Loss of Offsite Power Frequency Calculation II

Zhiping Li
Callaway Energy Center-Ameren Missouri, Fulton, USA

Abstract: The availability of alternating current (AC) power is essential for safe operation and accident recovery at commercial nuclear power plants. Normally, AC power is supplied by offsite sources via the electrical grid. Loss of this offsite power has significant contribution to the overall risk at nuclear power plants. Reliable offsite power is one key to minimizing the probability of severe accidents. The probability of losing all offsite power is an important input to nuclear power plant probabilistic safety assessments. Several studies have analyzed data on LOOP and/or offsite power restoration. However, significant differences in LOOP event description, category, duration, and applicability exist between the LOOP events used in NUREG/CR-6890 and the EPRI LOOP Reports. Different LOOP frequency calculation methods are used in NUREG/CR-6890 and in the EPRI's LOOP Reports. While the author was updating LOOP frequency for some nuclear power plants, it was found that there is a need to clarify how the LOOP frequency should be calculated. Loss of Offsite Power Frequency Calculation was presented to PSA2013, Columbia, SC in September 2013. A LOOP frequency calculation for an inland plant is performed. Insight about site specific LOOP frequency calculation and some discussion about applicability of LOOP events are presented. In addition, in Loss of Offsite Power Frequency Calculation II, LOOP frequencies for different categories will be calculated. Comparison and discussions about different LOOP frequency calculation methods will be presented.

Keywords: LOOP, LOSP, Frequency.

1. INTRODUCTION

The availability of alternating current (AC) power is essential for safe operation and accident recovery at commercial nuclear power plants. Normally, AC power is supplied by offsite sources via the electrical grid. Loss of this offsite power can have a major negative impact on a power plant's ability to achieve and maintain safe shutdown conditions. Risk analyses performed for U.S. commercial nuclear power plants indicate that the loss of all AC power contributes over 70% of the overall risk at some plants [1]. Clearly, loss of offsite power (LOOP, also referred to as LOSP) and subsequent restoration of offsite power are important inputs to plant probabilistic safety assessments (PSAs). These inputs must reflect current industry performance in order for PRAs to accurately estimate the risk from LOOP initiated scenarios.

Several studies have analyzed data on LOOP and/or offsite power restoration [2–6]; NUREG/CR-6890, *Reevaluation of Station Blackout Risk at Nuclear Power Plants* [1], extends the analysis to 2004. NUREG-1032, *Evaluation of Station Blackout Accidents at Nuclear Power Plants* [2], evaluated LOOP data from U.S. commercial nuclear reactors over the period 1968–1985. NUREG/CR-5496, *Evaluation of Loss of Offsite Power Events at Nuclear Power Plants: 1980–1996* [3], looked at data from 1980–1996. A more general report, NUREG/CR-5750, *Rates of Initiating Events at U.S. Nuclear Power Plants: 1987–1995* [4], covered a wide variety of initiating events, including LOOP for the period 1987–1995. NUREG/CR-6928, *Industry-Average Performance for Components and Initiating Events at U.S. Commercial Nuclear Power Plants* [5], covers LOOP frequencies which were based on NUREG/CR-6890. Electric Power Research Institute (EPRI) reports covering LOOP events have been issued periodically; the latest EPRI report covers LOOP events from 2003 to 2012 [6]. And NUREG-1784, *Operating Experience Assessment—Effects of Grid Events on Nuclear Power Plant Performance* [7], focuses on a subset of LOOP events (1985–2001) and the effects of deregulation on such events. That report contains more detailed engineering information concerning deregulation and its effects on the electrical grid and related LOOP events. NRC's *Analysis of Loss of Offsite Power Events 2010 Update* [8] collected and analyzed the LOOP data from calendar years 1986-2010. The data covered both critical (at power) and shutdown operations at these plants.

Reference [9] identified significant differences in LOOP event description, category, duration, and applicability between the LOOP events used in NUREG/CR-6890 and Entergy Nuclear South (ENS) plants' LOOP packages, which were based on EPRI LOOP reports with plant specific applicability analysis. It listed the differences between the data in NUREG/CR-6890 and EPRI reports and evaluated the applicability of the LOOP events to ENS plant specific PSA model.

