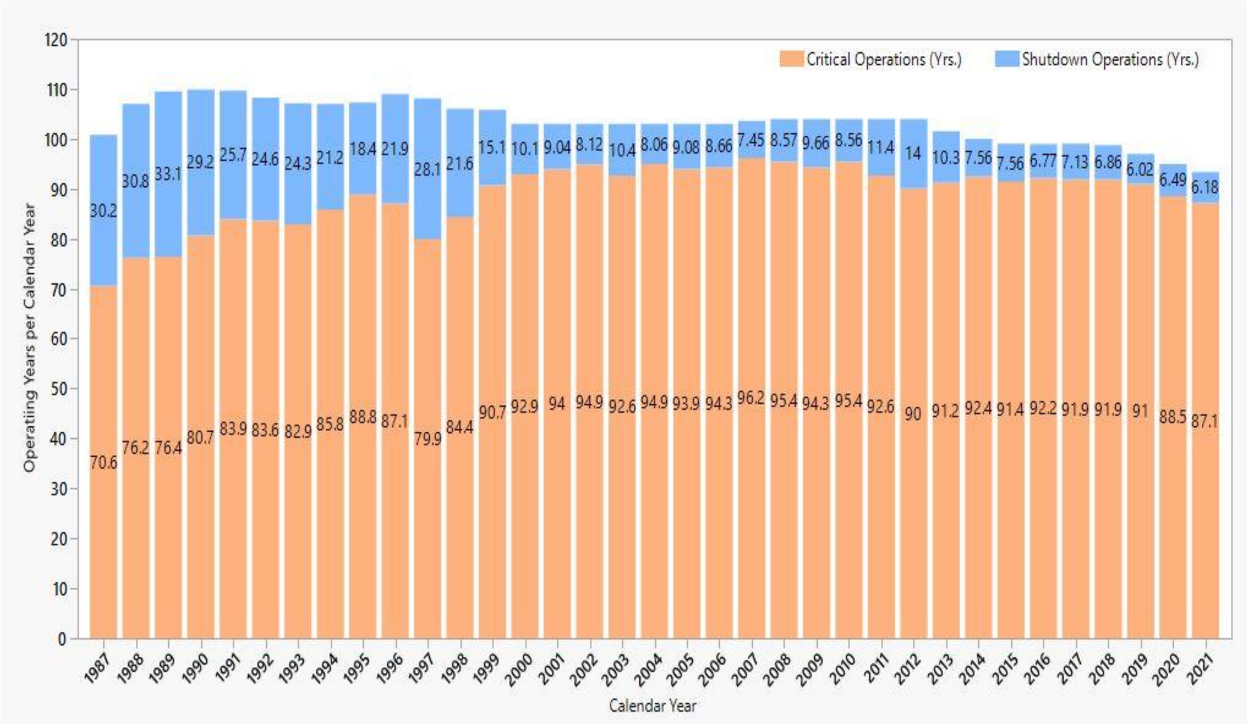


Figure 9. Operating Hours (1987–2021).

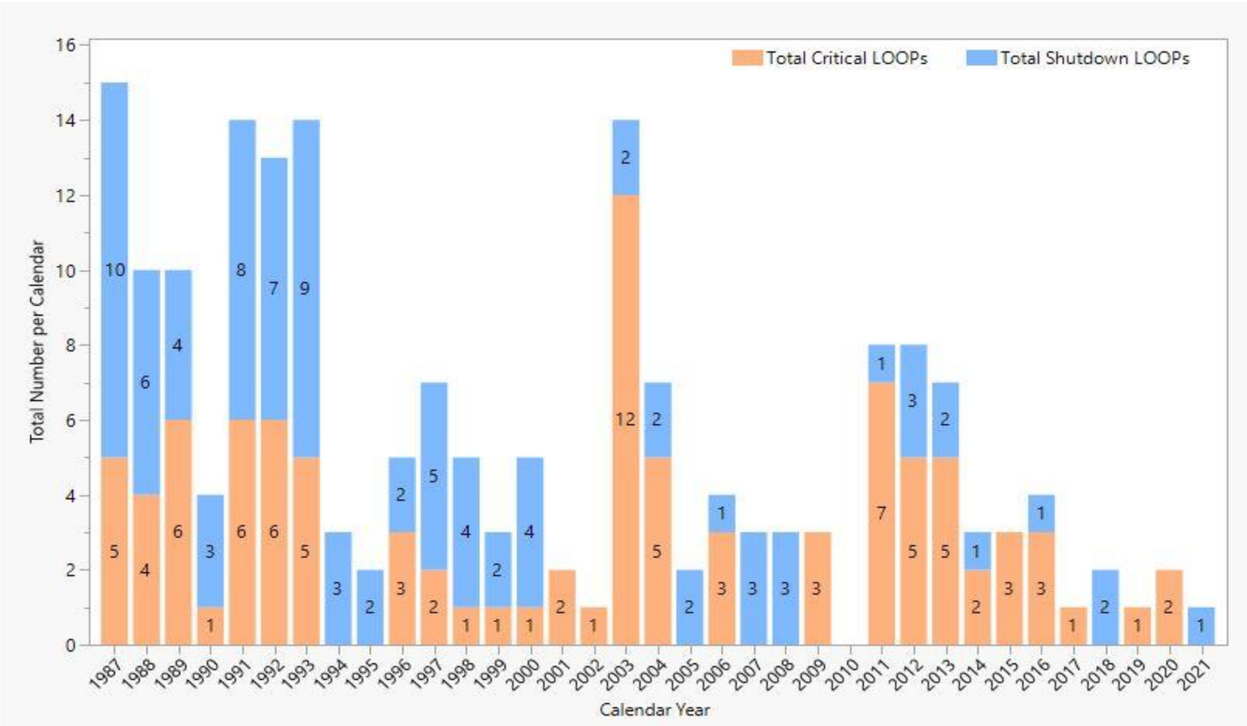


Figure 10. Critical and Shutdown LOOPs (1987–2021).

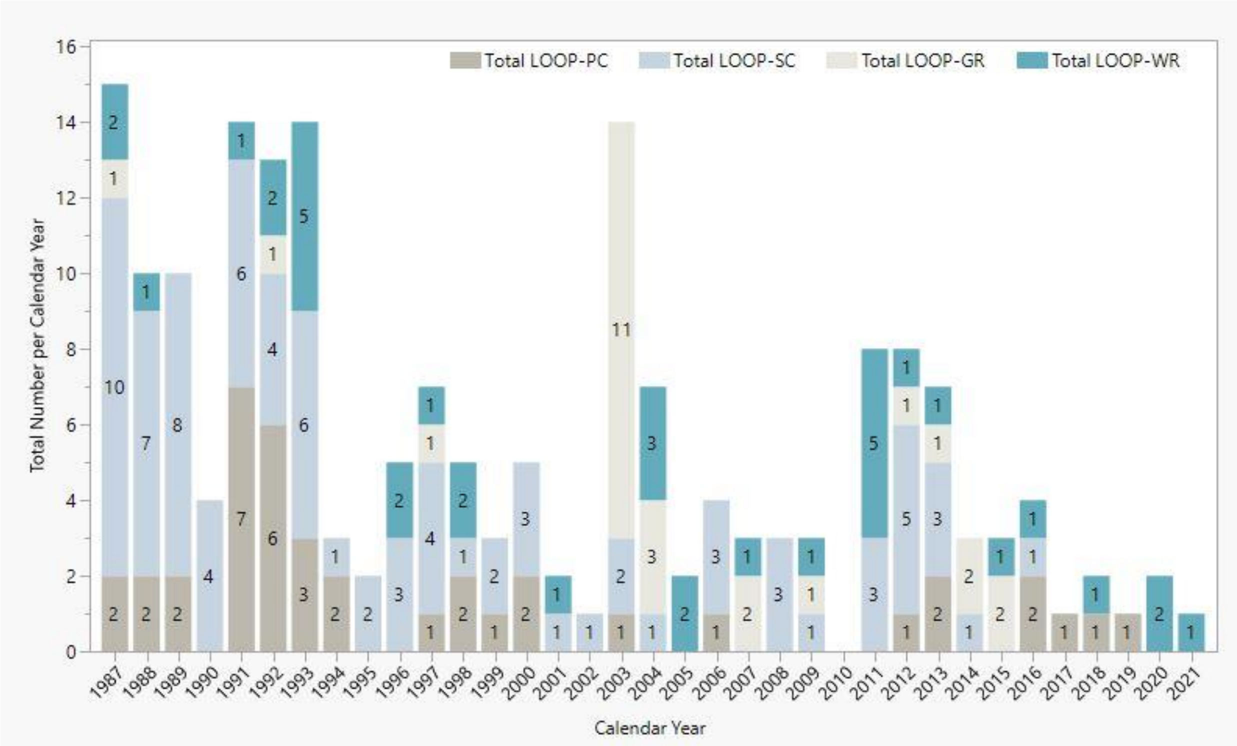


Figure 11. LOOP Event Counts by Category (1987–2021).

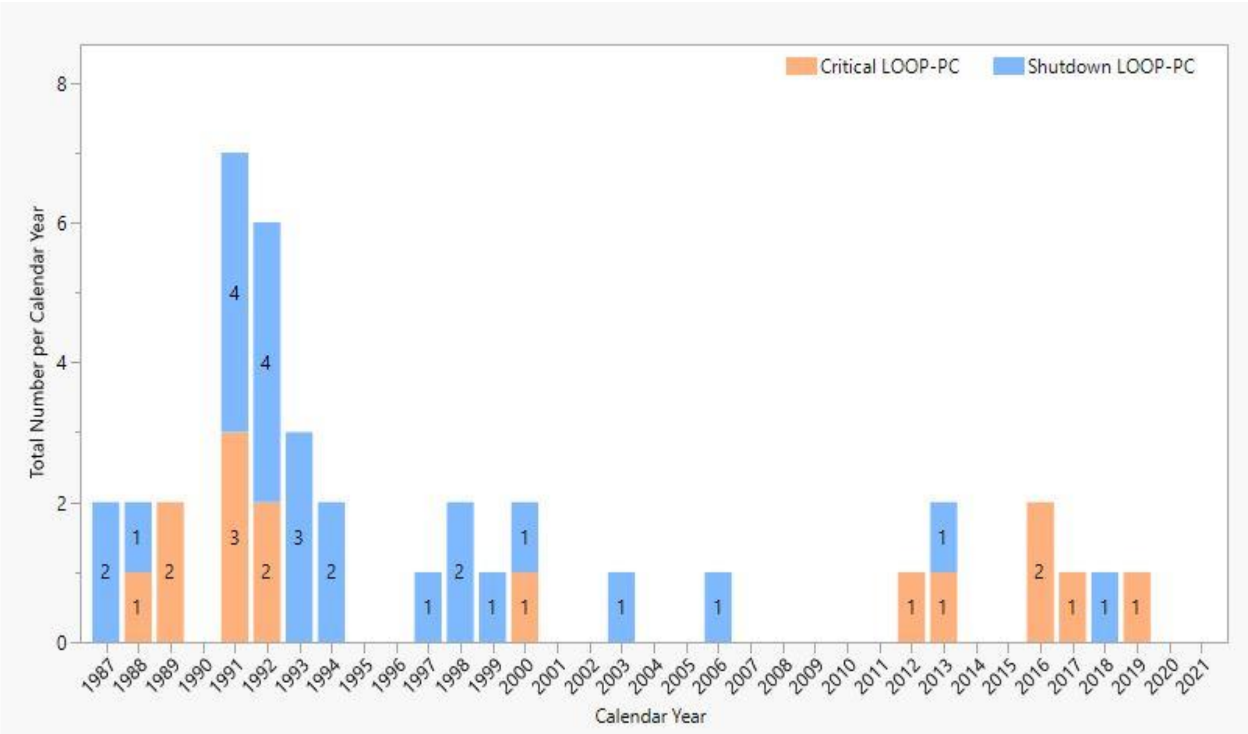


Figure 12. LOOPs-PC (1987–2021).

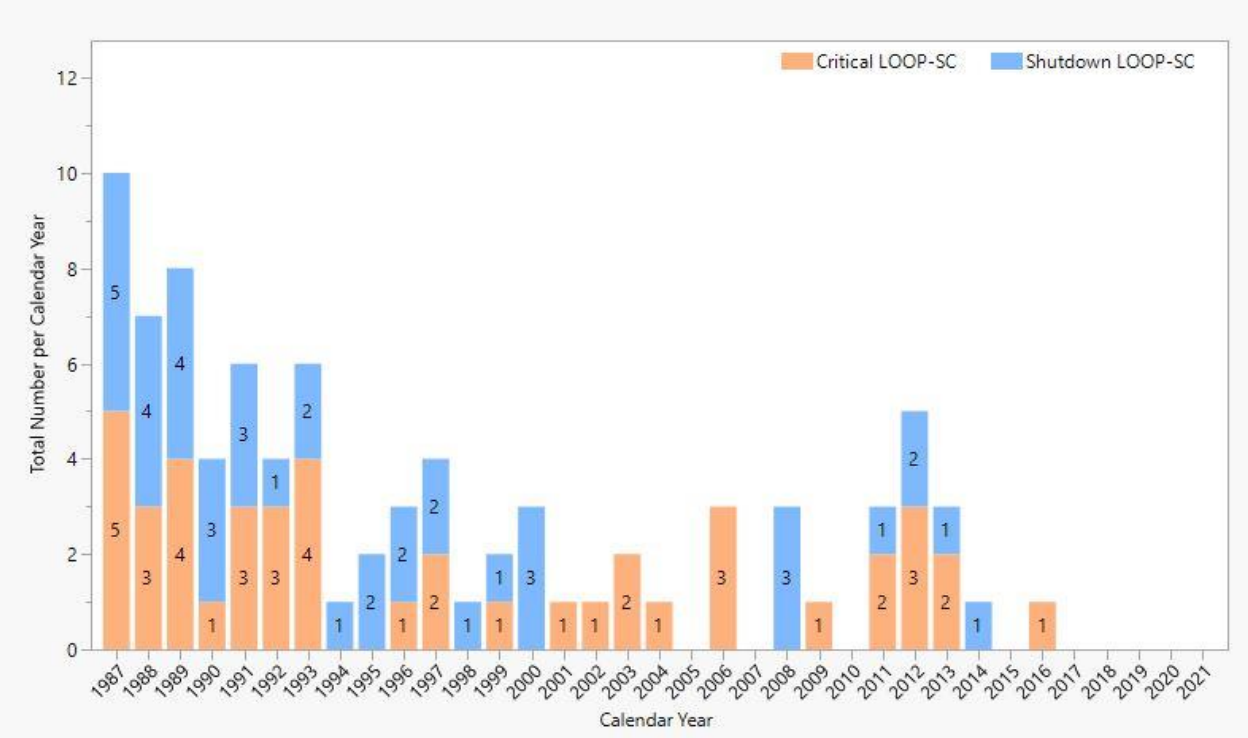


Figure 13. LOOPs-SC (1987–2021).

