Quantitative Assessment of Human-Induced Loss of Offsite Power (HI-LOOP) Event Frequencies at U.S. Commercial Nuclear Power Plants (NPP)

2013 TECHNICAL REPORT

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This document does NOT meet the requirements of 10CFR50 Appendix B, 10CFR Part 21, ANSI N45.2-1977 and/or the intent of ISO-9001 (1994).

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Abstract

This report provides a framework for developing improved methods and models for quantifying the frequencies of human-induced loss of offsite power (HI-LOOP) initiators at U.S. commercial nuclear power plants (NPPs). Leveraging these methods and models should enhance the NPP probabilistic risk assessment model completeness and would be useful for the NPP on-line risk models. The primary focus of the report is on investigating the impact of human activities on the frequencies of switchyard-centered and plant-centered HI-LOOP events during the NPP Power Operation (Power Op) and Hot Standby (HSB) conditions as these two LOOP categories are more likely to involve HI-LOOP contributors that are known to the plant operators. Moreover, the scope of this investigation is limited to total LOOP events covering the period 1986–2007. Both partial and total LOOP events are addressed for plant-centered HI-LOOPs, but only total LOOP events are addressed for the switchyard-centered HI-LOOPs. The latter limitation is due to data limitations.

The information gathered from the analyzed total LOOP events was used to identify the types of human activities that have historically contributed to Power Op and HSB switchyard-centered and plant-centered LOOP initiators and to develop methods to quantitatively evaluate the impact of human activities on the LOOP frequencies. In this investigation, quantitative adjustment factors (AF) were derived to enable the NPP risk analyst to adjust the LOOP initiating event frequency when switchyard-centered human activities are performed during Power Op and HSB conditions. For the plant-centered human activities during Power Op and HSB conditions, a methodology based on existing human reliability analysis methods was developed to estimate the human failures that lead to initiating HI-LOOP events. Specific examples are provided to demonstrate how the switchyard-centered AFs and the plant-centered human failure events can be incorporated into a typical NPP online risk monitor.

Keywords
Equipment-out-of-service (EOOS)
Human reliability analysis (HRA)
Loss of offsite power (LOOP)
On-line risk monitoring

Glossary of Terms

AF	Adjustment Factor
ASEP	Accident Sequence Evaluation Program
BE	Basic Event
CBDTM	Caused Based Decision Tree Method
CDF	Core Damage Frequency
EF	Error Factor
EOOS	Equipment Out Of Service software model
EPRI	Electric Power Research Institute
HEP	Human Error Probability
HFE	Human Failure Event
HI-LOOP	Human-Induced Loss of Offsite Power
HRA	Human Reliability Analysis
HSB	Hot Standby Condition (plant critical but at zero power)
LCO	Limited Condition for Operation
LER	Licensing Event Report
LERF	Large Early Release Frequency
LOOP	Loss of Offsite Power (is also abbreviated LOSP)
NPP	Nuclear Power Plant
OLRM	On-line risk monitor
Power Op	Power Operation (plant at a power level >0%)
PRA	Probabilistic Risk Assessment (same as PSA)
PSA	Probabilistic Safety Assessment (same as PRA)

THERP	Technique for Human Error Rate Prediction
T&M	Test and Maintenance

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Section 1: Proposed Assessment of HI-LOOP Event Frequencies

1.1 Objectives

Both human failures and loss of offsite power (LOOP) initiators are known to be important nuclear power plant (NPP) risk contributors. These facts motivated the interest to investigate the human-induced LOOP (HI-LOOP) initiators. The objective of the present contribution is to develop improved methods and models to quantify the HI-LOOP event frequencies where these values could be used in NPP on-line risk monitor (OLRM) models.

To support this investigation, a survey was conducted to better understand how LOOP events are treated in the U.S. NPP risk models. The survey results provided an additional incentive for developing new methods and models for assessing Power Operation (Power Op) and Hot Standby (HSB) HI-LOOPs. The survey questionnaire and responses are documented in Appendix A of this report. The responses provided by the sampled NPPs to the first survey question indicates that not all NPP risk models assess the risk impact of switchyard-centered and plant-centered human activities. Hence, the availability of quantitative methods to assess HI-LOOPs should assist the PRA analyst in quantifying the increased risk due to HI-LOOPs during operational and/or maintenance activities. This report provides a framework for developing these quantitative methods.

1.2 Background

Consistent with the guidelines provided in NUREG/CR-6890 [1] and other industry reports, LOOP events are typically categorized as either switchyard-centered, plant-centered, grid-related, or weather-related. NUREG/CR-6890 defines each of these four categories[1] as follows:

- ***Switchyard-Centered LOOP Event:*** A LOOP event in which the equipment or human-induced failure of the equipment[2] in the switchyard plays the major role in the loss of offsite power. The line of demarcation between

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[1] Note that these categories are assumed to be mutually exclusive.

[2] Note that this definition is based on what components are affected, not necessarily where the activity is conducted. Thus, for example, LOOPs caused by switchyard breaker relay test or maintenance are considered switchyard-centered LOOPs, regardless of whether the test is conducted in the switchyard or in the control room.

switchyard-centered events and grid-related events is the output bus bar in the switchyard. The bus bar is considered part of the switchyard.

- ***Plant-Centered LOOP Event:*** A LOOP event in which the design and operational characteristics of the nuclear power plant unit itself plays the major role in the cause and duration of the loss of offsite power. Plant-centered failures typically involve hardware failures, design deficiencies, human errors, and localized weather-induced faults (e.g., caused by lightning). The line of demarcation between plant-centered and switchyard-centered events is the nuclear power plant main and station power transformers high-voltage terminals. Both transformers are considered part of the switchyard.
- ***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, in which the weather was widespread, not just centered on the site, and capable of major disruption. Severe weather is defined to be weather with forceful and non-localized effects. An example is storm damage to transmission lines instead of just debris blown into a transformer. This does not mean that the event had to actually result in widespread damage, as long as the potential is there. Examples of severe weather include thunderstorms, snow, and ice storms. Lightning strikes, though forceful, are normally localized to one unit, and so are coded as plant-centered or switchyard-centered. Hurricanes, strong winds greater than 125 miles per hour, and tornadoes are examples of extreme-weather-related LOOPs.

The average LOOP event frequency of each category can be calculated using applicable plant-specific and industry operating experience (OE) as reported in NUREG/CR-6890 [1] and other available data sources. However, use of the average frequency value for each LOOP category does not allow on-line risk assessments to account for changes in the plant risk during activities and conditions that may significantly affect its LOOP frequency.

To compensate for this limitation, many NPP OLRMs provide "slider bars" (or the equivalent) to select adjustment factors (AF) to be applied to the frequency of each LOOP event during activities that could affect that category. For example, during severe weather conditions the weather-related LOOP frequency may increase. Also, during periods of potential grid instability, or when heavy use could cause voltage drops, the grid-related LOOP frequency may increase. Similar adjustments to the switchyard-centered and plant-centered LOOP frequencies could be applied during conditions and activities that increase the frequency for these LOOP categories. The NPP operators could use these adjustment factors to appropriately manage plant overall risk.

Given that the application of these adjustment factors can be used to assess on-line plant risk, it is desirable to develop stronger bases for these adjustment factors and to define conditions where they should be applied. Existing U.S. nuclear plant experience can be used to define both quantitative factors and the conditions where they should be applied. Where experience is not available or applicable, an HRA-based approach can be used to quantify the HI-LOOP frequency.

Of the four aforementioned LOOP categories, switchyard-centered and plant-centered LOOP categories are more likely to involve human-induced LOOP contributors that are known to the plant operators. This knowledge is important, because it will allow the operators to factor the effect of human activities that affect these LOOP contributors in OLRM evaluations. Thus, these two LOOP categories are most likely to benefit from improved HI-LOOP assessment methods, since there is a higher potential to modify, schedule, and otherwise manage these activities in order to minimize plant risk. Note that the risk of these human activities can be minimized only if the NPP operators are both aware of the activity and its risk impact and can control either how or when the activity is performed.

The scope of the present investigation is limited to total LOOP events during the period 1986 – 2007. Partial LOOPs were not considered due to non-existence of relevant data on partial LOOP events in the U.S. nuclear industry. As a result, in this report a LOOP event is considered a total LOOP, not a partial LOOP, unless otherwise stated. This investigation is also limited to HI-LOOPs occurring during Power Op and HSB conditions. HI-LOOPs occurring during other operating plant conditions (i.e., subcritical) are excluded from the scope of the investigation for the reasons:

- The risk associated with HI-LOOPs occurring during shutdown conditions is generally performed qualitatively at most U.S. NPPs, using a defense-in-depth approach rather than using a quantitative model. This qualitative treatment replaces the need for quantitative methods.
- Plant configurations during shutdown conditions could vary widely from plant to plant, depending on plant design and operating practices.
- The risks of HI-LOOPs during Power Op and HSB conditions are expected to dominate risks of HI-LOOP events that may occur during shutdown conditions. This can be due to the relatively short time available to reach a safe end state for Power Op and HSB events as compared to LOOPs during shutdown conditions.

1.3 Investigation Focus and Report Organization

The present contribution focuses on investigating the U.S. NPP experience related to HI-LOOPs and developing improved methods and models to quantify the switchyard-centered and plant-centered HI-LOOP event frequencies associated with plant activities during Power Op and HSB conditions. These HI-LOOP event frequencies could be used in the NPP on-line risk assessment model.

Section 2 of the report reviews the U.S. NPP experience regarding HI-LOOP events. Using insights from that experience, Section 3 summarizes the U.S. nuclear experience related to HI-LOOPs due to activities associated with switchyard equipment. This section uses this information to provide a quantitative method using generic adjustment factors (AF) to account for the potential for HI-LOOPs due to activities on switchyard equipment during power operation conditions. Because there is relatively little experience related to plant-centered HI-LOOPs, Section 4 provides a quantitative method using HRA tools to account for the potential for HI-LOOPs due to activities on plant equipment. Both subsections 3.3 and 4.5 describe how to incorporate the HI-LOOP methodology into a typical fault tree based NPP OLRM. To help clarify the implementation processes; each subsection provides a demonstration example. Section 5 summarizes the core findings of this investigation.

The report organization is shown graphically in Figure 1-1.

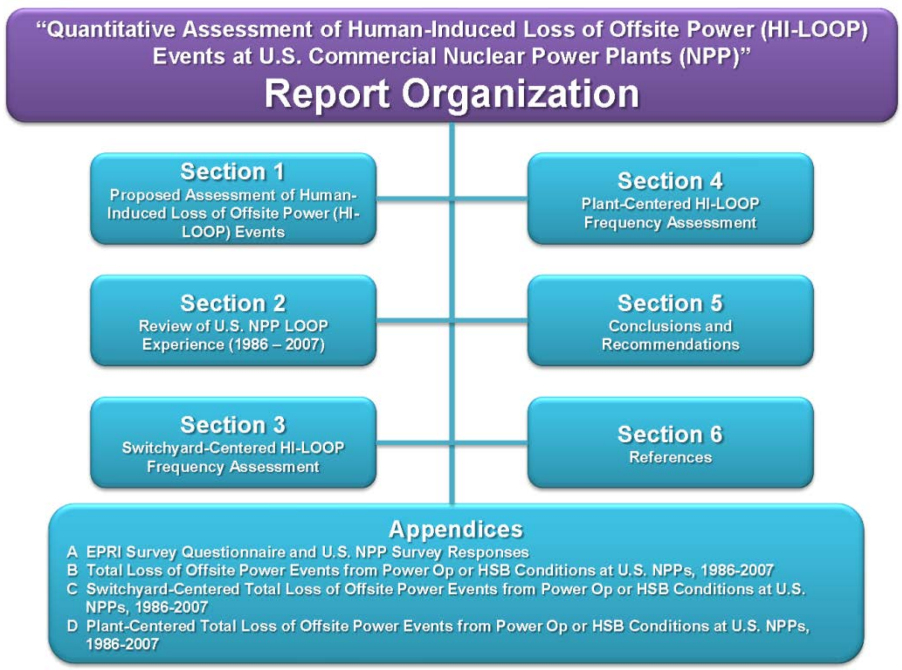

Figure 1-1
Report Organization by Section

Section 2: Review of U.S. NPP LOOP Experience

A review of LOOP events in the U.S. nuclear industry was performed to identify Power Op and HSB LOOPS during the period 1986 - 2007; the events were those assigned to EPRI LOOP categories Ia, Ib, II, IIa, and IIb (see Appendix B, Table B-2 for category definitions). The time interval was selected based on readily available information and the period was considered to be sufficient for providing statistically significant insights on HI-LOOPs. The data was collected from multiple sources. The primary sources were EPRI reports that described Power Op and HSB LOOP events for the stated period 1986 - 2007; these reports included the following:

- EPRI TR-110398 [2], which documented LOOPs in the period 1984-1997
- EPRI 1000158 [3], which documented LOOPs in the period 1988-1999
- EPRI 1002987 [4], which documented LOOPs in the period 1990-1993
- EPRI 1009889 [5], which documented LOOPs in the period 1994-2003
- EPRI 1013239 [6], which documented LOOPs in the period 1996-2005
- EPRI 1016484 [7]. which documented LOOPs in the period 1998-2007

Note that most of these reports cover a period longer than that described above; however, whenever more than one of these reports covered the same period, the most recently published report was used as the data source. In order to ensure data completeness and consistency, NUREG/CR-6890 [1] Table A-1, which documents LOOPs in the period 1986 - 2004, was also used. Moreover, consistent with the main focus of this investigation, only total LOOP events, covering the period between 1986 and 2007 during Hot Standby (HSB) or Power Operation (Power Op) conditions were reviewed.