While the author was updating LOOP frequency for some plants, it was found that there is a need to clarify how the LOOP frequency should be calculated. This paper provides the authors insight about site-specific LOOP frequency calculation and some discussion about applicability of LOOP events.

2. DEFINITION

LOOP or LOSP event - the simultaneous loss of electrical power to all unit safety buses (also referred to as emergency buses, Class 1E buses, and vital buses) requiring all emergency power generators to start and supply power to the safety buses. The nonessential buses may also be deenergized as a result of this.

Loss of Preferred Offsite Power - the interruption of the preferred power supply to the essential and nonessential switchgear buses necessitating or resulting in the use of emergency AC power supplies.

Plant-Centered LOOP event - a LOOP event in which the design and operational characteristics of the nuclear power plant unit itself play the major role in the cause and duration of the loss of offsite power. Plant-centered failures typically involve hardware failures, design deficiencies, human errors, and localized weather-induced faults such as lightning. The line of demarcation between plant-centered and switchyard-centered events is the nuclear power plant main and station power transformers high-voltage terminals. Plant-centered LOOP events occur within the plant, up to but not including the auxiliary or station transformers.

Switchyard-Centered LOOP event - a LOOP event in which the equipment, or human-induced failures of equipment, in the switchyard play the major role in the loss of offsite power. Switchyard-centered failures typically involve hardware failures, design deficiencies, human errors, and localized weather-induced faults such as lightning. The line of demarcation between switchyard-related events and grid-related events is the output bus bar in the switchyard. Switchyard-centered events occur within the switchyard, up to and including the output bus bar.

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

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

Extreme-Weather-Related LOOP event - a LOOP event caused by extreme weather. Examples of extreme weather are hurricanes, strong winds greater than 125 miles per hour, and tornadoes. Extreme-weather-related LOOP events are also distinguished from severe weather-related LOOP events by their potential to cause significant damage to the electrical transmission system and long offsite power restoration times. Extreme-weather-related events are included in the weather-related events category in NUREG/CR-6890 and EPRI's LOOP reports.

3. LOOP EVENT CATEGORIES

In NUREG/CR-6890, the LOOP events are classified based on the operating state of the plant at the time of the LOOP events. The LOOP categories in NUREG/CR-6890 are refined to four categories: plant-centered, switchyard-centered, grid-related and weather-related. NUREG/CR-6890 uses three categorization schemes to classify LOOP events. The first classifies LOOP events according to whether the plant was shut down or operating when the LOOP occurred and the consequences of the LOOP. The three main categories of LOOPs are those that occur (1) while a plant is shut down (LOOP-SD), (2) during critical operation and involve a plant trip (LOOP-IE), and (3) during critical operation but the plant is able to continue critical operation without a plant trip (LOOP-NT). LOOP-IE events are further subdivided, following the initiating event nomenclature in NUREG/CR-5750, into those in which the LOOP event causes the reactor trip (initial plant fault event or LOOP-IE-I) and those in which the LOOP occurs after the reactor trip. These latter events are included in the functional impact initiating event classification in NUREG/CR-5750, and include those in which the reactor trip causes a LOOP to occur (consequential LOOP or LOOP-IE-C) and those in which the reactor trip and LOOP are unrelated but occur during the same transient (LOOP-IE-NC). Each LOOP event is placed into one of the LOOP categories: LOOP-SD, LOOP-NT, LOOP-IE-I, LOOP-IE-C, or LOOP-IE-NC. This classification scheme helps determine which LOOP events should be included when determining LOOP frequency estimates. [1]

The EPRI's LOOP reports assign categories as Ia, Ib, IIa, IIb, III and IV. The definitions of EPRI's LOOP events categories are as: [6]

Ia - no offsite power available for 30 minutes or longer to the safety buses.

Ib - no offsite power available for less than 30 minutes to the safety buses.

IIa - with the unit on-line, the startup/shutdown sources of offsite power for the safety buses become deenergized. The main generator remains on-line (connected to the offsite grid) and power for the safety buses is available from a unit auxiliary transformer.