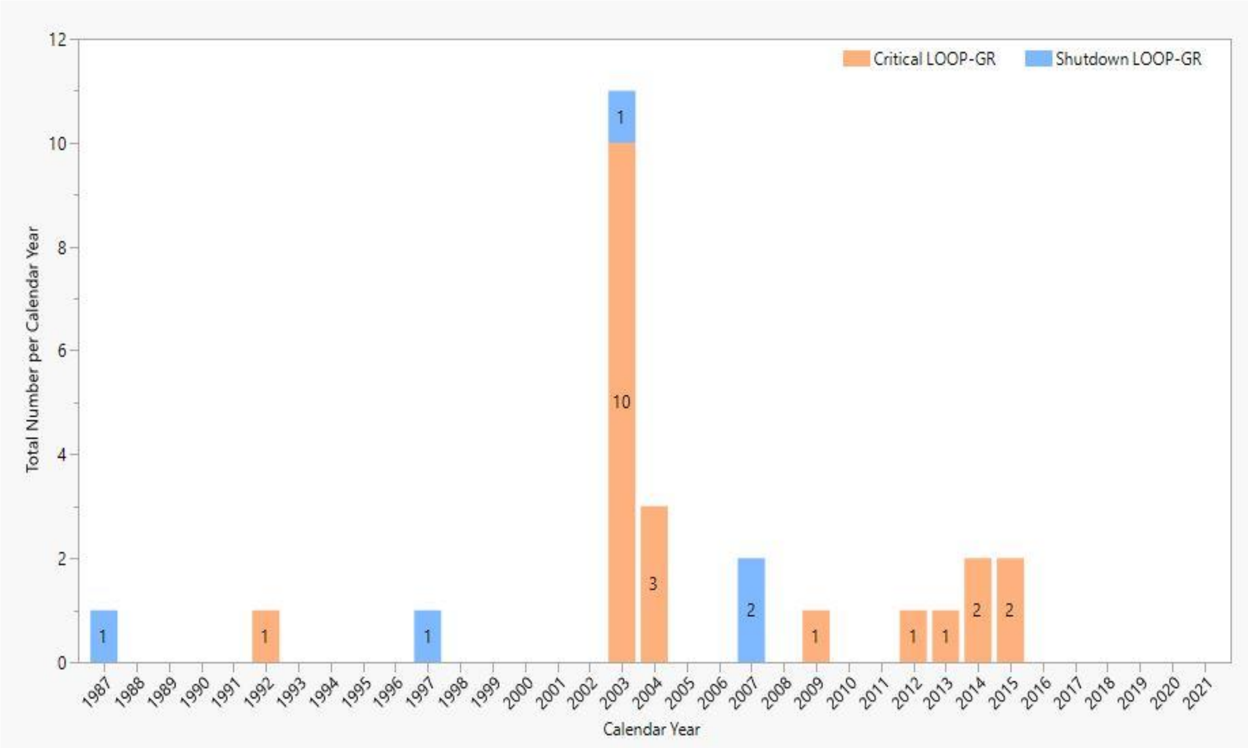


Figure 14. LOOPs-GR (1987–2021).

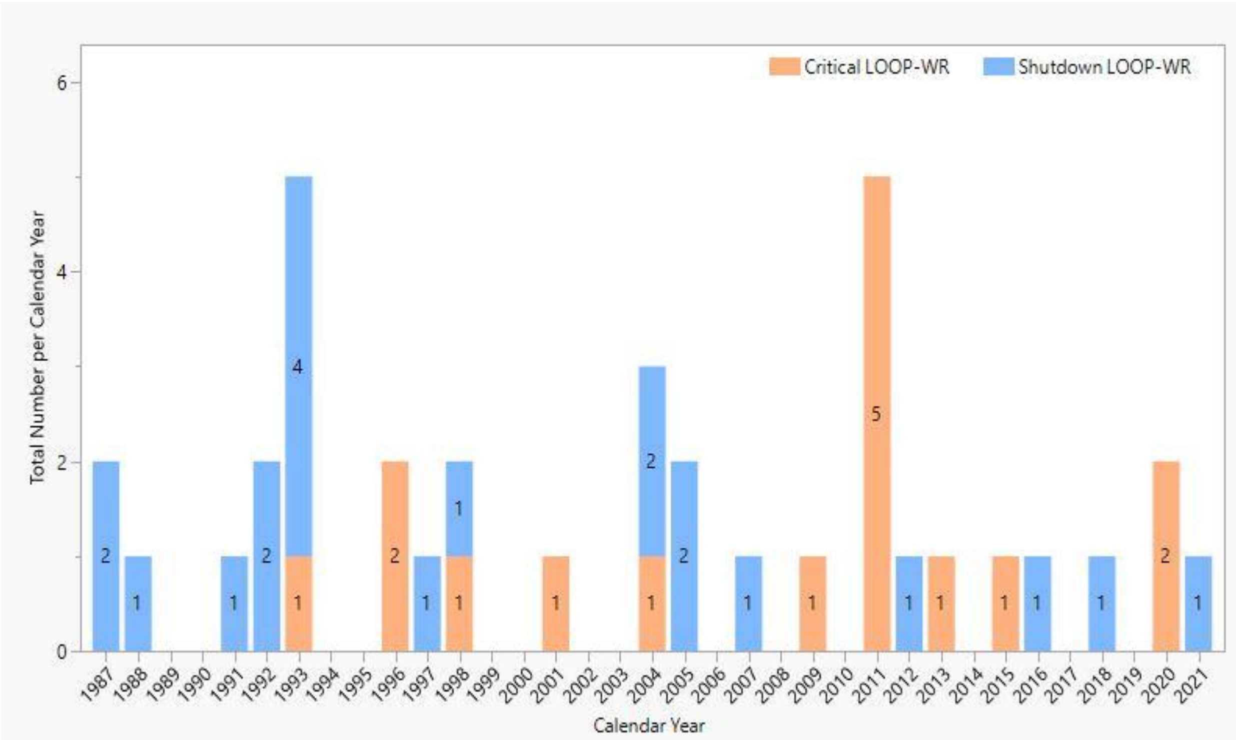


Figure 15. LOOPs-WR (1987–2021).

3. LOOP DURATION ANALYSIS

LOOP potential recovery times were selected as the parameter for modeling the duration of recovery times from LOOP. The recovery time is the duration, in minutes, from the event initiation until offsite electrical power could have been recovered to a safety bus (i.e., the potential bus restoration time). It is less than or equal to the actual bus restoration time (see the Glossary of this report and NUREG/CR-6890 for the discussions of the three LOOP recovery times: switchyard restoration time, potential bus restoration time, and actual bus restoration time).

When a LOOP event affects more than one unit at a site with multiple units, the duration of the event is defined as the time needed for all the affected units to be on offsite power. Thus, the duration associated with the plant unit with the longest duration time is the duration selected for the event. Individual unit duration times are not used in that situation in this study. This choice is based upon the assumption the plant unit-level LOOP events on a single day are not independent; therefore, the time to recovery at each plant unit should not be treated as independent.

Two analyses were performed in conjunction with these times. First, the data were analyzed to see if trends in the recovery times exist. Then, distributions characterizing the times were estimated.

3.1 Trends in Recovery Times

As in previous LOOP update studies, the recovery time data were evaluated for trends using the period since deregulation (1997–2021).

The recovery times for each LOOP category were trended using log linear regression. The recovery time trend data are shown in Figure 16; Table 8 provides the trend equations for each of the data subsets.

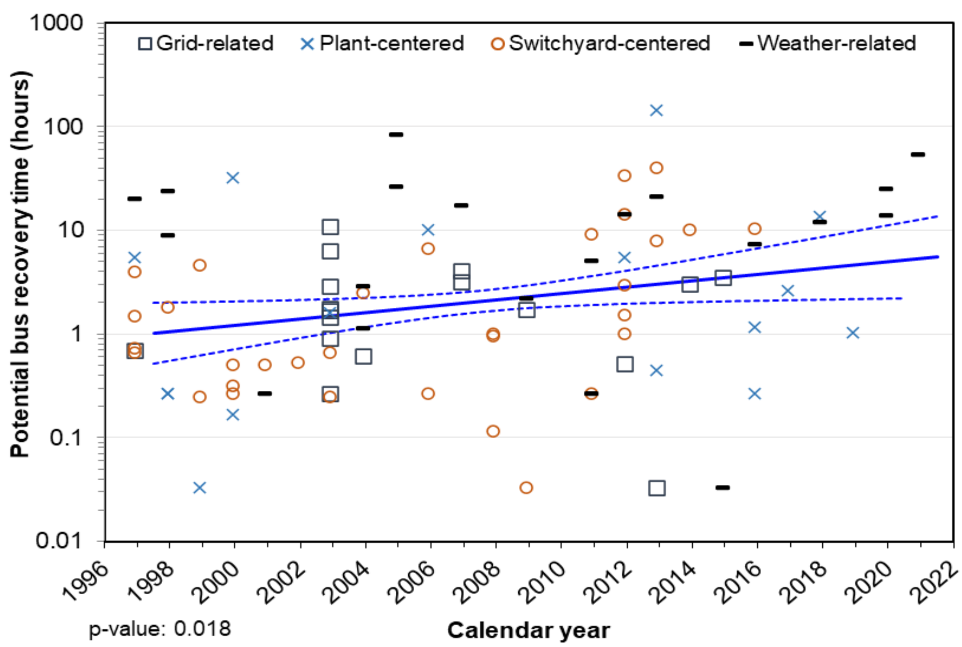


Figure 16. Statistically significant increasing trend for LOOP recovery times (all event types) from 1997–2021.

Table 8. Log linear regression of LOOP recovery times for the post-deregulation period (1997–2021).

LOOP Category	# of LOOP Events[b]	Trend Line Equation[a]	Standard Error of Slope	p-value	Trend and Significance
LOOP-PC	16	Exp(0.069 x (year-2021) +1.437)	0.07	0.322	No Trend
LOOP-SC	32	Exp(0.116 x (year-2021) +2.11)	0.05	0.016	Statistically Significant Increasing Trend
LOOP-GR	17	Exp(-0.038 x (year-2021) +-0.224)	0.07	0.591	No Trend
LOOP-WR	20	Exp(0.012 x (year-2021) +1.964)	0.06	0.849	No Trend
All-LOOPS	85	Exp(0.071 x (year-2021) +1.711)	0.03	0.018	Statistically Significant Increasing Trend
Critical Operation	47	Exp(0.036 x (year-2021) +0.886)	0.04	0.375	No Trend
Shutdown Operation	38	Exp(0.134 x (year-2021) +3.169)	0.04	0.003	Highly Statistically Significant Increasing Trend

[a] The best fitting regression line defined by exp(intercept + slope*(year difference)). The (year–2021) terms goes from -23 to 0.

[b] Multi-Unit LOOPs are counted as a single LOOP when evaluating LOOP recovery time (see the discussion at the beginning of this section).

The trend analysis of potential LOOP recovery times at the site level indicated:

- a statistically significant increasing trend for LOOPs-SC during all operations (p-value = 0.016)
- a statistically significant increasing trend for All-LOOPs during all operations (p-value = 0.018)
- a highly statistically significant increasing trend for All-LOOPs during shutdown operation (p-value = 0.003).

These increasing trends indicate that it takes longer to recover from the associated LOOP categories. They also highlight the possibility there may be underlying causes for the longer LOOP recoveries in the associated categories. There is no trend in recovery times for LOOPs-PC, LOOPs-GR, and LOOPs-WR during all operations, as well as for All-LOOPs during critical operation.

3.2 LOOP Recovery Times

This subsection presents the analysis on LOOP recovery times, or the probability of exceedance versus duration. For the study of LOOP duration, the largest possible data set was sought that could be considered representative of current operations. The presence of an adverse increasing trend in the duration data complicated the selection of a starting date. Using too much of the older data weights the durations in a non-conservative direction that cannot be considered representative of current industry conditions. Therefore, the largest population was sought with an end date in the most recent year that had a lognormal distribution. This resulted in using data from calendar years 1997 through 2021, since the data from 2007 through 2021 did not have a lognormal distribution. Also, in accordance with NUREG-6890, the data for shutdown and critical operations have been combined.

As in previous LOOP update studies, the lognormal family of distributions was selected to model variation in the recovery times. The exceedance probabilities (one minus the cumulative distribution function value) that come from these distributions are useful in PRAs where a failure event involves recovery times exceeding a specified number of hours.

For the LOOP recovery times in each category, lognormal distributions were fitted using a method that matches moments. More specifically, since the logarithms of lognormal data follow a normal distribution, the first step in identifying the best lognormal distribution for each set of data is to find the best underlying normal distribution. All the recovery times are greater than zero, so the natural logarithms of the data were computed. The underlying normal distribution mean (μ) is estimated by the average of these data, and the standard deviation (σ) is estimated by the sample standard deviation. For use in PRA analyses using Systems Analysis Programs for Hands-on Integrated Reliability Evaluations (SAPHIRE), the standard deviation of μ is computed as $\sigma/\sqrt{n}$, where n is the sample size. The standard deviation of σ is estimated by noting that, for normally distributed data, the sum of the squared deviations that form the numerator of the sample variance estimate, divided by the actual variance, has a chi-square distribution with (n − 1) degrees of freedom. The variance of this distribution is 2(n − 1). For any random variable X and constant, k, the variance of kX is k^2 times the variance of X. Therefore, the variance of the numerator sum is 2(n − 1) times the square of the actual variance. After some algebraic manipulations, the estimate of the standard deviation of σ is given as $\sigma/\sqrt{2(n-1)}$.