One of the objectives of reviewing the LOOP events was to categorize the events as either switchyard-centered, plant-centered, grid-related, or weather-related. While NUREG/CR-6890 [1] assigns each LOOP event to one of these categories; EPRI reports do not. However, EPRI's summary of each LOOP event can typically be used to assign the LOOP to one of the aforementioned categories. In order to ensure the validity of this classification, the Licensee

Event Report (LER)[3] issued on each LOOP event was also reviewed. These reviews provided a better understanding of human activities and actions (if any) that contributed to the LOOP events.

Appendix B, Table B-1 summarizes the information obtained from the aforementioned sources. For completeness, Table B-1 includes all total LOOP events at U.S. nuclear plants reported from the above EPRI sources, NUREG/CR-6890, and from plant-specific LERs for the period 1997 - 2007, regardless of plant condition, LOOP category, or cause of the event. However, only switchyard-centered or plant-centered events that occurred during Power Op and HSB conditions are of interest in this analysis. It is important to note that the category and/or cause for some LOOP events were revised from those cited in NUREG/CR-6890 or EPRI references. These changes were based on information presented in the LER; all the changes made are documented in Table B-1. Once again, LER information was found to be essential in order to obtain complete understanding of the role, if any, that human activities (e.g., test and maintenance activities) played in causing the LOOP events.

The information and data gathered were used to identify the types of human activities that have historically contributed to Power Op and HSB switchyard-centered and plant-centered LOOP initiators and to develop methods to quantify the effect of human activities and actions on the LOOP frequencies. Section 3 discusses HSB and Power Op switchyard-centered total LOOP events and Section 4 discusses HSB and Power Operation plant-centered total LOOP events.

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[3] Note that these LERs were obtained from the NRC's internet LER search page, *https://lersearch.inl.gov/SearchCriteria.aspx*.

Section 3: Switchyard-Centered HI-LOOP Frequency Assessment

3.1 Framework for Switchyard-Centered HI-LOOP Frequency Assessment

Table B-1 of Appendix B lists the total of Loss of Offsite Power (LOOP) events at any U.S. NPP during the period 1986 - 2007. Table C-1 of Appendix C lists switchyard-centered LOOPs during Power Op and HSB conditions extracted from the larger population of LOOP events listed in Table B-1. Each of these events was reviewed to identify whether a human activity on switchyard equipment was a contributor to the event.

Consistent with NUREG/CR-6890 [1], switchyard-centered HI-LOOPs are defined as LOOP events associated with equipment in the switchyard. Not every switchyard-centered HI-LOOP event involves the physical presence of humans within the switchyard boundaries; some events are due to human activities (e.g., testing) on switchyard equipment from locations other than the switchyard (mostly, from the NPP control room).

Each of the switchyard-centered LOOP events was reviewed to identify whether a human activity on equipment in the switchyard was a contributor to the event occurrence. These activities were further reviewed and grouped into five general switchyard activity types (i.e., 0 through 4) in Table C-1. A framework was then developed to use this information to derive quantitative adjustment factors (AFs) which can be used to adjust the LOOP initiating event frequency when these switchyard activities are in progress during Power Op and HBS conditions. The concept of using adjustment factors is adopted from practices employed by Entergy in its OLRM. The framework developed in this work provides a well-structured methodology to assess the potential for human activities on switchyard equipment that could result in switchyard-centered HI-LOOP events based on the available historical LOOP data. As a result, the proposed framework is empirical in nature.

As it is the case with all empirically-derived correlations, since Tables B-1 and C-1 are based on the U.S. NPP LOOP experience for the period 1986 - 2007, the resulting adjustment factors are applicable to that period and reflect the as-built and as-operated plants in that period. This period was selected because the data was readily available during this investigation and the period can be considered long enough to obtain a statistically meaningful understanding of the data trends and to estimate an average frequency for each LOOP category. The period 1986 – 2007 is much longer than the typical 10-year data interval used in NPP PRAs to estimate the probability/frequency of accident initiators. The longer interval used in the present investigation was deemed necessary to compensate for the relative scarcity of switchyard-centered LOOP events. As it is commonly known in the PRA field, it is appropriate to periodically update this data with more recent data as it becomes available and to exclude older data, if it is judged to be no longer representative of current operating practices.

Moreover, the data included in this investigation covered only total LOOP events in the period 1986 – 2007 and did not cover partial LOOPs as documentation of the occurrence of such events was very limited. The effect of excluding partial LOOP events can lead to potential underestimation of the risk impact of the human activities. However, this limitation is partially mitigated by the fact that partial LOOP events are not as likely to be risk significant as total LOOP events. In addition, the types of human activities that result in partial LOOPs, in many cases, are the same types of activities that result in total LOOPs.

It should also be noted that all LOOP events are assumed to be applicable to all plants, regardless of plant design, operation, or geographical location in the U.S. The assumption that the data is poolable and applicable for all plants is deemed appropriate for the purpose of this report, which is intended for general use as a framework. However, some data may be excluded on a plant-specific basis, if deemed appropriate by plant-specific features, operating procedures, and/or plant location. Pooling the data assumes that there is a fair degree of consistency in plant switchyard activities from plant to plant and over the entire period and that the effects of these activities on offsite power are consistent from plant to plant. These assumptions are not necessarily valid for all plants; however, applying them should lead to a reasonable estimate of the switchyard-centered LOOP frequency associated with activities which could lead to a LOOP event in a given plant. Another important aspect is that is necessary to make an assumption regarding the number of days that each type of human activity is conducted in a typical year. These assumptions are used to develop the conditional probability that a particular work activity is being performed in any year. These are assumed applicable for all plants and over the entire data interval. Potential inconsistencies in this assumption are somewhat mitigated by the fact that data is used only to adjust, not to establish, the plant-specific LOOP frequency in each PRA model.

Section 3.2 describes details of the human-induced switchyard-centered total Power Op and HSB LOOP frequency assessment methodology and Section 3.3 describes its implementation for a typical on-line fault tree based risk model.

3.2 Switchyard-Centered HI-LOOP Frequency Assessment Methodology

The U.S. NPP LOOP experience can be used to determine the historical fraction of switchyard-centered Power Op and HSB LOOP events that are human-induced. This fraction, together with the fraction of the Power Op and HSB plant condition where various types of Test and Maintenance (T&M) activities are being conducted in the switchyard, can be used to estimate the adjustment factor (AF), that is, the fractional increase (or decrease) in the average Power Op or HSB switchyard-centered LOOP frequency due to a human activity affecting switchyard equipment.

The "adjustment factor" can be defined as follows:

$$AF_{shi} = \frac{\nu_{shi}}{\bar{\nu_s}} \qquad \textit{Eq. 3-1}$$

where,

ν_{shi} = frequency of Power Op and HSB switchyard-centered LOOPs during a human activity i affecting switchyard equipment

$\bar{\nu_s}$ = average frequency of Power Op and HSB switchyard-centered LOOPs.

The value of $\bar{\nu_s}$ in units of "per reactor year" is calculated using the following expression,

$$\bar{\nu_s} = \frac{N_s}{T} * CF \qquad \textit{Eq. 3-2}$$

where,

N_s = number of Power Op and HSB switchyard-centered LOOPs during the data interval, regardless of cause,

T = number of Power Op and HSB U.S. NPP years in data interval,

CF = correction factor equal to the number of Power Op and HSB U.S. NPP years divided by the number of U.S. NPP calendar years in data interval [4].

Based on LOOP event descriptions provided in the NUREG/CR-6890 [1], EPRI, and, LER data sources, human activities on switchyard equipment during Power Op or HSB conditions which resulted in a LOOP event suggest that these activities can be conveniently categorized into one of five types as follows:

- Type 0: No switchyard maintenance
- Type 1: Switchyard battery maintenance
- Type 2: Switchyard Instrumentation and Control (I&C) maintenance, including breaker work
- Type 3: Heavy maintenance, e.g., bucket trucks in switchyard, cranes in/near switchyard, etc.
- Type 4: Other maintenance

[4] This correction factor ensures that the units of ν_{shi} are in "per reactor-years" as required by the PRA Standard.

Note that these activities are labeled as "maintenance" but may include activities other than those performed by plant maintenance crews and should include any activity on any switchyard equipment, including infrequent actions performed on switchyard equipment by plant maintenance, plant Operations, offsite utility crews, etc.

For each of these types of human activity, ν_{shi}, the instantaneous frequency of a Power Op and HSB switchyard-centered HI-LOOP in units of "per reactor year", is given by:

$$\nu_{shi} = \frac{N_{shi}}{T_{shi}} * CF \qquad \text{Eq. 3-3}$$

where,

N_{shi} = number of Power Op and HSB switchyard-centered LOOPs due to human activity i during the data interval,

T_{shi} = number of Power Op and HSB U.S. nuclear plant years in data interval during which human activity i is in progress.

The latter term is given by,

$$T_{shi} = f_{shi}T \qquad \text{Eq. 3-4}$$

where,

f_{shi} = fraction of time during Power Op and HSB conditions in which human activity i is in progress.

Using the above parameters, the Adjustment Factors can be calculated by combining Equations (3-1), (3-2), (3-3), and (3-4) as follows:

$$AF_{shi} = \frac{\nu_{shi}}{\nu_s} = \frac{\left(\frac{N_{shi}}{f_{shi}T}\right)*CF}{\left(\frac{N_s}{T}\right)*CF} = \frac{N_{shi}}{N_s f_{shi}}. \qquad \text{Eq. 3-5}$$

In order to calculate AF_{shi}, numerical values for N_s, N_{shi}, and f_{shi} are needed.

Table B-1 in Appendix B provides the total number of Power Op and HSB switchyard-centered LOOPs regardless of cause (N_s) and the number of Power Op and HSB switchyard-centered LOOPs which occurred during each human activity i in the data interval (N_{shi}). The values are as follows:

- Total number of Power Op and HSB switchyard-centered LOOPs:
  $N_s = 37$.
- Number of Power Op and HSB switchyard-centered LOOPs during switchyard battery maintenance (i = 1):
  $N_{sh1} = 4$

- Number of Power Op and HSB switchyard-centered LOOPs during I&C maintenance, including breaker work (i =2):
  $N_{sh2} = 10$
- Number of Power Op and HSB switchyard-centered LOOPs during heavy switchyard maintenance (i = 3):
  $N_{sh3} = 1$
- Number of Power Op and HSB switchyard-centered LOOPs during other switchyard maintenance (i = 4):
  $N_{sh4} = 2$
- Number of Power Op and HSB switchyard-centered LOOPs during no switchyard maintenance conditions (i = 0):
  $N_{sh0} = N_s - (N_{sh1} + N_{sh2} + N_{sh3} + N_{sh4)} = 20$

Values of f_{shi} were determined by discussions with plant personnel familiar with past maintenance in the switchyard at a reference plant. These discussions led to an estimate of the total number of days that each type of switchyard human activity is in progress during Power Op and HSB conditions during a typical year. These values are assumed to apply generically for the entire U.S. nuclear industry. The fractions f_{shi} are the number of days associated with each switchyard human activity type divided by 365. The fractions are the conditional probability that the particular switchyard activity is being performed at any given time during Power Op and HSB conditions.