IIb - with the unit on-line, the startup/shutdown sources of offsite power for the safety buses remain energized but in question. There is low or unstable grid voltage, or there might be if the unit trips, or trips along with a LOCA and emergency safety feature actuation. The main generator remains on-line (connected to the offsite grid) and power for the safety buses is available from a unit auxiliary transformer.

III - the unit auxiliary source of power for the safety buses becomes deenergized or unavailable, but offsite power for the safety buses remains available, or can be made available, from a startup/shutdown source. Utilization of this source may require a fast or slow automatic transfer, or manual switching from the control room. A loss of unit auxiliary power that is the result of a unit trip is not a Category III event. To be a Category III event the loss of power from the unit auxiliary source must be the initiating event and precede the unit trip. Most problems that trip the unit off-line are not Category III events. A Category III event is more properly associated with a failure of main electrical power hardware that makes near term availability of the unit auxiliary source of power for the safety buses unlikely.

IV - no offsite power available during cold shutdown because of special maintenance conditions that do not occur during or immediately following operations.

The Category I events (Ia and Ib) could occur at any time. The Category IV events can only occur during cold shutdown because of special maintenance conditions and these events are not applicable to power operation. The Category IIa, IIb, III events are partial loss of power events.

4. LOOP FREQUENCIES AT POWER

The proposed total LOOP initiator frequency for at-power model is calculated as follows:

$$f_{LOOP-At-Power} = \frac{\#\,of\ \ Applicable\ \ LOOP\ \ Events}{Rx\ \ Calendar\ \ Years} \qquad (1)$$

The unit of LOOP initiator frequency for at-power model is per reactor-calendar-year or per year. The concepts of *Reactor Calendar Years* and *Reactor Critical Years* may cause confusion to PRA analysts. Reference [11] provides an alternate description of the same concepts as by Note 1 to supporting requirement IE-C5 of the AMSE/ANS PRA Standard [10].

> *The ASME/ANS PRA Standard [10] IE-C5 requires the initiating event frequency to be expressed per Reactor Calendar Year (also commonly expressed as per Reactor-Year, which is the terminology that will be used in the remainder of this document) in order to be consistent with the needs of Reg. Guide 1.174 (that is, for comparison to the quantitative acceptance guidelines). This represents the annual risk contribution to CDF/LERF from at power operations, and, therefore, reflects the time the plant is at power.*
>
> *Some applications, however, require the analyst to consider the conditional probability of core damage/large early release given the plant is at power. One such example is a risk monitor, which uses PRA to assess the risk of the plant at a given configuration and operating state. For this application we consider initiating event frequencies in units of per Reactor Critical Year, or the annual frequency of the initiating event assuming the reactor is critical the entire year.*

The LOOP events can occur any time, regardless of plant operating state. When LOOP frequency is used in the PRA model, the value obtained from equation (1) should normally be multiplied by the plant availability factor, $F_{at\text{-}power}$, where

$F_{at\text{-}power}$ = fraction of year that, on average, the plant is at power, for example, 90% [0].

The time needed to restore offsite power after a LOOP event varies on different event categories. NUREG/CR-6890 [0] concludes that Plant-centered and switchyard-centered LOOPs have the lowest mean duration, while weather-related LOOPs have the highest. Similarly, the plant-centered and switchyard-centered probability of exceedance versus duration curves lie below those for the grid-related LOOPs, while the weather-related curve lies above all the others. In order to perform power recovery analysis, four LOOP frequencies can be calculated based on the four applicable event categories as:

$$f_{LOOP-At-Power-Plant} = \frac{\#\,of\ \ Applicable\ \ \ Plant\,LOOP\ \ \ events}{Rx\ \ \ Calendar\ \ \ Years} \tag{2}$$

$$f_{LOOP-At-Power-Switchyard} = \frac{\#\,of\ \ Applicable\ \ \ Switchyard\,LOOP\ \ \ events}{Rx\ \ \ Calendar\ \ \ Years} \tag{3}$$

$$f_{LOOP-At-Power-Grid} = \frac{\#\,of\ \ Applicable\ \ \ Grid\,\mathrm{Re}\,lated\,LOOP\ \ \ events}{Rx\ \ \ Calendar\ \ \ Years} \tag{4}$$

$$f_{LOOP-At-Power-Weather} = \frac{\#\,of\ \ Applicable\ \ \ Weather\,LOOP\ \ \ events}{Rx\ \ \ Calendar\ \ \ Years} \tag{5}$$