The parameters of the fitted lognormal distributions are provided in Table 9. The fitted lognormal density and cumulative distribution functions for the recovery times are as follows:[e]

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

$$F(t) = \Phi\left[\frac{\ln(t)-\mu}{\sigma}\right] = \text{Prob[potential recovery time <= t]} \quad (2)$$

Where:

t = offsite power potential bus recovery time

μ = mean of natural logarithms of data

σ = standard deviation of natural logarithms of data

Φ = cumulative distribution function.[f]

Note the values for μ and σ completely define the distribution; the lognormal median, mean, and 95th percentile of these distributions can then be found by direct calculation: exp(μ), exp(μ + σ^2/2), and exp(μ + 1.645σ), respectively.

[e] Equation 1 is a correction of the one in previous studies such as NUREG/CR-6890 and INL/EXT-18-45359.

[f] This term is a correction of the one in previous studies such as NUREG/CR-6890 and INL/EXT-18-45359, in which “error function” was used.

Table 9. Fitted lognormal recovery time distributions (1997–2021).

Parameter	PC	SC	GR	WR
LOOP event count	16	32	17	20
Mu (μ)	0.53	0.33	0.35	1.83
Standard error of μ	0.55	0.30	0.33	0.44
Sigma (σ)	2.19	1.69	1.36	1.99
Standard error of σ	0.39	0.21	0.23	0.31
Fitted median, hour	1.69	1.39	1.42	6.20
Fitted mean, hour	18.61	5.78	3.57	44.49
Fitted 95th percentile, hour	62.07	22.35	13.26	162.47
Error factor	36.71	16.14	9.35	26.19

The results show LOOPs-GR have the shortest recovery times with a mean value of 3.57 hours, while the LOOPs-WR have the longest recovery times with a mean value of more than 44 hours. The above results also present significant differences when comparing the results from the 2018 update (Johnson and Ma 2019) which used 1988–2018 data:

- Most LOOP categories have longer **mean** recovery times than the 2018 results: LOOPs-PC from 4.53 to 18.61 hours, LOOPs-SC from 3.53 to 5.78 hours, and LOOPs-WR from 40.98 to 44.49 hours. LOOPs-GR is the only category with a slightly shorter mean recovery time than the 2018 result, from 4.40 to 3.57 hours.
- It should also be noted that LOOPs-PC, LOOPs-SC, and LOOPs-WR have longer **median** recovery times than the 2018 results, but with a smaller degree than in the mean recovery times as shown the above: LOOPs-PC from 0.9 to 1.69 hours, LOOPs-SC from 1.16 to 1.39 hours, and LOOPs-WR from 5.62 to 6.20 hours . LOOPs-GR has a shorter median recovery time than the 2018 results: LOOPs-GR from 2.23 to 1.42 hours. The significant differences between the mean and median values (e.g., LOOPs-WR have a mean recovery time of about 44 hours versus a median value of about 6 hours) show that the events with very long recovery times skewed the results toward the right side.

The distributions in Table 9 Table 9. Fitted lognormal recovery time distributions (1997–2021).are plotted as probability of exceedance versus duration curve (1–F(t)) in Figure 17. The probability of LOOP duration exceeding T hours can be obtained either by calculating the distribution function of 1-F(t) or by drawing a vertical line at t = T hours in the plot and reading the intersect point values for non-recovery probabilities (within T hours) for different LOOP categories. Figure 17 shows visually the grid-related LOOPs have the shortest (on average) recovery times while the LOOPs-WR have the longest recovery times.

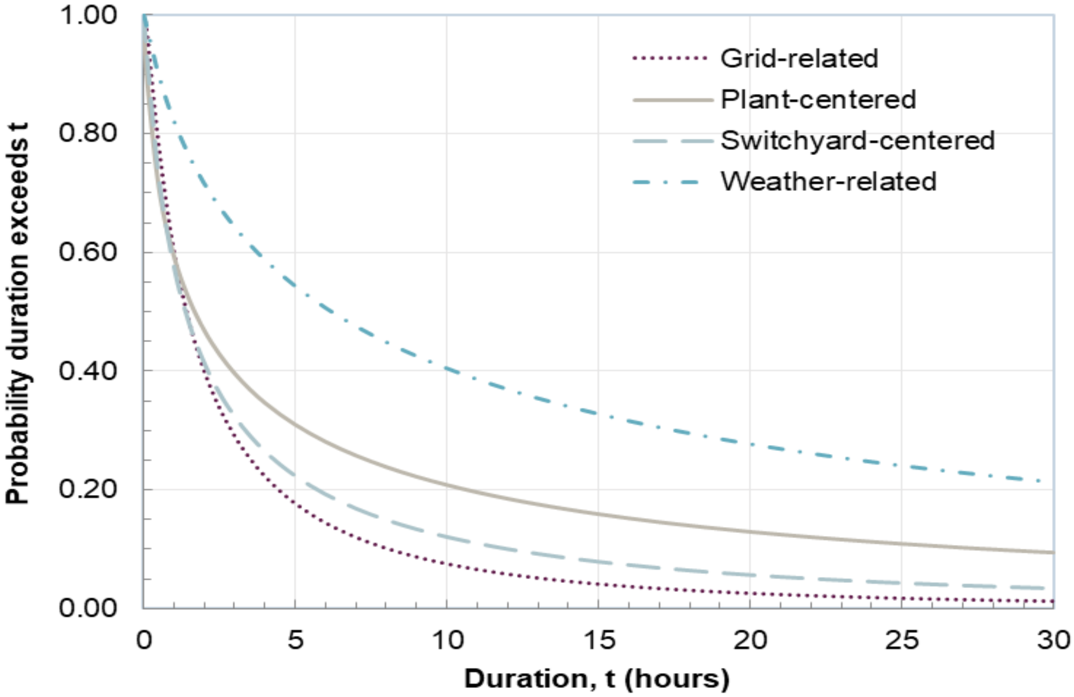


Figure 17. Probability of exceedance (non-recovery probability) vs. duration curves for all event types and operating modes (1997–2021).

4. SPECIAL TOPICS OF INTEREST

Several special topics are discussed in this section: seasonal variation in LOOP frequency, the effect of multi-unit LOOP events, and the consequential LOOP.

4.1 Seasonal Effects on LOOP Frequency

In 2003, Raughley and Lanik called attention to an emerging tendency for LOOPs-GR to occur during the summer:

> *This assessment noted that seven of the eight LOOPs (87%) involving a reactor trip since 1997 occurred in the summer—May to September—in contrast to 23 of 54 (44%) of LOOPs in the summers of 1985–1996. (Raughley and Lanik 2003)*

The authors did not perform a formal statistical test, but readers of their report found this early evidence compelling.

Table 10 shows LOOP counts from 2007 based on the month of occurrence, plant operating mode, and LOOP category.

The Rayleigh Test is a standard test for whether points are distributed uniformly around a circle (wind directions, fracture orientations) and adapts readily to testing whether a set of events are scattered uniformly through the year (Mardia and Jupp 2000). The test is applied separately for each column of Table 10.

Table 10. LOOP event counts by month and LOOP category by operating mode (2007–2021).

	Critical Operation				Shutdown Operation			
Month	PC	SC	GR	WR	PC	SC	GR	WR
Jan	0	2	0	1	0	0	0	0
Feb	1	0	0	1	0	1	0	1
Mar	1	0	0	0	1	1	0	1
Apr	2	2	2	5	0	2	1	0
May	0	1	2	0	1	1	1	0
Jun	0	0	0	0	0	0	0	0
Jul	1	1	2	0	0	0	0	0
Aug	1	2	0	3	0	0	0	1
Sep	0	0	0	0	0	0	0	0
Oct	0	1	1	0	0	1	0	2
Nov	0	0	0	0	0	1	0	0
Dec	0	0	0	0	0	1	0	0
p-values[a]	0.253	0.787	0.092	0.194	0.245	0.358	0.160	0.755

[a]Rayleigh Test.

Applying the Rayleigh test to the counts in Table 10 shows that the counts by LOOP category and by operating mode are uniformly distributed across the 12 months. The Rayleigh test indicates the counts are not uniform when $p < 0.05$.

Table 11 presents the LOOP counts by operating mode only, and the overall counts by month from 2007–2021 and the associated p-values from Rayleigh test, which shows the follow statistically significant results:

- the counts for LOOPs-GR during all operations are not uniformly distributed across the 12 months. The variation is statistically significant (p-value = 0.021)
- the counts for All-LOOPs during all operations are not uniformly distributed across the 12 months. The variation is highly statistically significant (p-value = 0.009)
- the counts for All-LOOPs during critical operation is not uniformly distributed across the 12 months. The variation is statistically significant (p-value = 0.012).

the counts for LOOP-WR during all operations, interestingly, are uniform across the calendar year, attributable to the combination of disparate WR events (snow/ice, tornados, lightning, hurricanes) being such that their impact evens out over the year.

Table 11 LOOP event total counts by month and by LOOP category or operating mode (2007–2021).

Month	LOOP Category				Operating Mode		All-LOOPs
	PC	SC	GR	WR	Critical	Shutdown	
Jan	0	2	0	1	3	0	3
Feb	1	1	0	2	2	2	4
Mar	2	1	0	1	1	3	4
Apr	2	4	3	5	11	3	14
May	1	2	3	0	3	3	6
Jun	0	0	0	0	0	0	0
Jul	1	1	2	0	4	0	4
Aug	1	2	0	4	6	1	7
Sep	0	0	0	0	0	0	0
Oct	0	2	1	2	2	3	5
Nov	0	1	0	0	0	1	1
Dec	0	1	0	0	0	1	1
p-values[a]	0.065	0.615	0.021	0.584	0.012	0.251	0.009

[a]Rayleigh Test.

4.2 Multi-Unit LOOP Events

Like NUREG/CR-6890 and previous annual LOOP updates, the analysis of LOOP events in this study is at the plant level (or unit level), in contrast to the site level or regional level. For example, if a single weather event causes both units at a site to experience a LOOP, it is counted as two unit-level LOOP events instead of one site-level LOOP event. This approach assumes the unit LOOP events are independent events. However, this is not consistent with experience , as demonstrated in the 2003 northeast blackout that affected nine units (eight in critical and one in shutdown) at seven sites.

Table 12 shows the multi-unit LOOP occurrences from 1987–2021 listed in chronological order. There were thirteen occasions during 1987–2006 and six occasions during 2007–2021 when more than one unit at a multi-unit site was affected by the same incident. The six occasions contributed 13 of the 49-unit events (from 2007–2021) counted in Table 4 (~27%), so that the simplifying assumption of treating each unit level LOOP as independent, may be questioned. This section presents an alternative means to address the multi-unit LOOP issue.

Table 12. Multi-unit LOOP events for 1987–2021.

Event	Site	Date	Units at Site	Units Affected	LOOP Category	Mode
1	Calvert Cliffs	1987-07-23	2	All	SC	Critical Operation
2	Peach Bottom	1988-07-29	2	All	SC	Shutdown Operation
3	Turkey Point	1992-08-24	2	All	WR	Shutdown Operation[1]
4	Sequoyah	1992-12-31	2	All	SC	Critical Operation
5	Brunswick	1993-03-17	2	All	WR	Shutdown Operation
6	Beaver Valley	1993-10-12	2	All	SC	Critical Operation/ Shutdown Operation
7	Prairie Island	1996-06-29	2	All	WR	Critical Operation
8	Fitzpatrick/Nine Mile Point 1	2003-08-14	2	All	GR	Critical Operation
9	Indian Point	2003-08-14	2	All	GR	Critical Operation
10	Peach Bottom	2003-09-15	2	All	GR	Critical Operation
11	Palo Verde	2004-06-14	3	All	GR	Critical Operation
12	St. Lucie	2004-09-25	2	All	WR	Shutdown Operation
13	Catawba	2006-05-20	2	All	SC	Critical Operation
14	Surry	2011-04-16	2	All	WR	Critical Operation
15	Browns Ferry	2011-04-27	3	All	WR	Critical Operation[2]
16	North Anna	2011-08-23	2	All	SC	Critical Operation
17	Lasalle	2013-04-17	2	All	SC	Critical Operation
18	Millstone[3,4]	2014-05-25	2	All	GR	Critical Operation
19	Calvert Cliffs	2015-04-07	2	All	GR	Critical Operation
Total			**40**	**40**		

[1]The units shut down in anticipation of bad weather. The weather events subsequently resulted in LOOPs at the site.

[2]Treated as though all three units experienced a LOOP, although a 161-kV offsite power line remained available for Browns Ferry 3. That unit also responded as though it, too, had experienced a LOOP. The # of units affected is changed from two to three in this study.

[3]Reclassified from SC to GR in the 2017 LOOP study (Johnson, Ma and Schroeder 2018).

[4]The number of units at the Millstone site is changed from three to two in this study. Millstone Unit 1 was decommissioned in June 1998. Any Millstone LOOP events that occurred after June 1998 should be treated as a dual-unit site instead of a three-unit site.

For multi-unit LOOP events, in general, there is a three-part question to be answered:

- First, what is the frequency of the underlying occurrence that led to the LOOP event?
- Second, how many sites were affected by the occurrence?
- Finally, how many units at each site were affected by the occurrence?

A qualitative analysis of the multi-unit LOOP event data provides the following insights:

- A LOOP-WR event is more likely to affect more than one unit at the same site within a few hours to a few days but is less likely to affect more than one site within a few hours to a few days.
- A LOOP-GR event could affect multiple sites, even sites hundreds of miles away (even as the likelihood of affecting two or more sites is low, the probability of affecting multiple sites is much higher than a simple Poisson approximation would imply) and usually affects all units at the same site.
- A LOOP-SC event may affect more than one unit at the same site, depending on where in the switchyard it happens, but should not affect other sites.
- A LOOP-PC event should not affect any other unit even at the same site.