These fractions are estimated as follows:

For Switchyard Battery Maintenance (i = 1):
Assume 1 day of battery test and maintenance activities in the switchyard during a typical operating year. Thus,

$$f_{sh1} = \frac{1\ day}{365\ days} = 2.74E\text{-}03$$

For Switchyard I&C Maintenance (i = 2):
Assume 5 days of I&C maintenance activities (including circuit breaker testing and manipulation) in the switchyard during a typical operating year. Thus,

$$f_{sh2} = \frac{5\ days}{365\ days} = 1.37E\text{-}02$$

For Heavy Switchyard Maintenance (i = 3):
Assume 1 day of heavy maintenance activities in the switchyard during a typical operating year. Thus,

$$f_{sh3} = \frac{1\ day}{365\ days} = 2.74E\text{-}03$$

For Other Switchyard Maintenance (i = 4):
Assume 20 days of other test and maintenance activities in the switchyard during a typical operating year. This work is assumed to be light work and

not having the potential to cause a LOOP to the extent of the other types of human activities described above. Thus,

$$f_{sh4} = \frac{20\ days}{365\ days} = 5.48E\text{-}02$$

For No Switchyard Maintenance (i = 0):
This fraction is the complement of the sum of the above fractions, i.e.,

$$f_{sh0} = 1 - (f_{sh1} + f_{sh2} + f_{sh3} + f_{sh4}) = 0.926 \qquad \text{Eq. 3-6}$$

Using the above values for N_s, N_{shi}, and f_{shi}, the values for AF_{shi} were calculated using Eqn. (3-5). These values are presented in Table 3-1.

Table 3-1
Adjustment Factors for Average Power Op and HSB Switchyard-Centered LOOP Frequency due to Human Activity on Switchyard Equipment

Adjustment Factor	Normalized Value
AF_{sh1}, Switchyard Battery Maintenance (Type 1)	39.5 (highest)
AF_{sh2}, Switchyard I&C Maintenance (Type 2)	19.7
AF_{sh3}, Heavy Switchyard Maintenance (Type 3)	9.9
AF_{sh4}, Other Switchyard Maintenance (Type 1)	1.0
AF_{sh0}, No Switchyard Maintenance (Type 0)	0.6 (lowest)

As indicated before, these adjustment factors are empirical and generic for the U.S. NPPs to account for changes in the Power Op and HSB switchyard-centered LOOP frequency due to human activities on switchyard equipment. Each AF_{shi} term is a multiplier for the average Power Op and HSB switchyard-centered LOOP frequency and accounts for the increased frequency of a switchyard-centered LOOP when the specific human activity is in progress during Power Op or HSB conditions.

The calculated adjustment factors are intended to account for all activities judged to have a significant potential to increase the LOOP frequency. Those activities judged to have a minimal impact on the LOOP frequency should be screened out as negligible. Also, consistent with the assumption that only one human activity is in progress at a given time, only one adjustment factor should be applied at any given time. It is recommended that the largest applicable adjustment factor be used for situations involving multiple concurrent activities. This limitation is not expected to present a significant application issue, since human activity in the switchyard during Power Op and HSB conditions is relatively infrequent.

Note that the value of the Adjustment Factor for no maintenance in the switchyard, AF_{sh0}, is less than unity. This is consistent with the expectation that the LOOP frequency should be lower when no maintenance is being performed on switchyard equipment. If desired, the use of an adjustment factor of 1 for this zero switchyard maintenance condition is acceptable and conservative. Note that the base case or nominal switchyard-centered LOOP frequency should use an adjustment factor of 1, since this factor represents an annualized average condition.

The Power Op and HSB LOOP during human activity in the switchyard is the sum of the adjusted switchyard LOOP frequency and the LOOP frequency associated with the other LOOP categories, namely, plant-centered, grid-related, and weather-related LOOP categories.

There are many sources of uncertainty associated with the switchyard centered HI-LOOP adjustment factors. Probably the single largest source of these is in the values of f_{shi}, since these may vary considerably from plant to plant and over the data interval for any given plant. The quantification of uncertainty is not included in this investigation, because uncertainty is not typically calculated for OLRM risk analyses which are used to minimize and manage risk rather than to estimate the risk's absolute magnitude and uncertainty. Uncertainty quantification is an area for future work. Uncertainty associated with the calculated adjustment factors could be quantified by using a Monte Carlo or Latin Hypercube process to combine the estimated mean and variance values associated with the terms contributing to the adjustment factors.

Section 3.3 describes how to incorporate the switchyard-centered HI-LOOP adjustment factors into a typical plant OLRM.

3.3 Incorporation of Switchyard-Centered HI-LOOPs into PRA Model

This section describes a methodology of incorporating switchyard-centered HI-LOOP events into the Power Op and HSB NPP OLRM. The approach is intended to be consistent with most current PRA fault tree models.

Most PRA models either explicitly include four basic events to represent the four LOOP categories, i.e., switchyard-centered, plant-centered, grid-related, and weather-related LOOPs, or a single basic event to represent all four LOOP categories combined. These two approaches are essentially identical. As an initiator, each of these basic events has frequency units, i.e., unit of "per reactor year". The frequency associated with LOOP initiator basic events are typically based on generic data applicable for the specific plant. Moreover, the LOOP basic events are placed in various locations in the PRA fault tree logic in order to account for the effect of a LOOP. Among these locations, is the portion of the model that accounts for the failure of offsite power. In other locations, the initiating event may be used as a "conditioning" event, allowing the model to adjust the plant and/or operator responses that may be unique to the LOOP initiator.

The four-basic-events-LOOP approach assumed in this report demonstrates how to incorporate the HI switchyard-centered LOOP adjustment factors into a typical plant OLRM. The fault tree structure associated with this modeling is shown below in Figure 3-1.

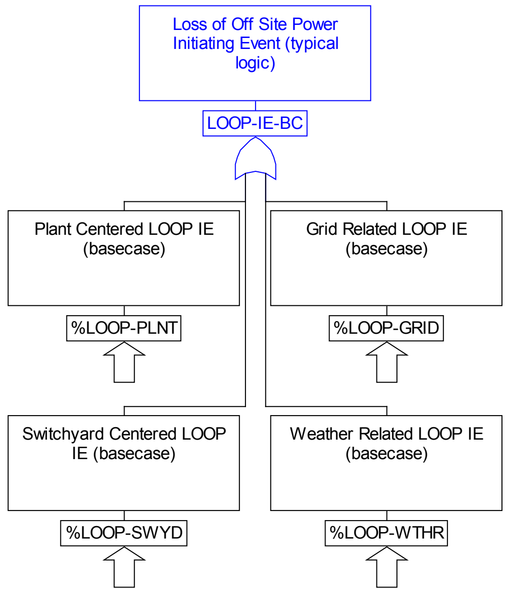

Figure 3-1
Four Basic Events LOOP Model - Static Version

In this approach, %LOOP-PLNT represents the plant-centered LOOP initiator, %LOOP-SWYD represents the switchyard-centered LOOP initiator, %LOOP-GRID represents the grid-related LOOP initiator, and %LOOP-WTHR represents the weather-related LOOP initiator. Each of these initiator basic events is assigned a frequency applicable for the specific plant based on data from sources that include NUREG/CR-6890 [1]. The LOOP logic top gate, i.e., LOOP-IE-BC, is logically the OR of all four LOOP categories.

The LOOP model shown in Figure 3-1 is "static" in that the LOOP initiating event frequencies are average values, which are appropriate for base case (BC) analyses associated with nominal plant conditions. They do not account for activities and conditions that change with time during the course of plant operation. The effect of human activities in switchyard equipment on plant risk must be addressed when these models are adopted for on-line risk monitors (OLRM), such as EOOS models. The simplest way to account for these effects is by defining a "slider bar" (or equivalent) that allows the switchyard-centered LOOP frequency to be numerically changed depending on the status of on-going human activities on switchyard equipment. Alternatively, the fault tree can be revised to account for these on-going human activities by replacing the switchyard LOOP basic event with logic shown in Figure 3-2.

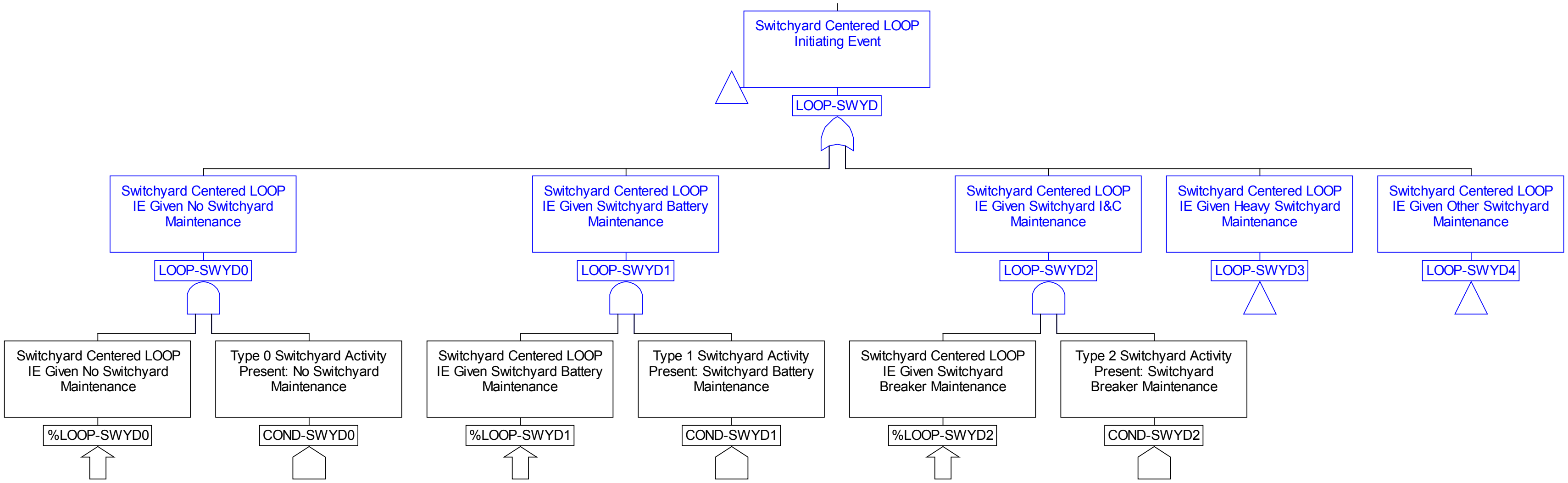

Figure 3-2
Four Basic Events LOOP Model - OLRM Version

In the revised logic shown in Figure 3-2, the switchyard-centered LOOP basic event is replaced by gate LOOP-SWYD which is the OR of five gates LOOP-SWYD0, LOOP-SWYD1, LOOP-SWYD2, LOOP-SWYD3, and LOOP-SWYD4. Each of these gates is an AND gate of one of the switchyard-centered LOOP frequency basic events (%LOOP-SWYDi, i = 0, 1, … , 4) and the conditional probability of its occurrence (COND-SWYDi). Note that only gates LOOP-SWYD0, LOOP-SWYD1, and LOOP-SWYD2 are shown in Figure 3-2 due to space limitations; however, the other gates, LOOP-SWYD4 and LOOP-SWYD5, are similar.

For the base-case PRA model, the values of each of the switchyard-centered LOOP frequency basic events %LOOP-SWYDi, is $\nu_{shi} = AF_{shi}\overline{\nu_s}$ and the value of COND-SWYDi is f_{shi}. for i = 0, 1, … , 4). The value of $\overline{\nu_s}$ is the average plant-specific switchyard-centered LOOP frequency; the values of AF_{shi} are provided in Table 3-1; and, the values of f_{shi} are provided in Section 3.2. The basecase model represents the nominal or average plant condition.

For the OLRM (e.g., in the EOOS model), one of the house events COND-SWYDi, the one best representing the status of on-going human activities affecting switchyard equipment, is set to 1 and the other house events COND-SWYDi are all set to 0. Essentially, the house events COND-SWYDi are used as flag events in the OLRM. Thus, the same Figure 3-2 fault tree structure not only allows the OLRM to account for the effect of on-going human activities on the switchyard centered LOOP frequency and but also ensures that the basecase PRA model uses the average switchyard centered LOOP frequency.

Note that normally, only one condition is present at any given time, but it is possible for multiple activities to occur concurrently. When no human activities are present, COND-SWYD0 should be set to 1 (or TRUE). As shown in Table 3-1, the frequency of %LOOP-SWYD0 associated with the no maintenance condition is smaller than the average switchyard-centered LOOP frequency.

Also, it should be noted that if the existing logic already includes HFEs that contribute to switchyard-centered LOOP events, these events should either be removed from the logic or use of the model be controlled to ensure that the adjustment factors are not concurrently applied with the HFEs. Otherwise, this would incorrectly account for the effects of operator failures leading to a LOOP event.