Based on EPRI's LOOP Report [0], for the past 10 years (2003–2012), on average, the frequency of losing all offsite power was approximately 0.03 per year per unit. This is slightly higher than the average for the period from 2002 through 2011 (0.02 per year). There has been a slight upward trend in both the frequency and duration of losses of offsite power, in part due to a higher rate of weather-related events in recent years. The findings confirm that natural phenomena (weather and seismic activity) are important contributors to the loss of offsite power experience.

The significant differences between NUREG and EPRI LOOP events cannot be simply resolved by combining the NUREG LOOP events with the EPRI LOOP events. In the LOOP frequency calculation, the site-specific LOOP initiators have to be examined to make sure all the applicable LOOP events are included appropriately. For example, for an inland plant, it is normally not vulnerable to the high wind effects and the flood surge effects of hurricanes. The LOOP events involving hurricanes should be excluded from the applicability to the site. For a site in an area that is not susceptible to severe snow/ice storms, LOOP events involving severe snow/ice storms should be excluded.

Table 1 provides the generating unit years from 2003 to 2012. Table 2 shows the applicable LOOP events at power to Callaway, an inland plant. Please note that one plant-centered LOOP event is exclude; four weather-related LOOP events are excluded; eight Switchyard-Centered LOOP events are also excluded because of their applicability. The excluded LOOP events are listed in Table 3. So the total applicable number of LOOP events for Callaway is 17 for the past 10 year period from 2003 to 2012. It should be noted that each reactor event is treated independently if two or more reactor plants were affected by a common cause LOOP event. These events are treated as they were multiple independent events. The LOOP frequencies at power for Callaway are calculated as:

$$f_{LOOP-At-Power} = \frac{\#\,of\ \ Applicable\ \ LOOP\ \ Events}{Rx\ \ Calendar\ \ Years} = \frac{17}{1035.66}$$

= 1.64E-2 (/rx-calendar-yr)

$$f_{LOOP-At-Power-Plant} = \frac{\# of \ Applicable \quad Plant\, LOOP \quad events}{Rx \quad Calendar \quad Years} = \frac{1}{1035.66}$$

= 9.66E-4 (/rx-calendar-yr)

$$f_{LOOP-At-Power-Switchyard} = \frac{\# of \ Applicable \quad Switchyard\, LOOP \quad events}{Rx \quad Calendar \quad Years}$$

= 3.86E-3 (/rx-calendar-yr)

$$f_{LOOP-At-Power-Grid} = \frac{\# of \ Applicable \quad Grid\, \mathrm{Re}lated\, LOOP \quad events}{Rx \quad Calendar \quad Years}$$

= 5.79E-3 (/rx-calendar-yr)

$$f_{LOOP-At-Power-Weather} = \frac{\# of \ Applicable \quad Weather\, LOOP \quad events}{Rx \quad Calendar \quad Years}$$

= 5.79E-33 (/rx-calendar-yr)

For at-power PRA model quantification, the LOOP frequency should be multiplied by plant availability factor.

Table 1: Generating Unit Years from 2003 to 2012

Year	Unit Capability (%)	EPRI Generating Years	Reactor Critical Years
2003	91.4	103	94.14
2004	91.4	103	94.14
2005	92.0	103	94.76
2006	91.4	103	94.14
2007	91.5	103.66	94.85
2008	91.0	104	94.64
2009	91.3	104	94.95
2010	91.3	104	94.95
2011	91.3	104	94.95
2012	91.2	104	94.85
10 Year Total	91.4	1035.66	946.38

Note: Unit Capabilities taken from the 2012 INPO Annual Report

Table 2: Applicable LOOP Events at Power to Callaway Plant (2003-2012)