From 2007 to 2021, there were 49 unit-level LOOP events, including 36 single-unit LOOP occurrences and six multi-unit events from the same occurrence, adding another 13 events. For 36 single-unit LOOPs, 18 occurred at single-unit sites, 15 occurred at two-unit sites, and three occurred at three-unit sites. For six multi-unit events, five involved both units at two-unit sites, and the other one involved all three units at a three-unit site. Table 13 shows the matrix of LOOP occurrences and unit-level LOOP events from 2007–2021, including LOOP events at multi-unit sites where only one unit shut down. In general, offsite power events affect multiple units, and as such, unit-based LOOP events are not independent.

Table 13. LOOP occurrences and unit-level LOOP events from 2007–2021.

Units/Site	**LOOP Occurrence**			**Unit-Level LOOP Events**
	Single-Unit	Two-Unit	Three-Unit	
Single	18	NA	NA	18
Two	15[a]	5	0	25
Three	3	0	1	6
Total	36	5	1	49

[a] Any Millstone LOOP occurrences after June 1998, when Millstone Unit 1 was decommissioned, are counted as LOOPs on a two-unit site instead of three-unit site. There were two single-unit LOOPs (April 25, 2007, at Millstone Unit 3 and May 24, 2008, at Millstone Unit 2) and one multi-unit LOOP (May 23, 2014, at Millstone Units 2 and 3) at the Millstone site which were categorized as being from a two-unit site.

Table 14 estimates the conditional probability of all units at a multi-unit site experiencing a LOOP if at least one unit experiences a LOOP. As shown in this table, a large portion of the LOOP events affect multiple units, which further reveals that unit-level LOOP events may not be independent.

Table 14. Conditional probability of all units at a multi-unit site experiencing a LOOP given a LOOP at one of the units using data from 2007–2021.

Loop Category	LOOP Event at Multi-Unit Sites Affecting All Units at the Site	LOOP Events at Multi-Unit Sites Affecting At Least One Unit	Conditional Probability of All Units at a Multi-Unit Site Experiencing a LOOP Given a LOOP at One Unit at the Site[1]				Beta Distribution Parameters	
			5%	Median	Mean	95%	α	β
LOOP-PC	0	7	2.71E-04	3.09E-02	6.25E-02	2.32E-01	0.5	7.5
LOOP-SC	2	10	6.02E-02	2.10E-01	2.27E-01	4.52E-01	2.5	8.5
LOOP-GR	2	4	1.65E-01	5.00E-01	5.00E-01	8.35E-01	2.5	2.5
LOOP-WR	2	3	2.36E-01	6.48E-01	6.25E-01	9.38E-01	2.50	1.50
All Events	6	24	1.30E-01	2.54E-01	2.60E-01	4.12E-01	6.5	18.5

[1]The beta distributions reflect the proportion of the events that affected the other units. The distributions are obtained by updating the Jeffreys noninformative beta distribution prior, beta (α, β) = beta (0.5, 0.5), with the row-specific data. Since the beta distribution is a conjugate distribution for binomial data, the updated distribution in each row is also a beta distribution (0.5 + number of events affecting all units, 0.5 + number of events affecting just one unit). The mean is α / (α + β) = (0.5 + all-unit event count) / (1 + total events).

The 2020 LOOP study (Johnson and Ma 2021) found an issue with prior years' reports in their estimation of the conditional probability of multi-unit LOOPs. For example, the 2018 LOOP study (Johnson and Ma 2019) used the site level LOOP event counts (the "LOOP Event at Multi-Unit Sites Affecting All Units at the Site" column of the table) and the unit level LOOP event counts at the multi-unit site (the "LOOP Events at Multi-Unit Sites Affecting At Least One Unit" column of the table) in the estimation of the conditional probability of multi-unit LOOPs, thus mixing unit level and site level in the same calculation. The mixed usage of the counts of unit level LOOPs and the counts of site level LOOPs in the conditional probability calculations is not correct. Instead, the counts of site level LOOPs should be used for both the numerator and the denominator. Table 14 shows the results of the conditional probability of multi-unit LOOPs using the corrected approach and the data from 2007–2021.

4.3 Consequential LOOPs

4.3.1 Consequential LOOP Given a Reactor Trip

NUREG/CR-6890 provides an estimate of conditional probabilities of a consequential LOOP (CLOOP) given a reactor trip, 5.3E–3 for the period 1997–2004 and 3.0E–3 for the period 1986–1996. The estimated conditional probability of 5.3E–3 has been used in the SPAR models to date. This study presents an update of the conditional probability using data from 2007–2021.

The estimation uses the same method as in NUREG/CR-6890 with the number of CLOOP events (LOOP-IE-C), the number of reactor trip, and the number of LOOP events that cause the reactor trip (LOOP-IE-I). The conditional probability of CLOOP given a reactor trip, $p(CLOOP|RT)$, is calculated as (Bayesian update with Jeffreys noninformative prior):

$$p(CLOOP|RT) = (n_{CLOOP} + 0.5)/[(\, n_{RT} - n_{LOOP-IE-I}) + 1] \qquad (10)$$

Where:

n_{CLOOP} = number of CLOOP events

n_{RT} = number of reactor trips (RTs)

$n_{LOOP-IE-I}$ = number of LOOP events that cause the reactor trip

There are currently six events classified as CLOOP events during the period 1987–2021: five CLOOPs from 1987–2006 and one CLOOP from 2007–2021 (see Table 15)[g]. For 1987–2005 period, there were 2,989 reactor trips, 56 of them caused by LOOP (i.e., 56 LOOP-IE-I events). For 2007–2021 period, there were 872 reactor trips, 21 of them caused by LOOP.

Table 15. Consequential LOOP events from 1987– 2021.

Event	LER	Plant Name	Date	LOOP Category
1	4551987019	Byron 2	10/2/1987	SC
2	3011989002	Point Beach 2	3/29/1989	SC
3	3951989012	Summer	7/11/1989	PC[a]
4	2371990002	Dresden 2	1/16/1990	SC
5	2191997010	Oyster Creek	8/1/1997	SC
6	4132012001	Catawba 1	4/4/2012	PC

[a] This event was recently reclassified from GR to PC in the 2020 update of this study (Johnson and Ma 2021)

Table 16 shows the updated conditional probabilities of CLOOP given a reactor trip: 1.76E–3 for the period of 2007–2021 and 1.87E–3 for the period of 1987–2006. The results of those from NUREG/CR-6890 and NUREG-1784 (Raughley and Lanik 2003) are also provided in the table for comparison.

Table 16. Conditional probability of consequential LOOP given reactor trip.

	This Study		**NUREG/CR-6890**		**NUREG-1784**[h]	
LOOP Classification	1987–2006	2007–2021	1986–1996	1997–2004	1985–1996	1997–2001
CLOOPs	5	1	6	3	7	2
Total Rx Trips (RTs)	2989	872	2,168	680	3,161	441
LOOP-Caused Rx Trips	56	21	32	19	Not Applied	
P(CLOOP|RT)	1.87E-03	1.76E-03	3.00E–03	5.30E–03	2.20E–03	4.50E–03

It should be noted the estimations of LOOP frequency in Section 0 include consequential LOOP events in the calculation. This presents a potential double-counting issue if a PRA models consequential LOOPs separately from LOOP initiating events. To address that double-counting, Table 17 presents the adjusted industry-average critical operation LOOP frequencies after consequential LOOP events are excluded from the estimations. The adjusted gamma mean value of LOOP-PC frequency is 3.98E–3/rcry, almost a 16% reduction from 4.70E–3/rcry (see Table 5) before the adjusting. There is no impact on LOOP-SC, LOOP-GR, and LOOP-WR

[g] NUREG/CR-6890 lists nine CLOOP events from 1986–2004, in which two CLOOPs that occurred in 1986 are outside of the period in this study, two CLOOPs (LERs 2471999015 and 4162003002) have been recoded and are no longer classified as CLOOPs. One new CLOOP (LER 4132012001) occurred after the study in NUREG/CR-6890. Note that two once classified as CLOOPs (LERs 3352016003 and 2962019001) were recoded and removed from the CLOOP category.

[h] NUREG-1784 does not exclude the LOOP-caused reactor trips from the CLOOP conditional probability estimations. Also, the estimation uses n(CLOOPs)/n(RTs) instead of the Bayesian update.

since there were no CLOOPs in these categories from 2007–2021. The overall critical operation LOOP frequency is 2.26E–2/rcry after the adjustment, a 3% reduction from 2.33E–2/rcry in Table 5Table 4.

Table 17. Adjusted industry-average critical operation LOOP frequencies after excluding consequential LOOP events (2007–2021).

LOOP Category	Events	Critical Years	Shape (α)	Scale (β)	Gamma Mean	Notes
LOOP-PC	5	1381.68	5.50	1381.68	3.98E-03	(a)
LOOP-SC	9	1381.68	9.50	1381.68	6.88E-03	(a)
LOOP-GR	7	1381.68	7.50	1381.68	5.43E-03	(a)
LOOP-WR	10	1381.68	0.69	94.30	7.26E-03	(b)
All	31	1388.68	0.97	42.93	2.26E-02	(b)

[a] Homogeneous. The data rule out the possibility of wide variations among plants. The Jeffreys noninformative prior is used.
[b] EB method was used There appears to be variability between plants.

4.3.2 Consequential LOOP Given a LOCA

Conditional probability of a consequential LOOP given a loss-of-coolant accident (LOCA) event was not estimated in NUREG/CR-6890 or previous annual LOOP analyses but rather in other technical reports. This subsection does not provide an updated analysis on conditional probability of a consequential LOOP given a LOCA, but rather presents the results from previous analyses. NUREG/CR-6538 (Martinez-Guridi et al. 1997) used data from 1984–1993 to estimate the conditional probability of a LOOP given a LOCA as 2.1E–2. A more recent Brookhaven National Laboratory report (Martinez-Guridi and Lehner, 2007) used data from Jan. 1, 1986, to July 31, 2007, and estimates the generic conditional probability of LOOP given a large break LOCA to be 2.0E–2.

5. ENGINEERING ANALYSIS OF LOOP DATA

LOOP events from an engineering perspective are considered in this section, qualitative insights into LOOP events, and LOOP events segregated according to specific cause.

5.1 Qualitative Insights of LOOP Events by Cause

LOOP events from 2007–2021 can be classified by cause. For example, what type of weather event caused a LOOP-WR or what kind of human activity caused a LOOP-PC. In the following figures, LOOP events are classified by the unit status as defined in the LOOP database: Power-Ops (LOOP occurred during power operation) and Shutdown (unit shutdown at time of LOOP with insignificant decay heat). The legacy category of Decay Heat (unit has significant decay heat and is not in low-pressure cooling) is no longer used as the few such events were reclassified as either Power-Ops or Shutdown events.

Figure 18 categorizes LOOP events from equipment failure by failed component. Sixteen out of 49 LOOP events from 2007–2021 were caused by equipment. The largest subcategories are failed relays and other.

In Figure 19, LOOP events from human error are tallied according to the type of activity in progress at the time. There have been very few LOOPs from human error since 2007 (six out of 49 events).The most common events of this cause have been maintenance and switching.

Figure 20 categorizes LOOP-WR events by the type of natural disaster. Twenty-two out of 49, almost 45%, of the LOOP events from 2007–2021 were caused by natural hazards. The most common events of this cause have been tornadoes followed by lightning and hurricane.

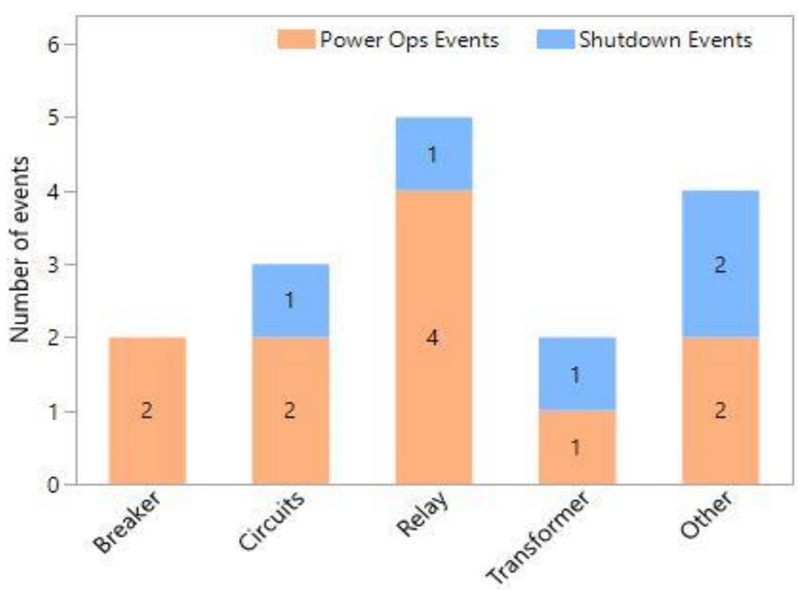


Figure 18. Failed components causing LOOP events from equipment failures (2007–2021).

Figure 19. Activities causing LOOP events from human error (2007–2021).

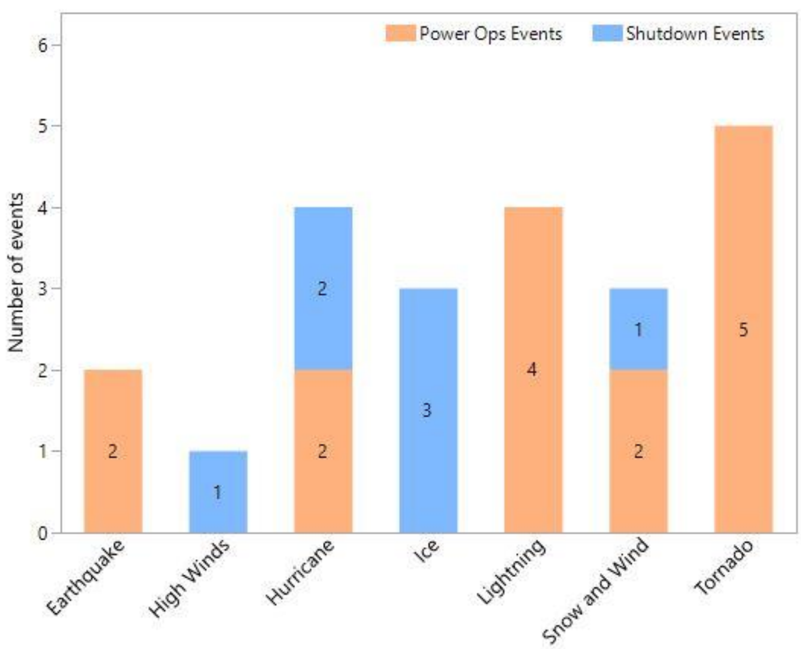


Figure 20. Natural disasters causing LOOP events from weather (2007–2021).