Section 4: Plant-Centered HI-LOOP Frequency Assessment

4.1 Framework for Plant-Centered HI-LOOP Frequency Assessment

Table B-1 of Appendix B lists the total of Loss of Offsite Power (LOOP) events at U.S. NPPs during the period 1986 - 2007. Table D-1 of Appendix D lists the set of plant-centered LOOPs during Power Op and HSB conditions extracted from the larger population of LOOP events listed in Table B-1. Each of these events was reviewed to identify whether a human activity in the plant was a contributor to the event.

Consistent with NUREG/CR-6890 [1], plant-centered HI-LOOPs are defined as LOOP events associated with in-plant equipment. It excludes weather-related and grid-related events. Moreover, it excludes LOOPs associated with switchyard equipment. The line of demarcation between plant-centered and switchyard-centered events is the NPP main and station power transformers high-voltage terminals. Both transformers are considered part of the switchyard.

Table D-1 data indicates that very few HI-LOOPs are plant-centered. This is due to the high degree of redundancy of the in-plant electrical system design, the highly proceduralized operation of electrical systems within the plant, and the avoidance of activities that could potentially interrupt off-site power sources and cause a plant trip. Given the relative rarity of plant-centered HI-LOOPs, the scarcity of information on these events, and the highly plant-specific nature of plant design and operation, it is deemed inappropriate to account for plant-centered HI-LOOPs using empirically-based, generically-applied adjustment factor approach, as used for switchyard-centered HI-LOOPs (discussed in Section 3 of this Report). An alternative framework is therefore necessary to account for plant-centered HI-LOOPs. This alternative approach uses HRA methods. Although the use of historical data is generally preferred over a theoretical model (e.g., HRA methods), the use of HRA methods can be applied to calculate the impact of human activities on both total <u>and partial</u> plant centered LOOP frequencies. Subsection 4.2 discusses the proposed plant-centered HI-LOOP frequency assessment methodology.

4.2 Plant-Centered HI-LOOP Frequency Assessment Methodology

This section describes a methodology to account for plant-centered HI-LOOPs in the NPP PRA model. This methodology includes the following steps: (1) review of maintenance and operational activities on in-plant equipment conducted during Power Op and HSB conditions to identify those human actions that could lead to a total or partial LOOP event, (2) identify specific Human Failure Events (HFEs) during the conduct of these activities that could lead to these events, (3) use Human Reliability Analysis (HRA) methods and tools to quantify the Human Event Probability (HEP) associated with each of these HFEs, and (4) incorporate these HFEs into the NPP PRA model.

The identification of plant activities that could lead to a total or partial plant-centered HI-LOOP requires a review of plant procedures. This review should be conducted by individuals familiar with these plant activities. Electrical maintenance activities are the most likely activities leading to a HI-LOOP, but other types of maintenance could also do so, e.g., mechanical maintenance that could inadvertently de-energize buses fed by off-site power sources. And, some operational activities, e.g., breaker manipulations on safety buses, could also lead to a plant-centered LOOP. This review effort may be difficult and time-consuming; however, fortunately, most plants should have few human activities conducted during Power Op and HSB conditions that could cause a total or partial LOOP. This review should be an integral part of the procedure preparation/maintenance process to ensure that procedural changes do not increase the LOOP frequency. In addition, special one-time pre-planned activities should also be reviewed.

If the plant activities that could lead to a HI-LOOP are performed periodically, the average number of times it is executed per year (n) and the average duration of the plant activity should be recorded. The value of n may be non-integer value, depending on the average testing cycle, e.g., n = 0.67/yr (= 1/1.5 yr) for an activity performed once per 18 month cycle. The accuracy of estimated activity duration depends on the on-line risk program. For example, if the activity can occur at any time during a work week, then a 40-hour duration is appropriate. If the activity is constrained to a single day of a work week, then an 8-hour duration is appropriate. More accurate time duration should be used if the activity is more rigorously constrained to a specific time interval due to restrictions with other activities that are performed concurrently.

Once an HFE that could lead to a partial or total plant-centered HI-LOOP is identified, its HEP can be assessed using standard Human Reliability Analysis tools. The EPRI HRA Calculator® [9] is one of these tools. It is designed to guide the PRA analyst through the HRA steps needed to document each HFE and to quantify its HEP. This process is described in Subsection 4.3.

Since HFEs are probability events (i.e., probability per demand, unitless) and the LOOP initiator is a frequency event (e.g., per year), there is need to convert units. This conversion can be made by dividing the HEP by the estimated duration of its associated activity. The result is a human failure rate. The rate should be converted to units of "per year" in order to be consistent that of other initiators. The resulting rate is per activity. For the basecase risk model, which generates the annual average Core Damage Frequency (CDF) or Large Early Release Frequency (LERF), this rate should be multiplied by the number of times (n) that the activity is conducted per year. After conversion to a human failure rate, the Human Error Probability (HEP) effectively becomes a Human Error Frequency (HEF). Unlike probability values (e.g., HEPs), frequency values (e.g., HEFs) can exceed 1.0.

The last step in the plant-centered HI-LOOP methodology is to incorporate the HI-LOOP HFEs as basic events (BEs) into the PRA model. It should be noted that the plant-centered HI-LOOP frequency methodology, unlike the switchyard-centered HI-LOOP methodology described in Section 3, provides a means to account for partial LOOP events. In fact, given that in-plant activities which could contribute to total LOOPs are likely to be extremely rare, most plant-centered HI-LOOP activities of interest will lead to partial, not total, LOOP events. Given that only total LOOPs are of interest in this report, for most human activities leading to a total plant-centered LOOP, it will be necessary to AND the human error frequency causing the loss of one offsite power source with the coincident failure of offsite power to other plant safety buses. Thus, it is expected that for most human activities leading to a total plant-centered LOOP, it will be necessary to develop a support system fault tree for the loss of other offsite power sources. In order to demonstrate the process, Subsection 4.4 provides an example of a plant activity that could lead to a plant-centered HI-LOOP and demonstrates how its HEP can be evaluated using the EPRI HRA Calculator®. And, Section 4.5 demonstrates how the HI-LOOP HFE can be incorporated into the NPP PRA model.

Note that the base-case or average plant-centered LOOP frequency should include all total LOOP contributors due to activities involving in-plant equipment during Power Op and HSB conditions. Thus, the average plant-specific plant-centered LOOP frequency should include the industry average plant-centered value obtained using U.S. nuclear industry experience plus plant-centered HI-LOOP frequency contributors identified and quantified using the process described in this section. However, if the calculated total contribution of the plant-centered HI-LOOP frequency is small, e.g., less than a percent of the generic plant-centered LOOP frequency, it is reasonable to exclude these small contributors and document their exclusion.

4.3 HRA Methodology for HFEs Leading to an Initiating Event

This section provides an overall description of the HRA methodology used to estimate the human failures that lead to initiating events. It is included because HRA plays an important role in the development of plant-centered HI-LOOP frequency as described in this report and this methodology is not often used or well-documented in the literature. Subsection 4.3 describes, using an example, the plant-centered HI-LOOP frequency assessment methodology.

Using the SHARP1 [8] classification scheme, Human Failure Events (HFEs) are classified into three general types:

- ***Type A events***. These HFEs occur prior to an initiating event and are due to surveillance testing and/or maintenance errors that leave a system or portion of a system unavailable to respond when called upon under emergency conditions. These are typically known as "pre-initiator HFEs".
- ***Type B events***. These HFEs contribute to an initiating event and are typically not explicitly modeled, because they are typically assumed to be included in initiating event frequency data. These can be called "initiator HFEs".
- ***Type C events***. These events occur after an initiating event. This type is further subcategorized into two types:
  - *Type C_P events*. These events represent the failure of the operating crew to respond correctly to an upset event when the response is delineated in emergency or other operating procedures. These typically known as "procedure-based post-initiator HFEs".
  - *Type C_R events*. These events account for failures to perform actions that are clearly warranted based on the operators' knowledge but that are not explicitly called for by procedures. These typically known "rule-based post-initiator HFEs".

The EPRI HRA Calculator®, like other HRA tools, provides methods to calculate HEPs for Type A, Type C_P, and Type C_R HFEs; however, it does not provide methods to account for Type B HFEs that contribute to initiators, since initiators are typically calculated using historical data. In fact, most of the research conducted on HFEs is on Type A, Type C_P, and Type C_R HFEs; little guidance is available for Type B HFEs. Fortunately, some of the HRA methods applicable to Type A, C_P, and C_R HFEs can be used to quantify HEPs for the Type B HI-LOOP HFEs. For this reason, the methods employed in the EPRI HRA Calculator® are summarized below.

The EPRI HRA Calculator® Version 4.0 applies the following methods for pre-initiator HFEs:

- Accident Sequence Evaluation Program Human Reliability Analysis Procedure (ASEP) [10].
- Technique for Human Error Rate Prediction (THERP) [11].
- Screening HEP[5].

The EPRI HRA Calculator® applies the following methods for post-initiator HFEs:

- Annunciator Response/THERP [11]
- Caused Based Decision Tree Method (CBDTM) [12]/THERP

[5]The "Screening HEP" is not a method but simply an option that allows a user to specific a manually input HEP value. Use of this option provides a means to easily incorporate a manually input HEP value into the PRA model database file.

- Human Cognitive Reliability/Operator Reactor Experiments (HCR/ORE) [12])/THERP
- ASEP [10]
- Combination Method[6] – either CBDTM [12] + HCR, Maximum of CBDTM and HCR, or CBDTM + ASEP
- SPAR-H [13]
- Screening HEP

Type B HFEs have much in common with Type A HFEs: both are performed during non-accident plant conditions and typically during test and maintenance activities. An important similarity is that typically neither Type A nor B HFEs are greatly affected by time pressure. A major difference between Type A and B HFEs is that there is generally a greater opportunity to recover from Type A HFEs. This is because Type A HFEs may be present for a relatively long latent time period and may be noticed and corrected prior to a plant condition that demands use of the affected equipment. Type B HFEs, on the other hand, produce an initiating event with no additional opportunity to prevent it. This does not mean that recovery opportunities do not exist for Type B HFEs, but only that the time window for a recovery is limited to the activity itself. This is a relatively short time window compared with the long latent period associated with Type A HFEs.

Thus, due to their similarities, Type A HFE assessment methods can often be applied to Type B HFEs. If this is not possible for a given Type B HFE, ASEP methods for pre-accident HFEs may be applied. NUREG/CR-4772 [10] provides guidance on these methods. And, the THERP handbook [11] provides numerical values that can be useful in quantifying HEPs for Type B HFEs. If all else fails, screening HEP estimates can be used. Generally, conservatively high estimates for HEPs are acceptable for HFEs leading to partial plant-centered HI-LOOPs, because these require other failures to occur to result in a total LOOP.

It should be noted that nominal HEPs reported in its NUREG/CR-1278 [11] tables represent medians of lognormal distributions of HEPs (as stated in the definition section of that report). Since PRA models use mean values, the median values must be converted to mean values. Note that this conversion is necessary if the EPRI HRA Calculator® is used, because it provides median (not mean) values.

The relationship between mean and median values for a lognormal distribution is given by the following expression, provided in Appendix B of the EPRI HRA Calculator® User's Manual [9],

$$\bar{\lambda} = \hat{\lambda} * exp\left[\frac{1}{2}\left(\frac{ln\,(EF)}{1.6448536270}\right)^2\right] \qquad \textit{Eq. 4-1}$$

[6]The "Combination Method" is not, by definition, a method, but rather, it combines the CBDTM, HRC/ORE or ASEP methods to calculate Pcog. THERP is used to calculate Pexe. Likewise, as noted above, the "Screening HEP" method is also not a method.

where,

$\bar{\lambda}$ = *mean of lognormal distribution*

$\hat{\lambda}$ = *median of lognormal distribution (often written, $\lambda_{0.5}$)*

EF = *Error Factor*

The general guidance used to establish EFs is provided in Table 7-2 of NUREG/CR-1278 [11]. This guidance is summarized in Table 4-1, below.

Table 4-1
NUREG/CR-1278 [11] Guidance on HEP EFs

HEP Probability Range	Assigned Error Factor
< 0.001	10
0.001 to 0.01	3
> 0.01	5

Section 4.4 provides an example to demonstrate how to develop the HEP for a Type B HFE.

4.4 HEP Assessment of an HFE Contributing to a Plant-Centered HI-LOOP Initiating Event

This section provides an example plant activity that contributes to a potential plant-centered HI-LOOP event. Although the actual activity is hypothetical, the example demonstrates how a plant-centered HI-LOOP HFE is identified and how its HEP is estimated. In general, plant activities associated with non-safety buses fed by the switchyard should be a focus area for potential plant-centered HI-LOOPs.