Site Name	Unit Number	Date	Category	EPRI Category	Condition	Applicable to Site
Palisades	0	3/25/2003	PLANT	Ia	Refueling	YES
Palo Verde	1	6/14/2004	GRID	Ia	100% Power	YES
Palo Verde	2	6/14/2004	GRID	Ia	100% Power	YES
Palo Verde	3	6/14/2004	GRID	Ia	100% Power	YES
Catawba	1	5/20/2006	SWITCHYARD	Ia	100% Power	YES
Catawba	2	5/20/2006	SWITCHYARD	Ia	100% Power	YES
Surry	1	10/7/2006	SWITCHYARD	Ia	100% Power	YES
Duane Arnold	1	2/24/2007	WEATHER	Ia	Refueling	YES
Oyster Creek	0	7/12/2009	GRID	Ia	100% Power	YES
Surry	1	4/16/2011	WEATHER	Ia	100% Power	YES
Surry	2	4/16/2011	WEATHER	Ia	98.3% Power	YES
Browns Ferry	1	4/27/2011	WEATHER	Ia	75% Power	YES
Browns Ferry	2	4/27/2011	WEATHER	Ia	75% Power	YES
Browns Ferry	3	4/27/2011	WEATHER	Ia	100% Power	YES
North Anna	1	8/23/2011	GRID	Ia	100% Power	YES
North Anna	2	8/23/2011	GRID	Ia	100% Power	YES
Wolf Creek	0	1/13/2012	SWITCHYARD	Ia	100% Power	YES

Table 3: Excluded LOOP Events to Callaway Plant (2003-2012)

Nulcear Unit	Date	Category	Comment
Brunswick 1	8/14/2004	WEATHER	Hurricane Charley
St. Luice 1	9/25/2004	WEATHER	Hurricane Jeane, Salt Spray
St. Luice 2	9/25/2004	WEATHER	Hurricane Jeane, Salt Spray
Brunswick 2	11/1/2006	SWITCHYARD	Loss of preferred offsite power
Point Beach 1	1/15/2008	SWITCHYARD	Loss of preferred offsite power
Byron 2	3/25/2008	SWITCHYARD	Loss of preferred offsite power
Salem*	7/29/2003	SWITCHYARD	At Callaway one off-site power feeds one safety bus and the other off-site power source feeds the other safety bus as a normal configuration. This event does not apply to Callaway
Dresden*	5/5/2004	SWITCHYARD	At Callaway this would be a partial LOOP as Callaway's could have lost one off-site source on clearing for a breaker failure
Nine Mile Point*	5/13/2008	SWITCHYARD	This event is not applicable to Callaway because of its multiple transmission line sources and separation that one off-site power feeds one safety bus and the other off-site power source feeds the other safety bus as a normal configuration
Millstone*	5/24/2008	SWITCHYARD	Callaway has separation in the switchyard and for the off-site power sources. One off-site power feeds one safety bus and the other off-site power source feeds the other safety bus. A single relay failure could only cause a loss of one of the sources (partial LOOP)
Braidwood*	7/30/2009	SWITCHYARD	Callaway does not power the safety busses from the unit auxiliary transformer and uses a 2 out of 2 coincidence on its sudden pressure relays
Byron 2	1/30/2012	SWITCHYARD	At Callaway one off-site power feeds one safety bus and the other off-site power source feeds the other safety bus as a normal configuration. This event does not apply to Callaway
Catawba 1,2	4/4/2012	PLANT	Callaway does not use underfrequency trips in the off-site power sources and the off-site power sources are independent of the main generator
Oyster Creek	10/29/2012	WEATHER	Hurricane Sandy

Note: * excluded after detail analysis by site Electric/I&C engineer mainly because of switchyard design differences

5. LOOP FREQUENCIES FOR SHUTDOWN

It is assumed that the at-power events could just as easily occur with the plant at shutdown as with it at power, therefore, the at-power LOOP events are included in the estimation of the frequency of LOOP while at shutdown. The at power applicable LOOP events are considered to be category Ia or Ib events from EPRI Reports and the shutdown LOOP events are category IV. The LOOP frequency contributed by category IV events at shutdown can be calculated as:

$$f_{LOOP-IV} = \frac{\#\,of\;\; Applicable\;\; CategoryIV\;\; Events}{Rx\;\; Shutdown\;\; Years} \tag{6}$$