6. REFERENCES

Eide, S, C D Gentillon, T E Wierman, and D M Rasmuson. 2005. *Reevaluation of Station Blackout Risk at Nuclear Power Plants.* NUREG/CR-6890, Nuclear Regulatory Commission. https://www.nrc.gov/reading-rm/doc-collections/nuregs/contract/cr6890/index.html.

Johnson, N., and Z. Ma. 2019. *Analysis of Loss-of-Offsite-Power Events: 1987–2018.* INL/EXT-19-54699, Idaho National Laboratory.

Johnson, N., Z. Ma, and J.A. Schroeder. 2018. *Analysis of Loss-of-Offsite-Power Events: 1987–2017.* INL/EXT-18-45359, Idaho National Laboratory. doi:https://doi.org/10.2172/1468434.

Johnson, Nancy, and Zhegang Ma. 2021. *Analysis of Loss-of-Offsite-Power Events 2020 Update.* INL/EXT-21-64151, Idaho National Laboratory.

Johnson, Nancy, and Zhegang Ma. 2021. *Initiating Event Rates at U.S. Nuclear Power Plants, 2020 Update.* INL/EXT-21-63577, Idaho National Laboratory.

Ma, Z. 2019. *Enhanced Component Performance Study: Emergency Diesel Generators 1998-2018.* INL/EXT-19-54609, Idaho National Laboratory. doi:10.2172/1631738.

Ma, Z. 2022. *Enhanced Component Performance Study: Emergency Diesel Generators 1998-2020.* INL/RPT-22-66601, Idaho National Laboratory.

Ma, Z., T. E. WAierman, and K. J. Kvarfordt. November 2021. *Industry-Average Performance for Components and Initiating Events at U.S. Commercial Nuclear Power Plants: 2020 Update.* INL/EXT-21-65055, Idaho National Laboratory.

Mardia, K., and P. Jupp. 2000. *Directional Statistics, 2nd Ed.* Chichester: John Wiley & Sons Ltd.

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

Appendix A
LOOP Events Listing (1987–2021)

Page intentionally left blank

Appendix A
LOOP Events Listing (1987–2021)

LOOP events were identified from licensee event reports (LERs) for 1987–2021. These events are listed in this appendix along with an explanation of the column's heading for the tables. Two tables are displayed, each representing a different breakdown of the information. The two tables are summarized below:

Table A-1	Listing of all LOOP events for 1987–2021, sorted by plant name.
Table A-2	Like Table A-1 but with information concerning the uncertainty in each of the three restoration times listed.

Explanation of Column Headers for tables A-1 and A-2:

LER	The LER number describing the LOOP Event.
Plant Name	The name of the plant that experienced the LOOP event.
Date	The date of the LOOP event.
Operating Mode	Power-Ops or Critical - The LOOP event caused a plant trip during power operation. Shutdown - The LOOP event occurred during plant hot or cold shutdown or during plant startup. The Decay Heat mode defined in NUREG/CR-6890 (the plant is at a significant decay-heat point after the scram or shutdown, and it is not able to put a low-pressure shutdown cooling system online) is included in the Shutdown mode in this study.
LOOP Category	See the Glossary for detailed information on the four LOOP categories: GR (grid related), PC (plant centered), SC (switchyard centered), and WR (weather related).
LOOP Class	See the Glossary for detailed information on the LOOP classes: LOOP-IE-I, LOOP-IE-C, LOOP-IE-NC, and LOOP-SD.
Restoration Time	See the Glossary for detailed information on the three restoration times: Switchyard Restoration Time, Potential Bus Recovery Time, and Actual Bus Restoration Time.
Cause	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 HE - Human error during any operating mode HES - Human error during any shutdown mode SEE - Severe external events: lightening, high winds (< 125 mph), snow and ice, salt spray, dust contamination, fires and smoke contamination, earthquake < R7, flooding < 500-year flood for the site

A specific cause is based on the selection of the Cause. Specific causes are listed below.

Cause	Specific Cause	Specific Cause Description
EEE	Earthquake ≥ 7.0	Earthquake ≥ 7.0 on the Richter Scale
EEE	Flooding ≥ 500 year	Flooding ≥ 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	Earthquake < 7.0 on the Richter Scale

Cause	**Specific Cause**	**Specific Cause Description**
SEE	Fire	Fire
SEE	Flooding	Flooding < 500-year flood for the site
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

Restoration time uncertainties include:

C Known - The restoration time is certain.
U Unknown - No information is available concerning the restoration time.
E Estimated - The restoration time was estimated based on information in the LER.

Table A- 1. LOOP events for 1987–2021, sorted by plant.

LER	Plant Name	Date	Operating Mode	LOOP Category	LOOP Class	Restoration Time (minutes): Switchyard Restoration Time	Restoration Time (minutes): Potential Bus Recovery Time	Restoration Time (minutes): Actual Bus Restoration Time	Cause	Specific Cause
3132013001	Arkansas 1	3/31/2013	Shutdown	PC	LOOP-SD	unk.	8640	8640	HES	Other
3341993013	Beaver Valley 1	10/12/1993	Critical	SC	LOOP-IE-I	15	28	28	HES	Maintenance
4121987036	Beaver Valley 2	11/17/1987	Critical	SC	LOOP-IE-I	0	4	4	Equip	Breaker
3341993013	Beaver Valley 2	10/12/1993	Shutdown	SC	LOOP-SD	15	28	28	HES	Maintenance
1551992000	Big Rock Point	1/29/1992	Shutdown	SC	LOOP-SD	77	82	82	Equip	Other
4561987048	Braidwood 1	9/11/1987	Shutdown	SC	LOOP-SD	62	63	63	Equip	Transformer
4561988022	Braidwood 1	10/16/1988	Critical	SC	LOOP-IE-I	95	118	213	Equip	Breaker
4561998003	Braidwood 1	9/6/1998	Shutdown	WR	LOOP-SD	528	533	533	SEE	High Winds
4572009002	Braidwood 2	7/30/2009	Critical	SC	LOOP-IE-I	1	2	3097	Equip	Relay
2592011001	Browns Ferry 1	4/27/2011	Critical	WR	LOOP-IE-I	1	16	7414	EEE	Tornado
2592011001	Browns Ferry 2	4/27/2011	Critical	WR	LOOP-IE-I	1	16	7414	EEE	Tornado
2961997001	Browns Ferry 3	3/5/1997	Shutdown	SC	LOOP-SD	39	44	44	Equip	Transformer
2592011001	Browns Ferry 3	4/27/2011	Critical	WR	LOOP-IE-I	1	16	7414	EEE	Tornado
2962012003	Browns Ferry 3	5/22/2012	Critical	SC	LOOP-IE-I	86	91	101	Equip	Relay
2962019001	Browns Ferry 3	3/9/2019	Critical	PC	LOOP-IE-NC	60	62	781	HE	Switching
3251993008	Brunswick 1	3/17/1993	Shutdown	WR	LOOP-SD	1120	1125	1508	SEE	Salt Spray
3252000001	Brunswick 1	3/3/2000	Shutdown	SC	LOOP-SD	15	30	136	HES	Testing
3252004002	Brunswick 1	8/14/2004	Critical	WR	LOOP-IE-I	167	172	183	EEE	Hurricane

LER	Plant Name	Date	Operating Mode	LOOP Category	LOOP Class	Restoration Time (minutes): Switchyard Restoration Time	Restoration Time (minutes): Potential Bus Recovery Time	Restoration Time (minutes): Actual Bus Restoration Time	Cause	Specific Cause
3252016001	Brunswick 1	2/7/2016	Critical	PC	LOOP-IE-I	1	16	196	Equip	Breaker
3252020003	Brunswick 1	8/3/2020	Critical	WR	LOOP-IE-I	838	839	898	EEE	Hurricane
3241989009	Brunswick 2	6/17/1989	Critical	SC	LOOP-IE-I	85	90	403	HE	Maintenance
3251993008	Brunswick 2	3/16/1993	Shutdown	WR	LOOP-SD	813	818	1018	SEE	Salt Spray
3241994008	Brunswick 2	5/21/1994	Shutdown	PC	LOOP-SD	2	17	42	HES	Testing
3242006001	Brunswick 2	11/1/2006	Critical	SC	LOOP-IE-I	1	16	1456	Equip	Transformer
4541996007	Byron 1	5/23/1996	Shutdown	SC	LOOP-SD	715	720	1763	Equip	Transformer
4542014003	Byron 1	3/15/2014	Shutdown	SC	LOOP-SD	613	613	613	Equip	Transformer
4551987019	Byron 2	10/2/1987	Critical	SC	LOOP-IE-C	1	16	507	HES	Switching
4542012001	Byron 2	1/30/2012	Critical	SC	LOOP-IE-I	1	2035	2172	Equip	Transformer
3171987012	Calvert Cliffs 1	7/23/1987	Critical	SC	LOOP-IE-I	113	118	118	Equip	Circuits
3172015002	Calvert Cliffs 1	4/7/2015	Critical	GR	LOOP-IE-I	200	210	210	G	Equip - other
3171987012	Calvert Cliffs 2	7/23/1987	Critical	SC	LOOP-IE-I	113	118	118	Equip	Circuits
3172015002	Calvert Cliffs 2	4/7/2015	Critical	GR	LOOP-IE-NC	19	29	29	G	Equip - other
4132006001	Catawba 1	5/20/2006	Critical	SC	LOOP-IE-I	385	400	542	Equip	Circuits
4132012001	Catawba 1	4/4/2012	Critical	PC	LOOP-IE-C	325	326	326	Equip	Circuits
4141996001	Catawba 2	2/6/1996	Critical	SC	LOOP-IE-I	115	120	330	Equip	Transformer
4132006001	Catawba 2	5/20/2006	Critical	SC	LOOP-IE-I	372	387	570	Equip	Circuits
4132012001	Catawba 2	4/4/2012	Shutdown	SC	LOOP-SD	60	61	393	Equip	Circuits

LER	Plant Name	Date	Operating Mode	LOOP Category	LOOP Class	Restoration Time (minutes): Switchyard Restoration Time	Restoration Time (minutes): Potential Bus Recovery Time	Restoration Time (minutes): Actual Bus Restoration Time	Cause	Specific Cause
4611999002	Clinton 1	1/6/1999	Shutdown	SC	LOOP-SD	270	275	492	Equip	Other
3971989016	Columbia	5/14/1989	Shutdown	SC	LOOP-SD	0	15	29	HES	Maintenance
3151991004	Cook 1	5/12/1991	Critical	PC	LOOP-IE-I	0	15	81	Equip	Other
3021987025	Crystal River 3	10/16/1987	Shutdown	SC	LOOP-SD	18	28	59	HES	Maintenance
3021989023	Crystal River 3	6/16/1989	Critical	SC	LOOP-IE-I	60	65	65	HE	Testing
3021989025	Crystal River 3	6/29/1989	Shutdown	SC	LOOP-SD	0	2	2	SEE	Lightning
3021991010	Crystal River 3	10/20/1991	Shutdown	PC	LOOP-SD	0	4	4	HES	Other
3021992001	Crystal River 3	3/27/1992	Critical	PC	LOOP-IE-I	20	30	150	HE	Maintenance
3021993000	Crystal River 3	3/17/1993	Shutdown	WR	LOOP-SD	72	77	102	SEE	Salt Spray
3021993002	Crystal River 3	3/29/1993	Shutdown	WR	LOOP-SD	0	15	37	SEE	Flooding
3021993004	Crystal River 3	4/8/1993	Shutdown	PC	LOOP-SD	1	16	136	HES	Maintenance
3461998006	Davis-Besse	6/24/1998	Critical	WR	LOOP-IE-I	1364	1428	1495	EEE	Tornado
3462000004	Davis-Besse	4/22/2000	Shutdown	PC	LOOP-SD	5	10	10	HES	Testing
3462003009	Davis-Besse	8/14/2003	Shutdown	GR	LOOP-SD	652	657	849	G	Other - load
2751991004	Diablo Canyon 1	3/7/1991	Shutdown	SC	LOOP-SD	261	285	285	HES	Maintenance
2751995014	Diablo Canyon 1	10/21/1995	Shutdown	SC	LOOP-SD	40	45	951	HES	Maintenance
2752000004	Diablo Canyon 1	5/15/2000	Critical	PC	LOOP-IE-I	1901	1906	2014	Equip	Other
2752007001	Diablo Canyon 1	5/12/2007	Shutdown	GR	LOOP-SD	209	245	279	Equip	Other
3231988008	Diablo Canyon 2	7/17/1988	Critical	SC	LOOP-IE-I	33	38	38	Equip	Transformer