The description of the hypothetical plant activity example is as follows:

An NRC notification was issued to Plant A requiring a mandatory inspection of a specific model of 4160 VAC breakers manufactured in a specific time frame. The inspection was required to be completed within ninety days upon receipt of the notification. This time frame provided sufficient lead time to prepare and execute the inspection in a timely and orderly manner. In response to this order, Plant A Electrical Design Engineering identified the breakers required to be inspected. All of the breakers (10 in all) were identified to be non-safety 4160 VAC bus load breakers on buses A1 and A2 (see Figure 4-7).

A one-time procedure was prepared by Plant A Electrical Maintenance and Operations to perform a series of inspections on the affected breakers. These inspections were to be performed during Power Op while all buses remained energized. The procedure required each breaker to be declared inoperable, opened, racked down, and removed from its cubicle. Each breaker was to be visually inspected in a well-lit area with Foreign Materials Exclusion (FME) controls in effect. Some disassembly of the breaker was required to perform the inspection; thus, tools would be necessary. After inspection, each breaker was to be returned to its cubicle, racked up, closed, and declared operable.

The inspection was to be performed during Power Op but at a reduced plant power level to accommodate the fact that each inspection would cause loss of power to specific Balance of Plant (BOP) equipment. All safety systems will be fully available during the inspection period and no other planned maintenance activities concurrently scheduled. The non-safety buses will be aligned to their normal source (Unit Aux Transformer) and their backup source (Startup Transformer) will be available. These conditions help minimize plant risk during the inspection. In addition, the procedure was written to minimize the impact of the inspection by "rotating" the specific equipment used for plant operation, i.e., an alternate equivalent piece of equipment on bus A2 was used for plant operation when a piece of equipment on bus A1 was made unavailable during a breaker inspection, and vice versa. As part of these precautions, the 10 breaker inspections would be performed in series, not in parallel, and in a pre-arranged order with hold points between breaker inspections to ensure that Operations could rotate equipment required for continued power operation. Thus, successful execution of the procedure (without a plant upset) would require close coordination between Electrical Maintenance and Operations. The inspection involved no safety related equipment or bus and was not expected to affect offsite power to safety related buses. Thus, no Limited Condition for Operation (LCO) was to be entered during the inspection process. And, in the event of an inadvertent loss of a non-safety bus, the on-site power sources would provide power to the safety related equipment.

The inspection was planned to start on a Saturday evening (~1800) to minimize its economic impact, i.e., the accompanying power reduction. It was estimated that each breaker inspection would require approximately 1 hour, from start to finish. Thus, the best estimate time to complete the entire activity of ten sequentially performed breaker inspections is 10 hours.

The inspection was planned activity in the normal work week schedule. The on-line risk monitor was to reflect the risk of the inspection activity.

From a plant risk perspective, the breaker inspection was judged to increase the probability of a plant trip during power operation due to the potential loss of adequate BOP equipment to continue power operation. The inspection was also judged to increase the probability of a partial or total LOOP due to the potential loss of one or both non-safety 4160 VAC buses. The first risk contributor can be accounted for by increasing the frequency of the turbine trip initiating event in the on-line PRA model. This contributor is outside the scope of this report; thus, it will not be evaluated here. However, the second risk contributor represents a potential plant-centered HI-LOOP; an HFE associated with this risk is identified and its associated HEP is estimated below.

As noted above, it was judged that the potential for undetected foreign material (e.g., a misplaced tool) remaining in the breaker after inspection and for this material to cause the non-safety bus to short to ground when the breaker was racked up in its cubicle. This failure is best categorized as a loss of administrative control in the ASEP methodology. This is an execution error; no cognitive errors are assumed. Consistent with a Type B HFE, ASEP Case I (no recovery) is assumed. Loss of a single non-safety bus would be a partial plant-centered LOOP. A total plant-centered LOOP would occur only if the other non-safety bus were lost. The on-line PRA model should be revised to account for both the loss of a single non-safety bus and the increased potential for a total plant-centered LOOP. The same HFE, named HFE1-PLT-CNTR-LOOP, contributes to both risk impacts.

The quantification of HFE1-PLT-CNTR-LOOP is performed using ASEP pre-initiator methods. This was accomplished using the EPRI HRA Calculator®. Snapshots of the EPRI HRA Calculator® windows are depicted in Figures 4-1 through 4-6 to provide guidance on the HEP quantification. Figure 4-1 shows the EPRI HRA Calculator® "Summary" snapshot; this snapshot provides the overall HEP results. Figure 4-2 shows the EPRI HRA Calculator® "BE Data" snapshot; this snapshot provides HEP values and a summary of the human interactions. Figure 4-3 shows the EPRI HRA Calculator® "Scenario Description" snapshot; this snapshot provides HEP values and a summary of the human interactions, which identifies the BE name whose HEP is being evaluated and key assumptions in the analysis. Figure 4-4 shows the EPRI HRA Calculator® "Performance Shaping Factors (PSFs)" snapshot; this snapshot provides PSF parameter values used to estimate the Basic (i.e., unrecovered) Human Failure Probability (BHEP). Figure 4-5 shows the EPRI HRA Calculator® "Critical Step Recovery Factors" snapshot; this snapshot provides the parameter values used to estimate the HFE Recovery Factor (RF). Figure 4-6 shows the EPRI HRA Calculator® "Critical Steps" snapshot; this snapshot lists the critical procedure steps that contribute to the HFE and the BHEP, RF, and calculated median recovered HEP values.

The ASEP based EPRI HRA Calculator® calculation is that the median HEP for HFE1-PLT-CNTR-LOOP is a median of 3.0E-2 with an EF of 5. This equates to a mean HEP of 4.9E-02 with an EF of 5. As stated above, this HFE represents the probability that a single breaker containing foreign material is racked up and subsequently causes its associated bus to fault to ground. This estimate is based on ASEP methods. Since it is not based on actual plant experience regarding the specific tasks associated with the breaker inspection, it is deemed to be conservatively high estimate.