The total LOOP frequency for shutdown model is as:

$$f_{LOOP-SD} = f_{LOOP-At-Power} + f_{LOOP-IV} \tag{7}$$

If there are no special maintenance conditions that do not occur during or immediately following operations and that could cause LOOP during shutdown, then the LOOP frequency for shutdown at this configuration equals the LOOP frequency for at-power model and it is as:

$$f_{LOOP-SD} = f_{LOOP-At-Power} \tag{8}$$

For Callaway, there are four category IV LOOP events that are applicable from 2003 to 2012 (EPRI category IV events only, given in Table VI). The LOOP frequency contributed by category IV events is as:

$$f_{LOOP-IV} = \frac{\#\,of\;\; Applicable\;\; CategoryIV\;\; Events}{Rx\;\; Shutdown\;\; Years}$$

$$= \frac{4}{(1035.66 - 946.38)} = \frac{4}{89.28} = 4.48E-2 \qquad \text{(/rx-shutdown-yr)}$$

The total LOOP frequency for shutdown model is as:

$$f_{LOOP-SD} = f_{LOOP-At-Power} + f_{LOOP-IV}$$

= 1.64E-2 + 4.48E-2 = 6.12E-2 (/rx-shutdown-yr)

Converting to hours:

$f_{LOOP-SD} =$ 6.12E-2/365/24=6.99E-6 (/shutdown-hour)

Table 4: Applicable LOOP IV Events to Callaway Plant (2003-2012)

Site Name	Unit Number	Date	Category	EPRI Category	Condition	Applicable to Site
Millstone	3	4/25/2007	SWITCHYARD	IV	Refueling	YES
Wolf Creek	1	4/7/2008	SWITCHYARD	IV	Refueling	YES
Diablo Canyon	1	5/12/2007	GRID	IV	Refueling	YES
Point Beach	1	11/27/2011	SWITCHYARD	IV	CSD	YES

6. DISCUSSION

While the author was reviewing LOOP frequency calculations for some plants, it was found that the following equation is used to calculate the LOOP frequency at power:

$$f_{LOOP-At-Power} = \frac{\#\,of\ \ Applicable\ \ LOOP\ \ Events}{Rx\ \ Critical\ \ Years} \tag{9}$$

It is obviously that equation (9) overestimates the LOOP frequency. For the past 10 year time period (2003-2012), the industry average unit capability is 91.4%. So the LOOP frequency at-power by equation (9) is overestimated by about 9.4%. This is similar as multiplying the result from equation (1) by an additional term $1/F_{at\text{-}power}$.

In at-power PSA, for initiating event frequencies in unit of 1/reactor-calendar-year, usually these frequencies are used by multiplying the plant availability factor. Per Reference [11], EPRI-3002000774, this does apply to the at-power LOOP frequency. This statement is different from Reference [12]. For online risk monitor tools, such as, EOOS, Safety Monitor, the LOOP frequency may not be multiplied by the plant availability factor.

Some LOOP events, particularly weather-related or grid-centered events, may not be applicable for some plants based on geographical and climatological conditions. For example, an inland plant is not susceptible to hurricane and salt spray events.

Detail analysis from engineering department is very helpful to determine the applicability of plant-centered LOOP events and switchyard-centered LOOP events.

The LOOP events at power, during which no plant trip was observed were not included in the frequency analyses in NUREG/CR-6890 [0] and NRC's analysis of loop events 2010 update [0]. In some other LOOP frequency calculations, these events are also excluded. This may underestimate the realistic site specific LOOP frequency. It is suggested to review the LOOP events that do not cause a scram to determine if the event would result in a scram at the associated site. If the event would result in a scram, then the event should be included in the LOOP frequency calculation for the site. For example, the LOOP event at Nine Mile Point 1 (05/13/2008) is an Ia event for most plants, which did not involve a reactor trip.

In NUREG/CR-6890, for shutdown operation, only the LOOP-SD events were used. In an unusual situation (such as the current situation in Japan with most units are shutdown), this could bring significant deviation, even unreasonable result, most likely, it may significantly underestimate the maintenance activities contribution to LOOP at shutdown. So it is suggested to use equation (3) and (4) to calculate the LOOP frequency for shutdown model.

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