LER	Plant Name	Date	Operating Mode	LOOP Category	LOOP Class	Restoration Time (minutes) Switchyard Restoration Time	Potential Bus Recovery Time	Actual Bus Restoration Time	Cause	Specific Cause
2371990002	Dresden 2	1/16/1990	Critical	SC	LOOP-IE-C	0	45	759	Equip	Transformer
2491989001	Dresden 3	3/25/1989	Critical	SC	LOOP-IE-I	45	50	50	Equip	Breaker
2492004003	Dresden 3	5/5/2004	Critical	SC	LOOP-IE-I	146	151	151	Equip	Breaker
3311990007	Duane Arnold	7/9/1990	Shutdown	SC	LOOP-SD	0	37	37	HES	Testing
3312007004	Duane Arnold	2/24/2007	Shutdown	WR	LOOP-SD	5	1048	1829	SEE	Ice
3312020001	Duane Arnold	8/10/2020	Critical	WR	LOOP-IE-I	1514	1515	1634	EEE	Hurricane
3482000005	Farley 1	4/9/2000	Shutdown	SC	LOOP-SD	18	19	19	Equip	Relay
3412003002	Fermi 2	8/14/2003	Critical	GR	LOOP-IE-I	379	384	582	G	Other - load
3331988011	FitzPatrick	10/31/1988	Shutdown	WR	LOOP-SD	1	16	70	SEE	High Winds
3332003001	FitzPatrick	8/14/2003	Critical	GR	LOOP-IE-I	169	174	414	G	Other - load
3332012005	FitzPatrick	10/5/2012	Shutdown	SC	LOOP-SD	847	847	847	HE	Maintenance
2851987008	Fort Calhoun	3/21/1987	Shutdown	SC	LOOP-SD	37	38	38	HES	Maintenance
2851987009	Fort Calhoun	4/4/1987	Shutdown	SC	LOOP-SD	0	4	4	HES	Maintenance
2851990006	Fort Calhoun	2/26/1990	Shutdown	SC	LOOP-SD	0	14	14	HES	Maintenance
2851998005	Fort Calhoun	5/20/1998	Shutdown	SC	LOOP-SD	104	109	109	Equip	Transformer
2851999004	Fort Calhoun	10/26/1999	Shutdown	PC	LOOP-SD	2	2	2	Equip	Other
2442003002	Ginna	8/14/2003	Critical	GR	LOOP-IE-I	49	54	297	G	Other - load
4162003002	Grand Gulf	4/24/2003	Critical	SC	LOOP-IE-NC	1	15	75	SEE	High Winds
2131993009	Haddam Neck	6/22/1993	Shutdown	PC	LOOP-SD	12	27	35	Equip	Circuits

LER	Plant Name	Date	Operating Mode	LOOP Category	LOOP Class	Restoration Time (minutes): Switchyard Restoration Time	Restoration Time (minutes): Potential Bus Recovery Time	Restoration Time (minutes): Actual Bus Restoration Time	Cause	Specific Cause
2131993010	Haddam Neck	6/26/1993	Shutdown	PC	LOOP-SD	3	18	40	Equip	Circuits
4002016005	Harris	10/8/2016	Shutdown	WR	LOOP-SD	unk.	443	524	EEE	Hurricane
2471991006	Indian Point 2	3/20/1991	Shutdown	SC	LOOP-SD	0	15	29	Equip	Other
2471991010	Indian Point 2	6/22/1991	Shutdown	PC	LOOP-SD	0	60	60	Equip	Breaker
2471998013	Indian Point 2	9/1/1998	Shutdown	PC	LOOP-SD	1	16	67	HES	Testing
2471999015	Indian Point 2	8/31/1999	Critical	SC	LOOP-IE-NC	1	15	779	Equip	Circuits
2472003005	Indian Point 2	8/14/2003	Critical	GR	LOOP-IE-I	97	102	214	G	Other - load
2861995004	Indian Point 3	2/27/1995	Shutdown	SC	LOOP-SD	30	40	132	HES	Maintenance
2861996002	Indian Point 3	1/20/1996	Shutdown	SC	LOOP-SD	30	40	145	Equip	Transformer
2861997008	Indian Point 3	6/16/1997	Shutdown	GR	LOOP-SD	37	42	42	HE	Maintenance
2862003005	Indian Point 3	8/14/2003	Critical	GR	LOOP-IE-I	97	102	241	G	Other - load
3731993015	La Salle 1	9/14/1993	Critical	SC	LOOP-IE-I	0	15	70	Equip	Transformer
3732013002	La Salle 1	4/17/2013	Critical	SC	LOOP-IE-NC	481	481	482	SEE	Lightning
3732013002	La Salle 2	4/17/2013	Critical	SC	LOOP-IE-NC	481	481	482	SEE	Lightning
3091988006	Maine Yankee	8/13/1988	Critical	SC	LOOP-IE-I	14	15	15	Equip	Transformer
3691987021	McGuire 1	9/16/1987	Shutdown	PC	LOOP-SD	0	6	6	HES	Testing
3691991001	McGuire 1	2/11/1991	Critical	PC	LOOP-IE-I	0	40	60	HE	Testing
3691988014	McGuire 2	6/24/1988	Shutdown	SC	LOOP-SD	8	8	8	HES	Switching
3701993008	McGuire 2	12/27/1993	Critical	SC	LOOP-IE-I	96	101	131	Equip	Transformer

LER	Plant Name	Date	Operating Mode	LOOP Category	LOOP Class	Restoration Time (minutes) Switchyard Restoration Time	Potential Bus Recovery Time	Actual Bus Restoration Time	Cause	Specific Cause
2451989012	Millstone 1	4/29/1989	Shutdown	SC	LOOP-SD	0	15	75	HES	Other
3361988011	Millstone 2	10/25/1988	Critical	PC	LOOP-IE-I	19	29	29	HE	Maintenance
3362008004	Millstone 2	5/24/2008	Shutdown	SC	LOOP-SD	57	57	1612	G	Equip - other
3362014006	Millstone 2	5/25/2014	Critical	GR	LOOP-IE-NC	179	184	209	Equip	Other
4232007002	Millstone 3	4/25/2007	Shutdown	GR	LOOP-SD	133	193	220	HES	Switching
3362014006	Millstone 3	5/25/2014	Critical	GR	LOOP-IE-NC	179	184	209	Equip	Other
2202003002	Nine Mile Pt. 1	8/14/2003	Critical	GR	LOOP-IE-NC	105	110	448	G	Other - load
4101988062	Nine Mile Pt. 2	12/26/1988	Shutdown	SC	LOOP-SD	9	24	54	Equip	Transformer
4101992006	Nine Mile Pt. 2	3/23/1992	Shutdown	PC	LOOP-SD	20	30	50	HES	Maintenance
4102003002	Nine Mile Pt. 2	8/14/2003	Critical	GR	LOOP-IE-I	100	105	551	G	Other - load
3382011003	North Anna 1	8/23/2011	Critical	SC	LOOP-IE-NC	467	547	547	SEE	Earthquake
3382011003	North Anna 2	8/23/2011	Critical	SC	LOOP-IE-NC	467	547	547	SEE	Earthquake
2701992004	Oconee 2	10/19/1992	Critical	PC	LOOP-IE-I	207	207	207	HE	Maintenance
2871987002	Oconee 3	3/5/1987	Shutdown	SC	LOOP-SD	150	155	155	HES	Maintenance
2872006001	Oconee 3	5/15/2006	Shutdown	PC	LOOP-SD	606	606	1730	HES	Maintenance
2872018002	Oconee 3	5/10/2018	Shutdown	PC	LOOP-SD	807	807	807	Equip	Relay
2191989015	Oyster Creek	5/18/1989	Critical	PC	LOOP-IE-I	1	16	54	HE	Maintenance
2191992005	Oyster Creek	5/3/1992	Critical	GR	LOOP-IE-I	5	65	1029	SEE	Fire
2191997010	Oyster Creek	8/1/1997	Critical	SC	LOOP-IE-C	30	40	40	Equip	Relay

LER	Plant Name	Date	Operating Mode	LOOP Category	LOOP Class	Restoration Time (minutes) Switchyard Restoration Time	Potential Bus Recovery Time	Actual Bus Restoration Time	Cause	Specific Cause
2192009005	Oyster Creek	7/12/2009	Critical	GR	LOOP-IE-I	94	103	103	SEE	Lightning
2192012001	Oyster Creek	7/23/2012	Critical	GR	LOOP-IE-I	1	31	88	Equip	Relay
2192012002	Oyster Creek	10/29/2012	Shutdown	WR	LOOP-SD	861	861	861	SEE	High Winds
2551987024	Palisades	7/14/1987	Critical	SC	LOOP-IE-I	388	388	446	HE	Maintenance
2551992032	Palisades	4/6/1992	Shutdown	PC	LOOP-SD	0	15	30	HES	Testing
2551998013	Palisades	12/22/1998	Shutdown	PC	LOOP-SD	1	16	20	Equip	Transformer
2552003003	Palisades	3/25/2003	Shutdown	PC	LOOP-SD	91	96	3261	HES	Maintenance
5282004006	Palo Verde 1	6/14/2004	Critical	GR	LOOP-IE-I	32	37	57	G	Equip - other
5282004006	Palo Verde 2	6/14/2004	Critical	GR	LOOP-IE-I	32	37	106	G	Equip - other
5282004006	Palo Verde 3	6/14/2004	Critical	GR	LOOP-IE-I	32	37	59	G	Equip - other
2771988020	Peach Bottom 2	7/29/1988	Shutdown	SC	LOOP-SD	9	24	125	Equip	Transformer
2772003004	Peach Bottom 2	9/15/2003	Critical	GR	LOOP-IE-I	1	16	41	Equip	Relay
2771988020	Peach Bottom 3	7/29/1988	Shutdown	SC	LOOP-SD	9	24	125	Equip	Transformer
2772003004	Peach Bottom 3	9/15/2003	Critical	GR	LOOP-IE-I	1	16	103	Equip	Relay
4402003002	Perry	8/14/2003	Critical	GR	LOOP-IE-I	82	87	123	G	Other - load
2931987005	Pilgrim	3/31/1987	Shutdown	WR	LOOP-SD	1	16	45	SEE	High Winds
2931987014	Pilgrim	11/12/1987	Shutdown	WR	LOOP-SD	1258	1263	1263	SEE	Salt Spray
2931989010	Pilgrim	2/21/1989	Shutdown	SC	LOOP-SD	1	16	920	Equip	Other
2931991024	Pilgrim	10/30/1991	Shutdown	WR	LOOP-SD	109	114	152	SEE	Salt Spray

LER	Plant Name	Date	Operating Mode	LOOP Category	LOOP Class	Restoration Time (minutes) Switchyard Restoration Time	Potential Bus Recovery Time	Actual Bus Restoration Time	Cause	Specific Cause
2931993004	Pilgrim	3/13/1993	Critical	WR	LOOP-IE-I	30	40	298	SEE	Snow
2931993010	Pilgrim	5/19/1993	Shutdown	SC	LOOP-SD	36	37	37	HES	Testing
2931993022	Pilgrim	9/10/1993	Critical	SC	LOOP-IE-I	10	25	200	SEE	Lightning
2931997007	Pilgrim	4/1/1997	Shutdown	WR	LOOP-SD	347	1200	1409	SEE	High Winds
2932008007	Pilgrim	12/20/2008	Shutdown	SC	LOOP-SD	2	60	120	SEE	Ice
2932013003	Pilgrim	2/8/2013	Critical	WR	LOOP-IE-I	656	1258	1843	SEE	Snow and Wind
2932013003	Pilgrim	2/10/2013	Shutdown	SC	LOOP-SD	2271	2387	3333	SEE	Ice
2932013009	Pilgrim	10/14/2013	Critical	GR	LOOP-IE-I	1	2	1382	G	Equip - other
2932015001	Pilgrim	1/27/2015	Critical	WR	LOOP-IE-I	1	2	3641	SEE	Snow and Wind
2932018004	Pilgrim	3/13/2018	Shutdown	WR	LOOP-SD	720	721	4018	SEE	Snow and Wind
2661992003	Point Beach 1	4/28/1992	Shutdown	PC	LOOP-SD	0	15	30	HES	Maintenance
2662011001	Point Beach 1	11/27/2011	Shutdown	SC	LOOP-SD	1	16	334	Equip	Other
3011989002	Point Beach 2	3/29/1989	Critical	SC	LOOP-IE-C	90	95	202	HE	Maintenance
2661994010	Point Beach 2	9/27/1994	Shutdown	PC	LOOP-SD	0	15	15	HES	Switching
2821996012	Prairie Island 1	6/29/1996	Critical	WR	LOOP-IE-I	296	301	301	SEE	High Winds
2821996012	Prairie Island 2	6/29/1996	Critical	WR	LOOP-IE-I	296	301	301	SEE	High Winds
2651991005	Quad Cities 1	4/2/1991	Shutdown	PC	LOOP-SD	unk.	0	0	Equip	Transformer
2651992011	Quad Cities 2	4/2/1992	Shutdown	PC	LOOP-SD	35	35	35	Equip	Transformer
2652001001	Quad Cities 2	8/2/2001	Critical	SC	LOOP-IE-I	15	30	154	SEE	Lightning

LER	Plant Name	Date	Operating Mode	LOOP Category	LOOP Class	Restoration Time (minutes): Switchyard Restoration Time	Restoration Time (minutes): Potential Bus Recovery Time	Restoration Time (minutes): Actual Bus Restoration Time	Cause	Specific Cause
2611992017	Robinson 2	8/22/1992	Critical	SC	LOOP-IE-I	454	459	914	Equip	Transformer
2612016005	Robinson 2	10/8/2016	Critical	SC	LOOP-IE-I	1	621	621	G	Equip - other
2722003002	Salem 1	7/29/2003	Critical	SC	LOOP-IE-I	30	40	480	Equip	Circuits
3111994014	Salem 2	11/18/1994	Shutdown	SC	LOOP-SD	295	300	1675	Equip	Relay
3622002001	San Onofre 3	2/27/2002	Critical	SC	LOOP-IE-I	32	32	32	HE	Testing
4431988004	Seabrook	8/10/1988	Shutdown	PC	LOOP-SD	4	5	5	HES	Switching
4431991008	Seabrook	6/27/1991	Critical	SC	LOOP-IE-I	0	20	20	Equip	Relay
4432001002	Seabrook	3/5/2001	Critical	WR	LOOP-IE-I	1	16	2122	SEE	Snow
3271992027	Sequoyah 1	12/31/1992	Critical	SC	LOOP-IE-I	96	101	116	Equip	Breaker
3271997007	Sequoyah 1	4/4/1997	Shutdown	PC	LOOP-SD	325	330	345	HE	Maintenance
3271992027	Sequoyah 2	12/31/1992	Critical	SC	LOOP-IE-I	96	101	116	Equip	Breaker
3352004004	St. Lucie 1	9/25/2004	Shutdown	WR	LOOP-SD	8	68	667	EEE	Hurricane
3352016003	St. Lucie 1	8/21/2016	Critical	PC	LOOP-IE-NC	1	70	70	Equip	Circuits
3352004004	St. Lucie 2	9/25/2004	Shutdown	WR	LOOP-SD	8	68	613	EEE	Hurricane
3951989012	Summer	7/11/1989	Critical	PC	LOOP-IE-C	95	100	120	G	Equip - other
2802011001	Surry 1	4/16/2011	Critical	WR	LOOP-IE-I	303	304	346	EEE	Tornado
2802011001	Surry 2	4/16/2011	Critical	WR	LOOP-IE-I	303	304	424	EEE	Tornado
2891997007	Three Mile Isl 1	6/21/1997	Critical	SC	LOOP-IE-I	85	90	90	Equip	Circuits
2501991003	Turkey Point 3	7/24/1991	Shutdown	SC	LOOP-SD	0	11	11	Equip	Breaker