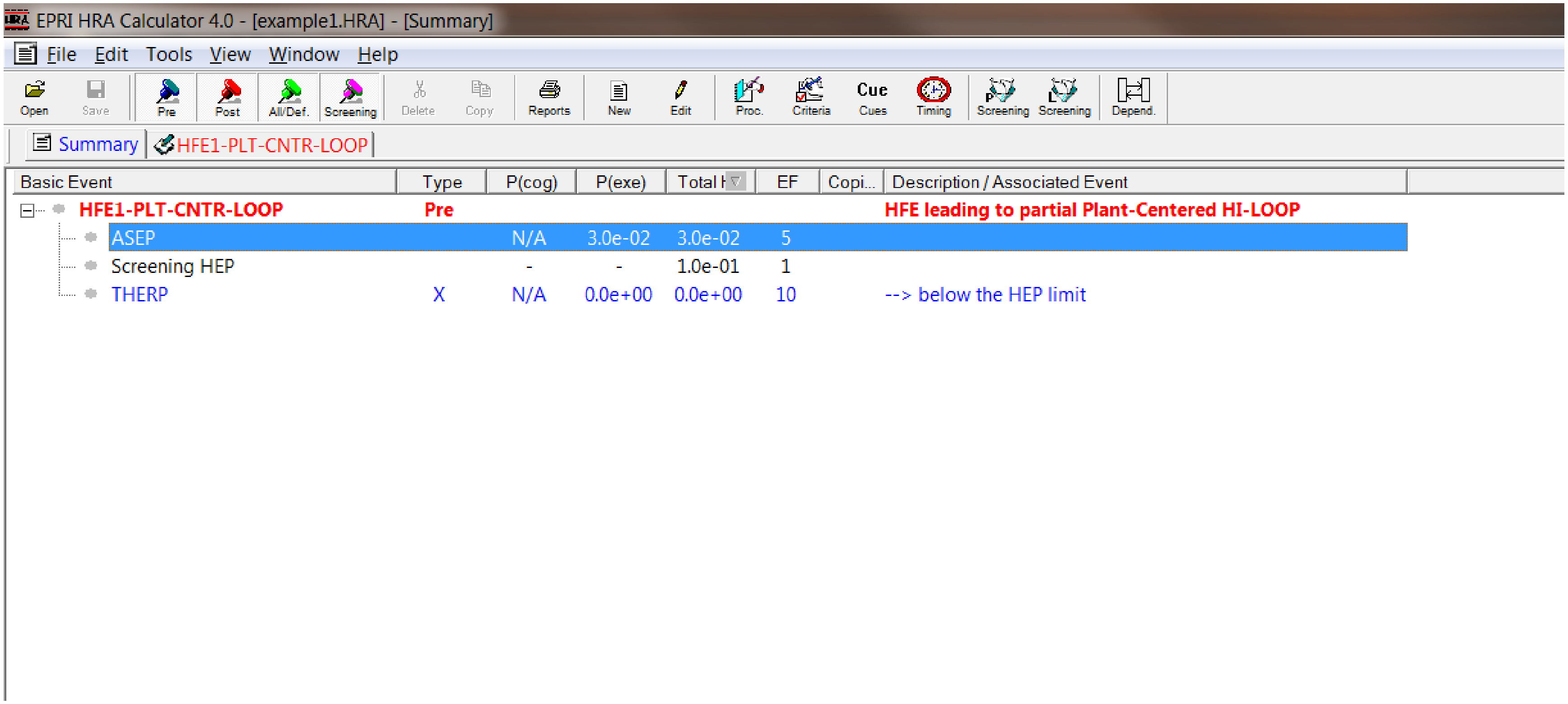

Figure 4-1
EPRI HRA Calculator® "Summary" Snapshot of HFE1-PLT-CNTR-LOOP

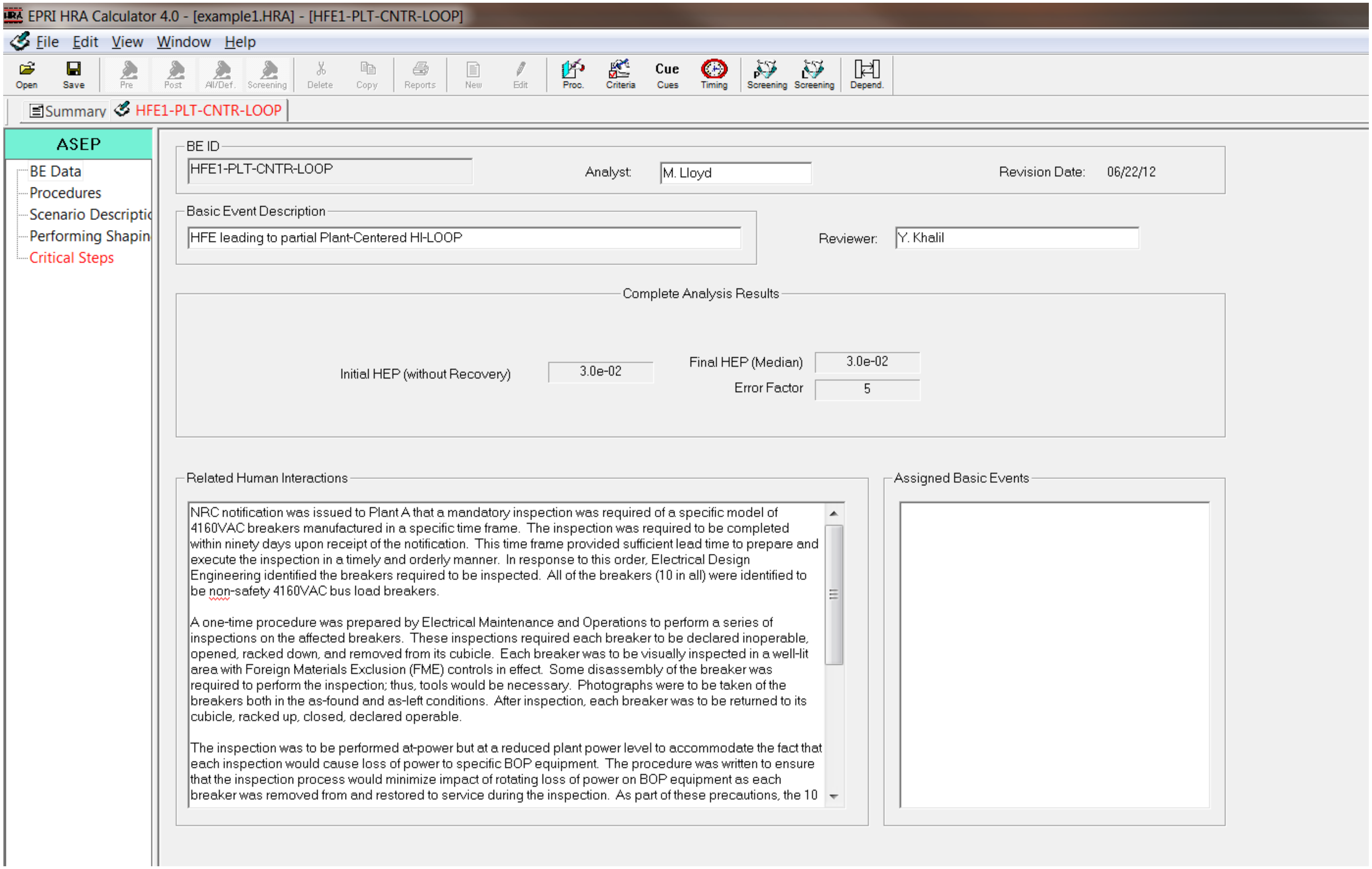

Figure 4-2
EPRI HRA Calculator® "BE Data" Snapshot of HFE1-PLT-CNTR-LOOP

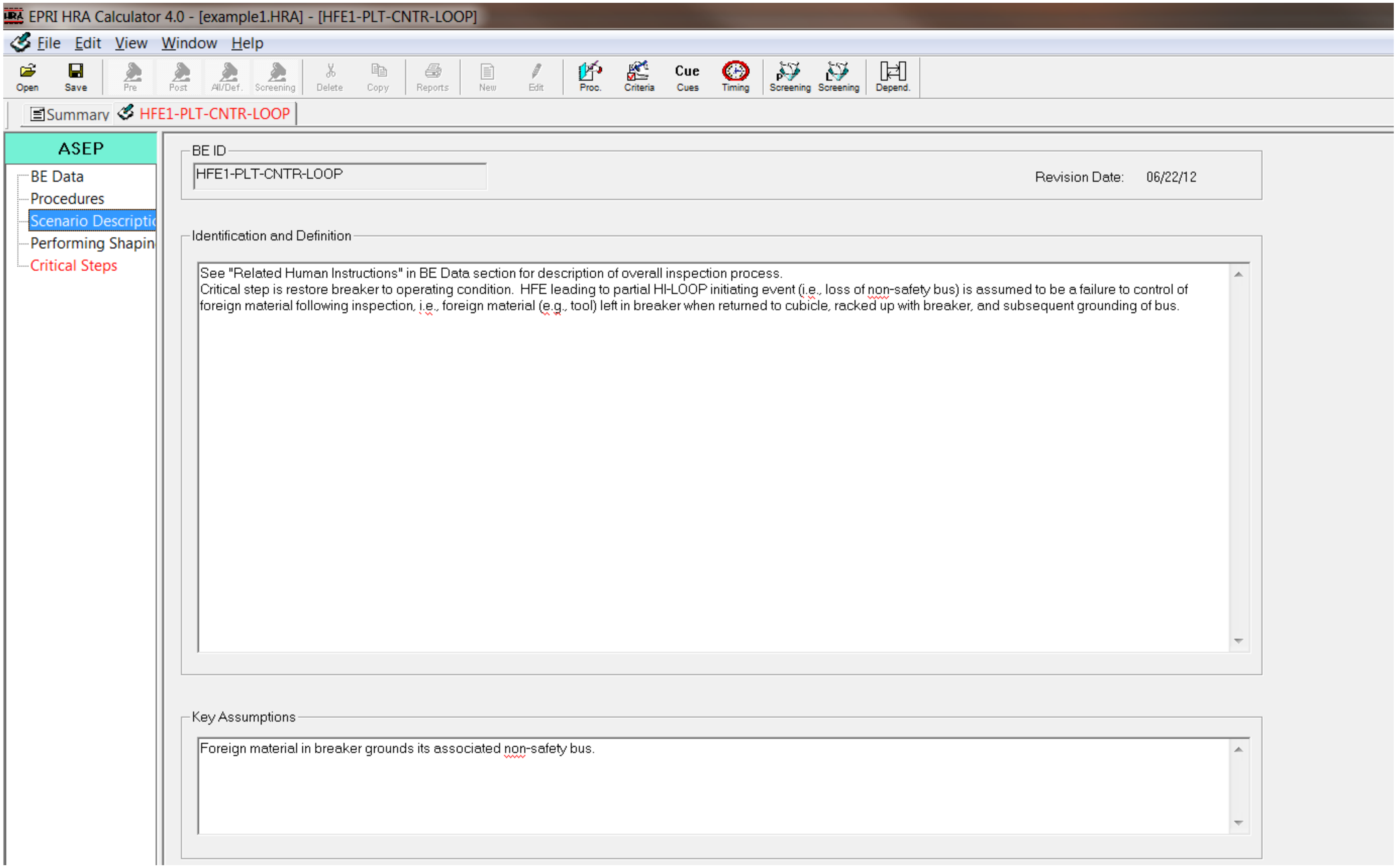

Figure 4-3
EPRI HRA Calculator® "Scenario Description" Snapshot of HFE1-PLT-CNTR-LOOP

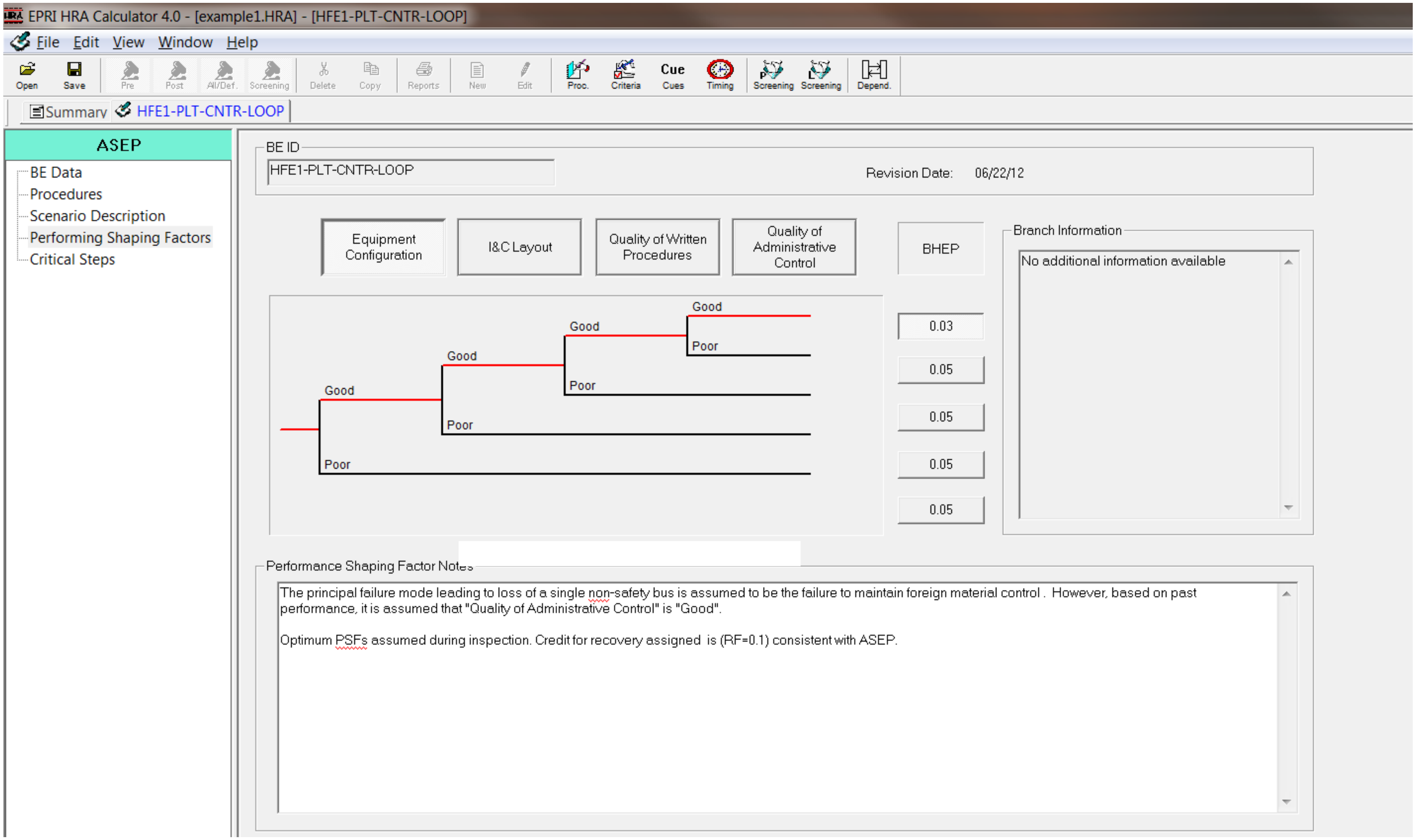

Figure 4-4
EPRI HRA Calculator® "Performance Shaping Factors (PSFs)" Snapshot of HFE1-PLT-CNTR-LOOP

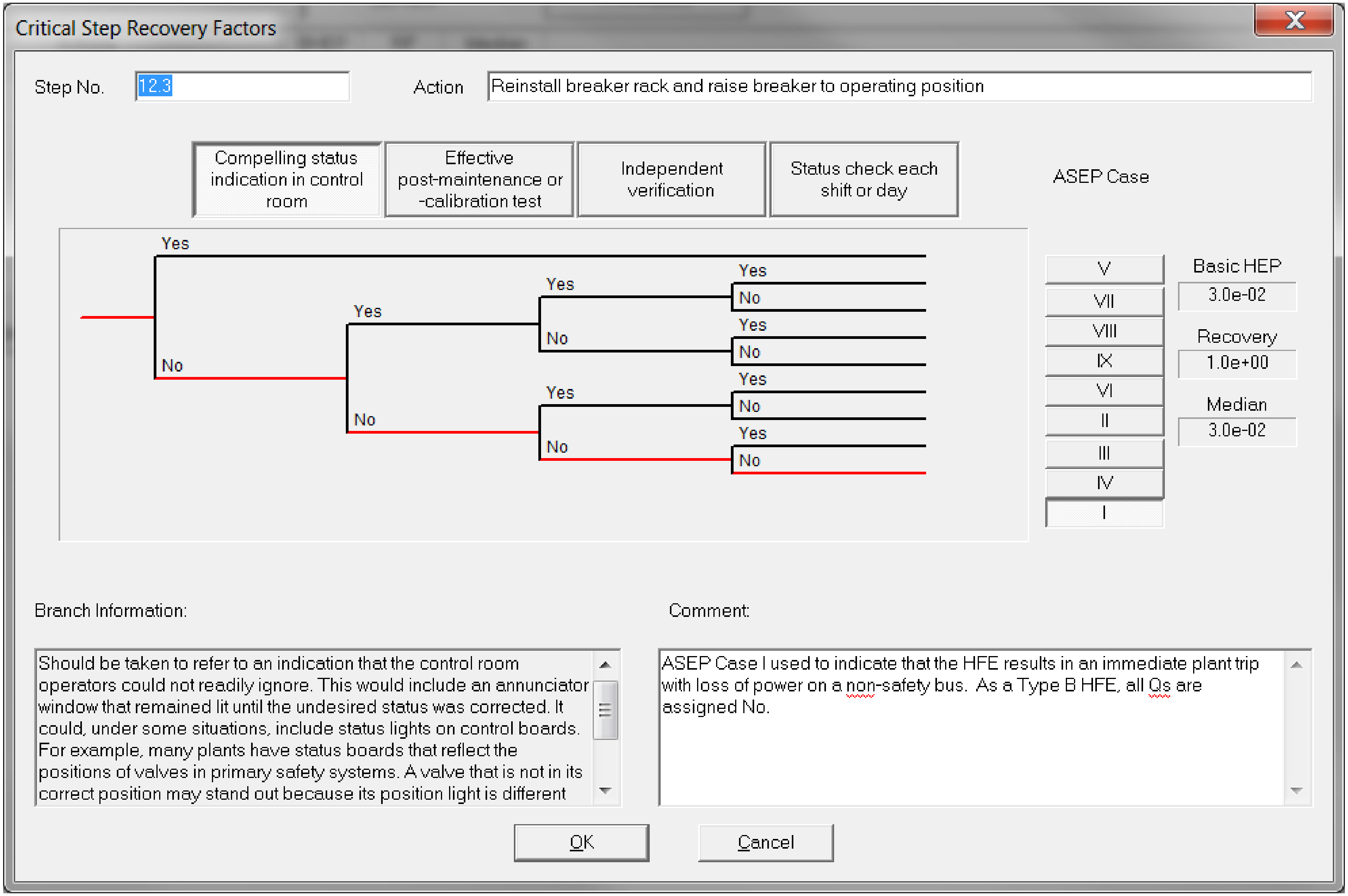

Figure 4-5
EPRI HRA Calculator® "Critical Step Recovery Factors" Snapshot of HFE1-PLT-CNTR-LOOP