LER	Plant Name	Date	Operating Mode	LOOP Category	LOOP Class	Restoration Time (minutes): Switchyard Restoration Time	Restoration Time (minutes): Potential Bus Recovery Time	Restoration Time (minutes): Actual Bus Restoration Time	Cause	Specific Cause
2501992000	Turkey Point 3	8/24/1992	Shutdown	WR	LOOP-SD	7950	7955	9221	EEE	Hurricane
2511991001	Turkey Point 4	3/13/1991	Shutdown	PC	LOOP-SD	62	67	67	Equip	Relay
2501992000	Turkey Point 4	8/24/1992	Shutdown	WR	LOOP-SD	7908	7913	9442	EEE	Hurricane
2512000004	Turkey Point 4	10/21/2000	Shutdown	SC	LOOP-SD	1	16	111	Equip	Circuits
2512005005	Turkey Point 4	10/31/2005	Shutdown	WR	LOOP-SD	1	1598	1615	SEE	Salt Spray
2512013002	Turkey Point 4	4/19/2013	Critical	PC	LOOP-IE-NC	24	27	30	HE	Testing
2711987008	Vermont Yankee	8/17/1987	Shutdown	GR	LOOP-SD	2	17	77	Equip	Other
2711991009	Vermont Yankee	4/23/1991	Critical	PC	LOOP-IE-I	277	282	822	HE	Maintenance
4241990006	Vogtle 1	3/20/1990	Shutdown	SC	LOOP-SD	140	145	217	HES	Other
3822005004	Waterford 3	8/29/2005	Shutdown	WR	LOOP-SD	4981	4982	5242	EEE	Hurricane
3822017002	Waterford 3	7/17/2017	Critical	PC	LOOP-IE-I	145	158	158	Equip	Relay
3822021002	Waterford 3	8/29/2021	Shutdown	WR	LOOP-SD	3206	3211	3211	EEE	Hurricane
4821987048	Wolf Creek	10/14/1987	Shutdown	PC	LOOP-SD	0	17	17	HES	Maintenance
4822008004	Wolf Creek	4/7/2008	Shutdown	SC	LOOP-SD	7	7	153	HES	Maintenance
4822009002	Wolf Creek	8/19/2009	Critical	WR	LOOP-IE-I	1	133	133	SEE	Lightning
4822012001	Wolf Creek	1/13/2012	Critical	SC	LOOP-IE-I	177	177	198	Equip	Breaker
291991002	Yankee-Rowe	6/15/1991	Critical	SC	LOOP-IE-I	24	25	25	SEE	Lightning
2951997007	Zion 1	3/11/1997	Shutdown	SC	LOOP-SD	235	240	240	Equip	Circuits
3041991002	Zion 2	3/21/1991	Critical	SC	LOOP-IE-I	0	60	60	Equip	Transformer

Table A- 2. LOOP events showing restoration time uncertainty for 1987–2021.

LER	Plant Name	Date	Operating Mode	LOOP Category	LOOP Class	Switchyard Restoration		Potential Bus Restoration		Actual Bus Restoration	
						Time	Certainty[a]	Time	Certainty[a]	Time	Certainty[a]
3132013001	Arkansas 1	3/31/2013	Shutdown	PC	LOOP-SD	unk.	U	8640	E	8640	E
3341993013	Beaver Valley 1	10/12/1993	Critical	SC	LOOP-IE-I	15	C	28	E	28	C
4121987036	Beaver Valley 2	11/17/1987	Critical	SC	LOOP-IE-I	0	C	4	C	4	C
3341993013	Beaver Valley 2	10/12/1993	Shutdown	SC	LOOP-SD	15	C	28	E	28	C
1551992000	Big Rock Point	1/29/1992	Shutdown	SC	LOOP-SD	77	E	82	E	82	E
4561987048	Braidwood 1	9/11/1987	Shutdown	SC	LOOP-SD	62	C	63	E	63	C
4561988022	Braidwood 1	10/16/1988	Critical	SC	LOOP-IE-I	95	C	118	C	213	C
4561998003	Braidwood 1	9/6/1998	Shutdown	WR	LOOP-SD	528	E	533	E	533	E
4572009002	Braidwood 2	7/30/2009	Critical	SC	LOOP-IE-I	1	C	2	E	3097	E
2592011001	Browns Ferry 1	4/27/2011	Critical	WR	LOOP-IE-I	1	E	16	E	7414	C
2592011001	Browns Ferry 2	4/27/2011	Critical	WR	LOOP-IE-I	1	E	16	E	7414	C
2961997001	Browns Ferry 3	3/5/1997	Shutdown	SC	LOOP-SD	39	E	44	E	44	C
2592011001	Browns Ferry 3	4/27/2011	Critical	WR	LOOP-IE-I	1	E	16	E	7414	C
2962012003	Browns Ferry 3	5/22/2012	Critical	SC	LOOP-IE-I	86	E	91	E	101	C
2962019001	Browns Ferry 3	3/9/2019	Critical	PC	LOOP-IE-NC	60	E	62	E	781	E
3251993008	Brunswick 1	3/17/1993	Shutdown	WR	LOOP-SD	1120	C	1125	E	1508	C
3252000001	Brunswick 1	3/3/2000	Shutdown	SC	LOOP-SD	15	E	30	E	136	C
3252004002	Brunswick 1	8/14/2004	Critical	WR	LOOP-IE-I	167	C	172	E	183	C
3252016001	Brunswick 1	2/7/2016	Critical	PC	LOOP-IE-I	1	E	16	E	196	C

LER	Plant Name	Date	Operating Mode	LOOP Category	LOOP Class	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]
3252020003	Brunswick 1	8/3/2020	Critical	WR	LOOP-IE-I	838	E	839	E	898	E
3241989009	Brunswick 2	6/17/1989	Critical	SC	LOOP-IE-I	85	E	90	C	403	C
3251993008	Brunswick 2	3/16/1993	Shutdown	WR	LOOP-SD	813	C	818	E	1018	C
3241994008	Brunswick 2	5/21/1994	Shutdown	PC	LOOP-SD	2	C	17	E	42	C
3242006001	Brunswick 2	11/1/2006	Critical	SC	LOOP-IE-I	1	E	16	E	1456	C
4541996007	Byron 1	5/23/1996	Shutdown	SC	LOOP-SD	715	E	720	C	1763	E
4542014003	Byron 1	3/15/2014	Shutdown	SC	LOOP-SD	613	E	613	E	613	C
4551987019	Byron 2	10/2/1987	Critical	SC	LOOP-IE-C	1	E	16	E	507	C
4542012001	Byron 2	1/30/2012	Critical	SC	LOOP-IE-I	1	C	2035	C	2172	C
3171987012	Calvert Cliffs 1	7/23/1987	Critical	SC	LOOP-IE-I	113	E	118	C	118	C
3172015002	Calvert Cliffs 1	4/7/2015	Critical	GR	LOOP-IE-I	200	E	210	E	210	E
3171987012	Calvert Cliffs 2	7/23/1987	Critical	SC	LOOP-IE-I	113	E	118	C	118	C
3172015002	Calvert Cliffs 2	4/7/2015	Critical	GR	LOOP-IE-NC	19	E	29	E	29	E
4132006001	Catawba 1	5/20/2006	Critical	SC	LOOP-IE-I	385	E	400	C	542	C
4132012001	Catawba 1	4/4/2012	Critical	PC	LOOP-IE-C	325	E	326	E	326	E
4141996001	Catawba 2	2/6/1996	Critical	SC	LOOP-IE-I	115	C	120	E	330	C
4132006001	Catawba 2	5/20/2006	Critical	SC	LOOP-IE-I	372	E	387	C	570	C
4132012001	Catawba 2	4/4/2012	Shutdown	SC	LOOP-SD	60	E	61	E	393	C
4611999002	Clinton 1	1/6/1999	Shutdown	SC	LOOP-SD	270	C	275	E	492	C

LER	Plant Name	Date	Operating Mode	LOOP Category	LOOP Class	Switchyard Restoration		Potential Bus Restoration		Actual Bus Restoration	
						Time	Certainty[a]	Time	Certainty[a]	Time	Certainty[a]
3971989016	Columbia	5/14/1989	Shutdown	SC	LOOP-SD	0	C	15	E	29	C
3151991004	Cook 1	5/12/1991	Critical	PC	LOOP-IE-I	0	C	15	E	81	C
3021987025	Crystal River 3	10/16/1987	Shutdown	SC	LOOP-SD	18	C	28	E	59	C
3021989023	Crystal River 3	6/16/1989	Critical	SC	LOOP-IE-I	60	C	65	E	65	E
3021989025	Crystal River 3	6/29/1989	Shutdown	SC	LOOP-SD	0	E	2	C	2	C
3021991010	Crystal River 3	10/20/1991	Shutdown	PC	LOOP-SD	0	C	4	C	4	C
3021992001	Crystal River 3	3/27/1992	Critical	PC	LOOP-IE-I	20	E	30	E	150	C
3021993000	Crystal River 3	3/17/1993	Shutdown	WR	LOOP-SD	72	C	77	E	102	E
3021993002	Crystal River 3	3/29/1993	Shutdown	WR	LOOP-SD	0	C	15	E	37	C
3021993004	Crystal River 3	4/8/1993	Shutdown	PC	LOOP-SD	1	E	16	E	136	C
3461998006	Davis-Besse	6/24/1998	Critical	WR	LOOP-IE-I	1364	C	1428	C	1495	C
3462000004	Davis-Besse	4/22/2000	Shutdown	PC	LOOP-SD	5	E	10	C	10	C
3462003009	Davis-Besse	8/14/2003	Shutdown	GR	LOOP-SD	652	C	657	E	849	C
2751991004	Diablo Canyon 1	3/7/1991	Shutdown	SC	LOOP-SD	261	C	285	C	285	C
2751995014	Diablo Canyon 1	10/21/1995	Shutdown	SC	LOOP-SD	40	C	45	E	951	C
2752000004	Diablo Canyon 1	5/15/2000	Critical	PC	LOOP-IE-I	1901	C	1906	E	2014	C
2752007001	Diablo Canyon 1	5/12/2007	Shutdown	GR	LOOP-SD	209	C	245	C	279	C
3231988008	Diablo Canyon 2	7/17/1988	Critical	SC	LOOP-IE-I	33	E	38	C	38	C
2371990002	Dresden 2	1/16/1990	Critical	SC	LOOP-IE-C	0	C	45	E	759	C

LER	Plant Name	Date	Operating Mode	LOOP Category	LOOP Class	Switchyard Restoration		Potential Bus Restoration		Actual Bus Restoration	
						Time	Certainty[a]	Time	Certainty[a]	Time	Certainty[a]
2491989001	Dresden 3	3/25/1989	Critical	SC	LOOP-IE-I	45	E	50	E	50	E
2492004003	Dresden 3	5/5/2004	Critical	SC	LOOP-IE-I	146	E	151	E	151	C
3311990007	Duane Arnold	7/9/1990	Shutdown	SC	LOOP-SD	0	C	37	C	37	C
3312007004	Duane Arnold	2/24/2007	Shutdown	WR	LOOP-SD	5	C	1048	C	1829	C
3312020001	Duane Arnold	8/10/2020	Critical	WR	LOOP-IE-I	1514	E	1515	E	1634	E
3482000005	Farley 1	4/9/2000	Shutdown	SC	LOOP-SD	18	C	19	C	19	C
3412003002	Fermi 2	8/14/2003	Critical	GR	LOOP-IE-I	379	C	384	E	582	C
3331988011	FitzPatrick	10/31/1988	Shutdown	WR	LOOP-SD	1	C	16	E	70	C
3332003001	FitzPatrick	8/14/2003	Critical	GR	LOOP-IE-I	169	C	174	E	414	C
3332012005	FitzPatrick	10/5/2012	Shutdown	SC	LOOP-SD	847	E	847	E	847	C
2851987008	Fort Calhoun	3/21/1987	Shutdown	SC	LOOP-SD	37	C	38	E	38	C
2851987009	Fort Calhoun	4/4/1987	Shutdown	SC	LOOP-SD	0	C	4	C	4	C
2851990006	Fort Calhoun	2/26/1990	Shutdown	SC	LOOP-SD	0	C	14	C	14	C
2851998005	Fort Calhoun	5/20/1998	Shutdown	SC	LOOP-SD	104	E	109	E	109	C
2851999004	Fort Calhoun	10/26/1999	Shutdown	PC	LOOP-SD	2	C	2	C	2	C
2442003002	Ginna	8/14/2003	Critical	GR	LOOP-IE-I	49	C	54	E	297	C
4162003002	Grand Gulf	4/24/2003	Critical	SC	LOOP-IE-NC	1	E	15	E	75	E
2131993009	Haddam Neck	6/22/1993	Shutdown	PC	LOOP-SD	12	C	27	E	35	C
2131993010	Haddam Neck	6/26/1993	Shutdown	PC	LOOP-SD	3	E	18	E	40	E

LER	Plant Name	Date	Operating Mode	LOOP Category	LOOP Class	Switchyard Restoration		Potential Bus Restoration		Actual Bus Restoration	
						Time	Certainty[a]	Time	Certainty[a]	Time	Certainty[a]
4002016005	Harris	10/8/2016	Shutdown	WR	LOOP-SD	unk.	U	443	C	524	C
2471991006	Indian Point 2	3/20/1991	Shutdown	SC	LOOP-SD	0	C	15	E	29	C
2471991010	Indian Point 2	6/22/1991	Shutdown	PC	LOOP-SD	0	C	60	C	60	C
2471998013	Indian Point 2	9/1/1998	Shutdown	PC	LOOP-SD	1	E	16	E	67	C
2471999015	Indian Point 2	8/31/1999	Critical	SC	LOOP-IE-NC	1	E	15	E	779	C
2472003005	Indian Point 2	8/14/2003	Critical	GR	LOOP-IE-I	97	C	102	E	214	C
2861995004	Indian Point 3	2/27/1995	Shutdown	SC	LOOP-SD	30	E	40	E	132	C
2861996002	Indian Point 3	1/20/1996	Shutdown	SC	LOOP-SD	30	E	40	E	145	C
2861997008	Indian Point 3	6/16/1997	Shutdown	GR	LOOP-SD	37	E	42	C	42	C
2862003005	Indian Point 3	8/14/2003	Critical	GR	LOOP-IE-I	97	C	102	E	241	C
3731993015	La Salle 1	9/14/1993	Critical	SC	LOOP-IE-I	0	C	15	E	70	C
3732013002	La Salle 1	4/17/2013	Critical	SC	LOOP-IE-NC	481	E	481	E	482	C
3732013002	La Salle 2	4/17/2013	Critical	SC	LOOP-IE-NC	481	E	481	E	482	C
3091988006	Maine Yankee	8/13/1988	Critical	SC	LOOP-IE-I	14	C	15	E	15	C
3691987021	McGuire 1	9/16/1987	Shutdown	PC	LOOP-SD	0	C	6	C	6	C
3691991001	McGuire 1	2/11/1991	Critical	PC	LOOP-IE-I	0	C	40	C	60	E
3691988014	McGuire 2	6/24/1988	Shutdown	SC	LOOP-SD	8	C	8	C	8	C
3701993008	McGuire 2	12/27/1993	Critical	SC	LOOP-IE-I	96	C	101	E	131	C
2451989012	Millstone 1	4/29/1989	Shutdown	SC	LOOP-SD	0	C	15	E	75	E

LER	Plant Name	Date	Operating Mode	LOOP Category	LOOP Class	Switchyard Restoration		Potential Bus Restoration		Actual Bus Restoration	
						Time	Certainty[a]	Time	Certainty[a]	Time	Certainty[a]
3361988011	Millstone 2	10/25/1988	Critical	PC	LOOP-IE-I	19	E	29	E	29	E
3362008004	Millstone 2	5/24/2008	Shutdown	SC	LOOP-SD	57	C	57	C	1612	C
3362014006	Millstone 2	5/25/2014	Critical	GR	LOOP-IE-NC	179	E	184	E	209	E
4232007002	Millstone 3	4/25/2007	Shutdown	GR	LOOP-SD	133	E	193	E	220	C
3362014006	Millstone 3	5/25/2014	Critical	GR	LOOP-IE-NC	179	E	184	E	209	E
2202003002	Nine Mile Pt. 1	8/14/2003	Critical	GR	LOOP-IE-NC	105	E	110	E	448	C
4101988062	Nine Mile Pt. 2	12/26/1988	Shutdown	SC	LOOP-SD	9	C	24	E	54	C
4101992006	Nine Mile Pt. 2	3/23/1992	Shutdown	PC	LOOP-SD	20	C	30	E	50	E
4102003002	Nine Mile Pt. 2	8/14/2003	Critical	GR	LOOP-IE-I	100	C	105	E	551	C
3382011003	North Anna 1	8/23/2011	Critical	SC	LOOP-IE-NC	467	C	547	E	547	C
3382011003	North Anna 2	8/23/2011	Critical	SC	LOOP-IE-NC	467	C	547	E	547	C
2701992004	Oconee 2	10/19/1992	Critical	PC	LOOP-IE-I	207	C	207	C	207	C
2871987002	Oconee 3	3/5/1987	Shutdown	SC	LOOP-SD	150	E	155	E	155	C
2872006001	Oconee 3	5/15/2006	Shutdown	PC	LOOP-SD	606	C	606	E	1730	C
2872018002	Oconee 3	5/10/2018	Shutdown	PC	LOOP-SD	807	E	807	E	807	C
2191989015	Oyster Creek	5/18/1989	Critical	PC	LOOP-IE-I	1	E	16	E	54	C
2191992005	Oyster Creek	5/3/1992	Critical	GR	LOOP-IE-I	5	C	65	E	1029	C
2191997010	Oyster Creek	8/1/1997	Critical	SC	LOOP-IE-C	30	E	40	C	40	C
2192009005	Oyster Creek	7/12/2009	Critical	GR	LOOP-IE-I	94	C	103	C	103	C

LER	Plant Name	Date	Operating Mode	LOOP Category	LOOP Class	Switchyard Restoration		Potential Bus Restoration		Actual Bus Restoration	
						Time	Certainty[a]	Time	Certainty[a]	Time	Certainty[a]
2192012001	Oyster Creek	7/23/2012	Critical	GR	LOOP-IE-I	1	E	31	E	88	E
2192012002	Oyster Creek	10/29/2012	Shutdown	WR	LOOP-SD	861	C	861	C	861	C
2551987024	Palisades	7/14/1987	Critical	SC	LOOP-IE-I	388	C	388	C	446	C
2551992032	Palisades	4/6/1992	Shutdown	PC	LOOP-SD	0	C	15	E	30	E
2551998013	Palisades	12/22/1998	Shutdown	PC	LOOP-SD	1	E	16	E	20	E
2552003003	Palisades	3/25/2003	Shutdown	PC	LOOP-SD	91	E	96	E	3261	C
5282004006	Palo Verde 1	6/14/2004	Critical	GR	LOOP-IE-I	32	C	37	E	57	C
5282004006	Palo Verde 2	6/14/2004	Critical	GR	LOOP-IE-I	32	C	37	E	106	C
5282004006	Palo Verde 3	6/14/2004	Critical	GR	LOOP-IE-I	32	C	37	E	59	C
2771988020	Peach Bottom 2	7/29/1988	Shutdown	SC	LOOP-SD	9	E	24	C	125	C
2772003004	Peach Bottom 2	9/15/2003	Critical	GR	LOOP-IE-I	1	C	16	E	41	E
2771988020	Peach Bottom 3	7/29/1988	Shutdown	SC	LOOP-SD	9	E	24	C	125	C
2772003004	Peach Bottom 3	9/15/2003	Critical	GR	LOOP-IE-I	1	C	16	E	103	C
4402003002	Perry	8/14/2003	Critical	GR	LOOP-IE-I	82	C	87	E	123	C
2931987005	Pilgrim	3/31/1987	Shutdown	WR	LOOP-SD	1	E	16	E	45	C
2931987014	Pilgrim	11/12/1987	Shutdown	WR	LOOP-SD	1258	E	1263	C	1263	C
2931989010	Pilgrim	2/21/1989	Shutdown	SC	LOOP-SD	1	E	16	E	920	C
2931991024	Pilgrim	10/30/1991	Shutdown	WR	LOOP-SD	109	C	114	E	152	C
2931993004	Pilgrim	3/13/1993	Critical	WR	LOOP-IE-I	30	E	40	E	298	C

LER	Plant Name	Date	Operating Mode	LOOP Category	LOOP Class	Switchyard Restoration		Potential Bus Restoration		Actual Bus Restoration	
						Time	Certainty[a]	Time	Certainty[a]	Time	Certainty[a]
2931993010	Pilgrim	5/19/1993	Shutdown	SC	LOOP-SD	36	C	37	C	37	C
2931993022	Pilgrim	9/10/1993	Critical	SC	LOOP-IE-I	10	C	25	E	200	C
2931997007	Pilgrim	4/1/1997	Shutdown	WR	LOOP-SD	347	C	1200	C	1409	C
2932008007	Pilgrim	12/20/2008	Shutdown	SC	LOOP-SD	2	E	60	E	120	E
2932013003	Pilgrim	2/8/2013	Critical	WR	LOOP-IE-I	656	C	1258	C	1843	C
2932013003	Pilgrim	2/10/2013	Shutdown	SC	LOOP-SD	2271	C	2387	C	3333	C
2932013009	Pilgrim	10/14/2013	Critical	GR	LOOP-IE-I	1	E	2	E	1382	C
2932015001	Pilgrim	1/27/2015	Critical	WR	LOOP-IE-I	1	C	2	C	3641	C
2932018004	Pilgrim	3/13/2018	Shutdown	WR	LOOP-SD	720	E	721	E	4018	E
2661992003	Point Beach 1	4/28/1992	Shutdown	PC	LOOP-SD	0	C	15	E	30	C
2662011001	Point Beach 1	11/27/2011	Shutdown	SC	LOOP-SD	1	E	16	E	334	E
3011989002	Point Beach 2	3/29/1989	Critical	SC	LOOP-IE-C	90	E	95	E	202	C
2661994010	Point Beach 2	9/27/1994	Shutdown	PC	LOOP-SD	0	C	15	E	15	E
2821996012	Prairie Island 1	6/29/1996	Critical	WR	LOOP-IE-I	296	E	301	E	301	C
2821996012	Prairie Island 2	6/29/1996	Critical	WR	LOOP-IE-I	296	C	301	E	301	C
2651991005	Quad Cities 1	4/2/1991	Shutdown	PC	LOOP-SD	unk.	U	0	U	0	U
2651992011	Quad Cities 2	4/2/1992	Shutdown	PC	LOOP-SD	35	C	35	C	35	C
2652001001	Quad Cities 2	8/2/2001	Critical	SC	LOOP-IE-I	15	C	30	E	154	C
2611992017	Robinson 2	8/22/1992	Critical	SC	LOOP-IE-I	454	C	459	E	914	C

LER	Plant Name	Date	Operating Mode	LOOP Category	LOOP Class	Switchyard Restoration		Potential Bus Restoration		Actual Bus Restoration	
						Time	Certainty[a]	Time	Certainty[a]	Time	Certainty[a]
2612016005	Robinson 2	10/8/2016	Critical	SC	LOOP-IE-I	1	C	621	E	621	E
2722003002	Salem 1	7/29/2003	Critical	SC	LOOP-IE-I	30	E	40	E	480	C
3111994014	Salem 2	11/18/1994	Shutdown	SC	LOOP-SD	295	E	300	C	1675	C
3622002001	San Onofre 3	2/27/2002	Critical	SC	LOOP-IE-I	32	E	32	E	32	C
4431988004	Seabrook	8/10/1988	Shutdown	PC	LOOP-SD	4	E	5	E	5	E
4431991008	Seabrook	6/27/1991	Critical	SC	LOOP-IE-I	0	C	20	C	20	C
4432001002	Seabrook	3/5/2001	Critical	WR	LOOP-IE-I	1	E	16	E	2122	C
3271992027	Sequoyah 1	12/31/1992	Critical	SC	LOOP-IE-I	96	C	101	E	116	E
3271997007	Sequoyah 1	4/4/1997	Shutdown	PC	LOOP-SD	325	C	330	E	345	E
3271992027	Sequoyah 2	12/31/1992	Critical	SC	LOOP-IE-I	96	C	101	E	116	E
3352004004	St. Lucie 1	9/25/2004	Shutdown	WR	LOOP-SD	8	C	68	E	667	C
3352016003	St. Lucie 1	8/21/2016	Critical	PC	LOOP-IE-NC	1	C	70	E	70	C
3352004004	St. Lucie 2	9/25/2004	Shutdown	WR	LOOP-SD	8	C	68	E	613	C
3951989012	Summer	7/11/1989	Critical	PC	LOOP-IE-C	95	C	100	E	120	C
2802011001	Surry 1	4/16/2011	Critical	WR	LOOP-IE-I	303	C	304	C	346	C
2802011001	Surry 2	4/16/2011	Critical	WR	LOOP-IE-I	303	C	304	C	424	C
2891997007	Three Mile Isl 1	6/21/1997	Critical	SC	LOOP-IE-I	85	E	90	C	90	C
2501991003	Turkey Point 3	7/24/1991	Shutdown	SC	LOOP-SD	0	C	11	C	11	C
2501992000	Turkey Point 3	8/24/1992	Shutdown	WR	LOOP-SD	7950	E	7955	E	9221	C

LER	Plant Name	Date	Operating Mode	LOOP Category	LOOP Class	Switchyard Restoration		Potential Bus Restoration		Actual Bus Restoration	
						Time	Certainty[a]	Time	Certainty[a]	Time	Certainty[a]
2511991001	Turkey Point 4	3/13/1991	Shutdown	PC	LOOP-SD	62	E	67	C	67	C
2501992000	Turkey Point 4	8/24/1992	Shutdown	WR	LOOP-SD	7908	E	7913	E	9442	C
2512000004	Turkey Point 4	10/21/2000	Shutdown	SC	LOOP-SD	1	E	16	E	111	C
2512005005	Turkey Point 4	10/31/2005	Shutdown	WR	LOOP-SD	1	E	1598	E	1615	C
2512013002	Turkey Point 4	4/19/2013	Critical	PC	LOOP-IE-NC	24	E	27	E	30	C
2711987008	Vermont Yankee	8/17/1987	Shutdown	GR	LOOP-SD	2	C	17	E	77	E
2711991009	Vermont Yankee	4/23/1991	Critical	PC	LOOP-IE-I	277	C	282	E	822	C
4241990006	Vogtle 1	3/20/1990	Shutdown	SC	LOOP-SD	140	C	145	E	217	C
3822005004	Waterford 3	8/29/2005	Shutdown	WR	LOOP-SD	4981	C	4982	C	5242	C
3822017002	Waterford 3	7/17/2017	Critical	PC	LOOP-IE-I	145	C	158	C	158	C
3822021002	Waterford 3	8/29/2021	Shutdown	WR	LOOP-SD	3206	C	3211	E	3211	E
4821987048	Wolf Creek	10/14/1987	Shutdown	PC	LOOP-SD	0	C	17	E	17	C
4822008004	Wolf Creek	4/7/2008	Shutdown	SC	LOOP-SD	7	C	7	C	153	C
4822009002	Wolf Creek	8/19/2009	Critical	WR	LOOP-IE-I	1	C	133	E	133	E
4822012001	Wolf Creek	1/13/2012	Critical	SC	LOOP-IE-I	177	C	177	C	198	C
291991002	Yankee-Rowe	6/15/1991	Critical	SC	LOOP-IE-I	24	C	25	C	25	C
2951997007	Zion 1	3/11/1997	Shutdown	SC	LOOP-SD	235	E	240	E	240	C

[a] C: Known - The restoration time is certain.
U: Unknown - No information is available concerning the restoration time.
E: Estimated - The restoration time was estimated based on information in the LER.