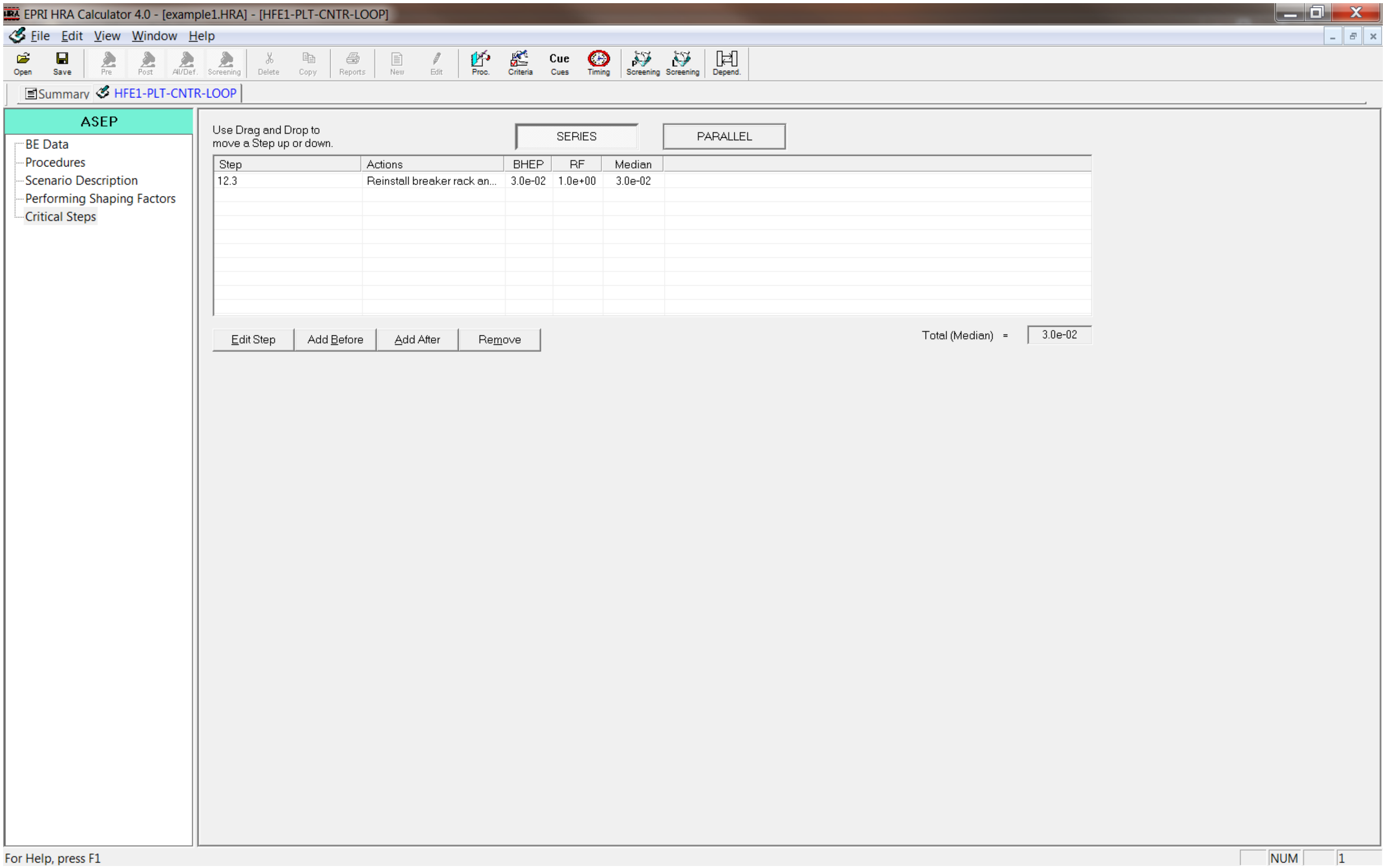

Figure 4-6
EPRI HRA Calculator® "Critical Steps" Snapshot of HFE1-PLT-CNTR-LOOP

A demonstration of how event HFE1-PLT-CNTR-LOOP can be integrated into the NPP OLRM is provided in Subsection 4.5. As noted in Subsection 4.2, one step in this process includes converting the human error probability (HEP) into a human error frequency. And, if the HFE leads to only a partial LOOP, it should be AND'ed with other events that are required to generate a total LOOP event. This logic should then be OR'ed with every occurrence of the plant-centered LOOP initiating event in the model.

4.5 Incorporation of Plant-Centered HI-LOOPs into PRA Model

This section demonstrates how a HFE contributing to a partial plant-centered HI-LOOP can be integrated into an OLRM to account for the risk associated with a total plant-centered HI-LOOP. This demonstration uses event HFE1-PLT-CNTR-LOOP, developed in Subsection 4.4, to estimate the plant-centered HI-LOOP frequency event that could be initiated by this activity.

The Human Error Probability (HEP) for HFE1-PLT-CNTR-LOOP can be converted to a Human Error Frequency (HEF) by dividing the HEP by the estimated time required to complete a single breaker inspection, i.e., 1-hour. Note that use of the 1-hour time interval per inspection is consistent with tracking the risk of the activity via the on-line risk monitor on an hourly basis. If the activity is tracked on a different basis, e.g., on a work week basis, where the activity can occur anytime during the week, the risk should be spread over the tracking interval, 5 days. The "instantaneous" risk is reduced. At first, this would appear to non-conservatively reduce the risk associated with the activity; however, it actually tends to increase the average plant risk, because it allows other potentially high risk activities to be performed concurrently with the HI-LOOP activity.

Using 1-hour per breaker inspection, the HEP for HFE1-PLT-CNTR-LOOP can be converted to HEF by dividing the HEP by 1 hour. The "per hour" unit of the HEF should be converted to "per year" in order to make it consistent with those of other initiating events. Thus, the HEF for HFE1-PLT-CNTR-LOOP is 4.9E-02/hr or 429.2/yr ($= (\frac{4.9E-2}{1\,hr})(\frac{24\,hr}{1\,day})(\frac{365\,days}{1\,yr})$). This is an extremely high frequency value. It represents the estimated frequency of a loss of a single 4160 VAC BOP bus, either Bus A1 or A2, during a single breaker inspection activity at Plant A. The frequency over the entire inspection of 10 breakers is the same, since the HEP is 10 times that of one and the interval for all 10 breakers in 10 hours.

Although the estimated frequency for the loss of a single balance of plant (BOP) bus during this inspection process is high, the loss of a single non-safety 4160 VAC bus does not result in the total loss of offsite power initiating event. A total plant-centered LOOP requires the additional loss of the other non-safety 4160 VAC bus. Since controls in place during the inspection require full availability and no testing or maintenance activities on electrical systems, the failure of the other non-safety 4160 VAC bus is due to random failures. These are unlikely for the relatively short inspection interval. The probability of the random loss of the other 4160 VAC non-safety bus can be estimated by extracting the fault tree logic associated with the 4160 VAC Bus A1 (for an inspection on the Bus A2 breakers) and fault tree logic associated with the 4160 VAC Bus A2 (for an inspection on the Bus A1 breakers). This logic should be cut away from the rest of the existing PRA model and AND'ed with the HFE for the plant-centered HI-LOOP initiating event, i.e., basic event HFE1-PLT-CNTR-LOOP.

If the 4160 VAC non-safety buses are symmetric, their fault tree logic is also symmetric and the random probability of failure of the buses is the same. Even if the buses are not exactly symmetric, if their random probabilities are approximately the same, only one bus needs to be assessed. Its numerical value can be used for both bus inspection periods. In the case that symmetry does not exist, the random failure of each bus must be quantified. The logic of each can be extracted from the existing on-line PRA model.

For this demonstration example, the 4160 VAC electrical system and its power sources are assumed as shown in Figure 4-7. This system is typical of that of a currently operating U.S. nuclear plant, but does not represent any specific plant. In the example, the five 4160 VAC breakers A1-04 through A1-08 are to be inspected on bus A1 (requiring a total of 5 hours to inspect) and the five 4160 VAC breakers A2-04 through A1-08 are to be inspected on bus A2 (requiring an additional 5 hours).

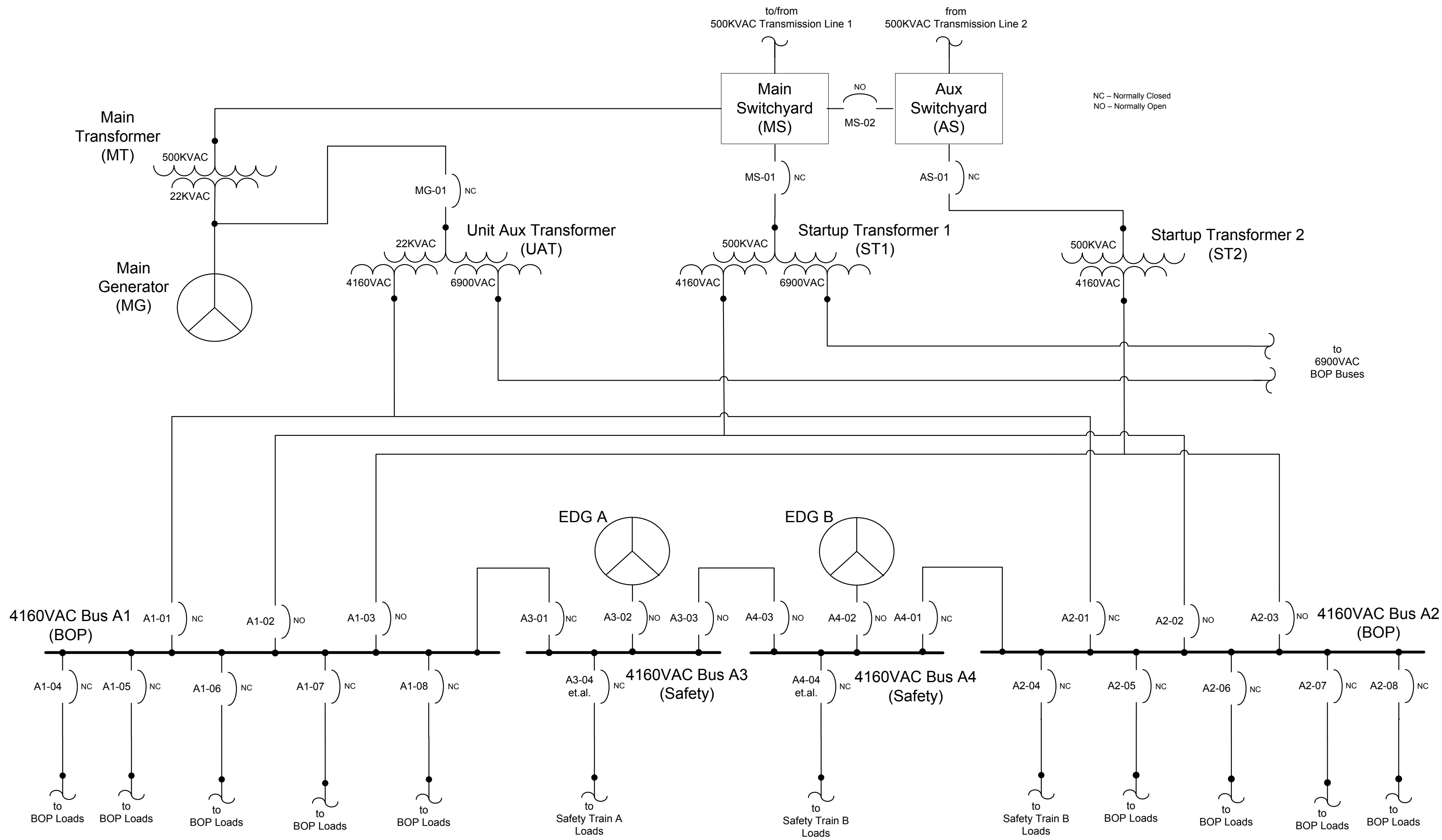

Figure 4-7
Plant A 4160 VAC Electrical System and Its Power Sources

Since the buses are symmetric, only one needs be extracted from the existing on-line PRA model. For this purpose, the top gate for loss of Bus A1 was extracted. The frequency of a HI plant-centered total LOOP due to the breaker inspection activity is twice the frequency of the HFE1-PLT-CNTR-LOOP HEF times the random probability of the loss of bus A1. It is recommended that a 24 hour exposure interval be assumed for basic events in the fault tree. This time interval is a measure of the time that the plant continues to operate following the HI-LOOP on a single non-safety bus, either Bus A1 (or A2). A total LOOP can occur during this time period if power is randomly lost on the remaining 4160 VAC bus. It is assumed that for the breaker inspection activity, a plant trip will not occur if only the affected bus is lost due to the precautions taken for the inspection activity (reduced power, using a "rotating" set of plant equipment to maintain continued plant operation, etc.). Thus, the exposure interval accounts for the duration of the inspection. The use of 24 hours is also relatively easy, since it is the typical mission time assumed in the NPP PRA. Justification should be made for use of an exposure interval shorter than 24 hours.

For simplicity, to avoid the need for an external calculation, a new top gate, PC-LOOP-A2, was created in the PRA model. This gate is an AND gate of HFE1-PLT-CNTR-LOOP and the random probability of failure of bus A1. A screenshot of the upper portion of this logic is shown in Figure 4-8, below.

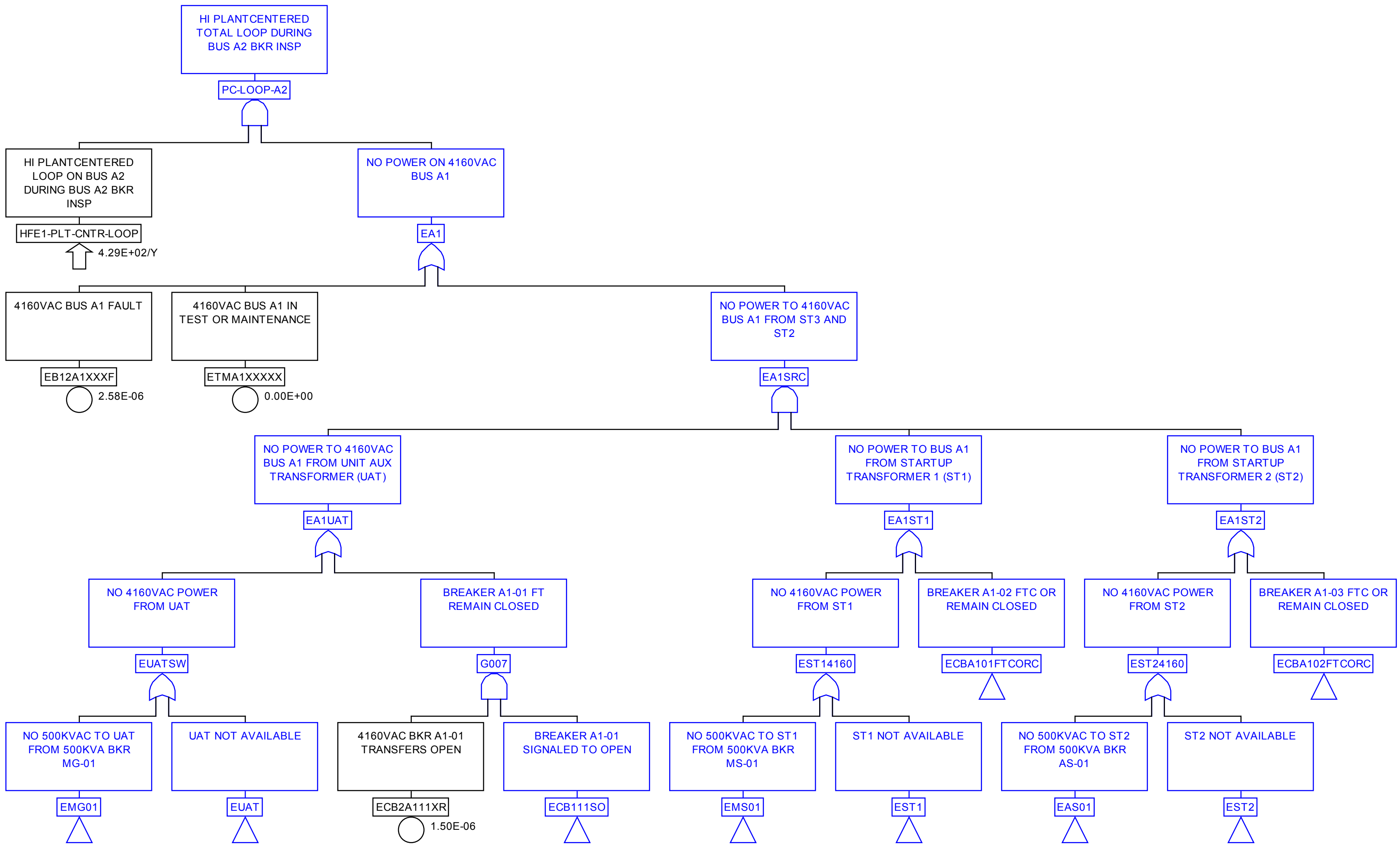

Figure 4-8
Screen Shot of Gate PC-LOOP-A2

The logic under gate EA1 was extracted from the PRA model. Note that test and maintenance (T&M) events are all set to zero, consistent with no maintenance unavailability concurrent with the breaker inspection. Note that if this logic is retained with the existing plant PRA model, the gates and basic event names used in the new plant-centered HI-LOOP support system fault tree logic must differ from that used in the rest of the PRA model.

Gate PC-LOOP-A2 was quantified and found to have a value of 3.28E-3. This value represents a frequency of a total plant-centered HI-LOOP of 3.28E-3/yr averaged over the entire breaker inspection activity. This frequency should be numerically added to the plant-centered LOOP frequency event for use only during this plant activity. Alternatively, if the activity is periodic, the above logic should be OR'ed with the existing plant-centered LOOP frequency event using flag events, similar to those described in Section 3.3 for the switchyard-centered HI-LOOPs. The flag events are set to 1 when the activity is in progress and zero when not. In addition, the flag event can be set to the average number of times the activity is performed per year when the PRA model is used to calculate the basecase annual average risk.

There are many sources of uncertainty associated with the plant centered HI-LOOP frequency values. Probably the single largest source of these is in the HEP (and HEF) values, since these use HRA methods, which are highly uncertain. The EPRI HRA Calculator® provides estimates for the HEP EFs. As noted in Section 3, quantification of uncertainties is outside the scope of this investigation because uncertainty is not typically calculated for OLRM risk analyses. Uncertainty is an area that should be addressed in a future work. However, the uncertainty associated with the calculated plant centered HI-LOOP frequency values could be quantified by using a Monte Carlo process (or using the Latin hypercube method) to combine the estimated mean and variance values associated with the HEP and other terms contributing to the frequency (e.g., terms contributor to gate PC-LOOP-A2 in Figure 4-8).

Section 5: Conclusions

This report describes a quantitative risk assessment framework for evaluating the frequencies of switchyard-centered and plant-centered HI-LOOP events during NPP during Power Op and Hot Standby (HSB) conditions. Improved methods and models are provided with specific examples on how to incorporate HI-LOOP events in NPP probabilistic risk assessment (PRA) models. Leveraging these methods and models should enhance the NPP PRA model completeness and would be useful for the NPP OLRM.

The core findings of this study are as follows:

- Quantitative adjustment factors (AFs) are derived and can be used to adjust the LOOP initiating event frequency in OLRMs when switchyard-centered human activities are performed during Power Op and HSB conditions. The relative order (from the highest to the lowest) of the calculated AF values for switchyard-centered HI-LOOPs is as follows:
    - Switchyard Battery Maintenance (highest risk)
    - Switchyard I&C Maintenance
    - Heavy Switchyard Maintenance
    - Other Switchyard Maintenance
    - No Switchyard Maintenance (lowest risk)
- For the plant-centered human activities during Power Op and HSB conditions, an HRA-based methodology can be used to estimate human failures that lead to initiating events. Existing HRA software tools (e.g., EPRI HRA Calculator®) can be used to assess the probability of these human failures and the calculated HRA events can be incorporated into the risk model to estimate their impact on the LOOP frequency in the NPP OLRM.

Section 6: References

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Appendix A: EPRI SURVEY QUESTIONNAIRE AND NPP SURVEY RESPONSES

A.1 EPRI Survey Questionnaire

EPRI conducted a survey (Table A-1) to assess the risk factors and strategies for control and management of human activity in NPP switchyards. Fifteen U.S. nuclear licensees volunteered to participate in the survey (12 PWRs and 3 BWRs) and agreed to provide their plant-specific responses to the survey questionnaire.

The survey is part of an on-going EPRI program to quantify risk to nuclear power plants associated with its connection to the power-grid. The survey responses are used primarily to:

1. Estimate the amount of time humans engage in activities that affect the high-voltage equipment at any given NPP and
2. Establish an understanding of the switchyard maintenance controls/access and frequency as well as type of switchyard entries to perform corrective or preventive maintenance, surveillances, tests or other activities.

The survey questions (Table A-1) are grouped by topics and within each topic is a general term for the staff expected to have sufficient expertise to answer the question or supply the information requested. Three general groups are used: (i) PRA, (ii) NPP staff (e.g., operations, maintenance, and construction) and (iii) Transmission System Operations (TSO) staff. The PRA group is expected to be able to answer most of the questions, except those dealing with control of work done with high-voltage equipment. Because there is an ownership issue, some of the questions are directed at the TSO rather than the NPP staff. The TSO-related questions are derived from common high-voltage equipment practices found on the internet, particularly the United States Bureau of Reclamation.

This survey uses the term "switchyard" to include all of the high-voltage equipment between the main generator's leads and the circuits leaving the NPP switchyard. The arrangement of high-voltage equipment at the U.S. NPPs varies widely, making it difficult to define the switchyard boundary consistently at all NPPs. Thus, the survey questions refer to specific equipment that is common for the high-voltage systems at an NPP. Questions regarding access control are envisioned to apply to the high-voltage bus area surrounded by a physical fence or wall. That enclosure typically has one building/structure containing the protective relays, control devices, and batteries typical to a switchyard. Questions regarding high-voltage equipment work orders are envisioned to be answered by straight-forward queries of computer databases – there is no intent for the NPP staff to sift through paper records in order to provide responses to these questions. If no such database exists, then the response should be simply N/A. If the database does exist, then an effort should be made to obtain the counts from a person or group with appropriate rights to run queries on the database.

Table A-1
Results of NPP Responses to EPRI Survey Questionnaire

NPP Name: ____________________

Date: ___________________

Subject Matter Expert	Question / Request	Response Choices	Additional Comments
	Risk Management Actions associated with NPP Switchyard Tasks		
PRA Staff	1) Does the risk assessment for NPP switchyard work depend on the type of equipment staff will bring into the NPP switchyard, e.g., trucks, cherry-pickers, etc?	Yes ◻ No ◻	
	Off-Site Resources		
PRA Staff	2) Does the NPP risk model include special off-site recovery assumptions (e.g., use of black start equipment)?	Yes ◻ No ◻	If yes, describe source of "black Start" capability. ---------------------------- ---------------------------- ---------------------------- ----------------------------
	3) Are off site human factors considered in black-start recovery assessment?	Yes ◻ No ◻	
	Switchyard Modeling		
PRA Staff	4) Are the high-voltage (i.e., >4160V) switchyard components explicitly modeled with basic events, T&M events, etc?	Yes ◻ No ◻	
	5) If high-voltage equipment is explicitly modeled, what is the source of data for the reliability values in the model?		
	6) List the number of at-power protective actuations of breakers in the NPP and its switchyard rated for high-voltage (i.e., 4.16kV or higher) during the last ten years in a table format you find convenient.		
	7) Are the equipment along all of the high-voltage feeder lines to the plant switchyard explicitly modeled with basic events, T&M events, etc?	Yes ◻ No ◻	
	8) Is the reliability of each circuit to the plant switchyard treated the same?	Yes ◻ No ◻	

Subject Matter Expert	Question / Request	Response Choices	Additional Comments
	9) Is the reliability of each circuit to the plant switchyard determined for each circuit based on its own merits?	Yes □ No □	
	Auxiliary Transformer Usage		
PRA Staff	10) Does the NPP divert main generator power to house-loads during power-operation?	Yes □ No □	
	11) Does the NPP safety-related AC power come directly from off-site sources?	Yes □ No □	
	Dual Unit Resource Sharing		
PRA Staff	12) Does the NPP have an adjacent nuclear or fossil plant that can supplement the on-site AC generating capacity?	Yes □ No □	
	AAC Systems		
PRA Staff	13) Does the NPP have a licensed AAC source of power (re 10CFR§50.63).	Yes □ No □	

A.2 EPRI Survey Questionnaire Responses

Fifteen U.S. nuclear licensees (12 PWRs and 3 BWRs) participated in this survey and provided responses to the survey questions. The NPP responses to the survey in Table A-1 are displayed graphically in Figures A-1 through A-11. Only the multiple choice responses are provided. Responses to Questions 5 and 6 are excluded, since they have numerical and/or text responses.

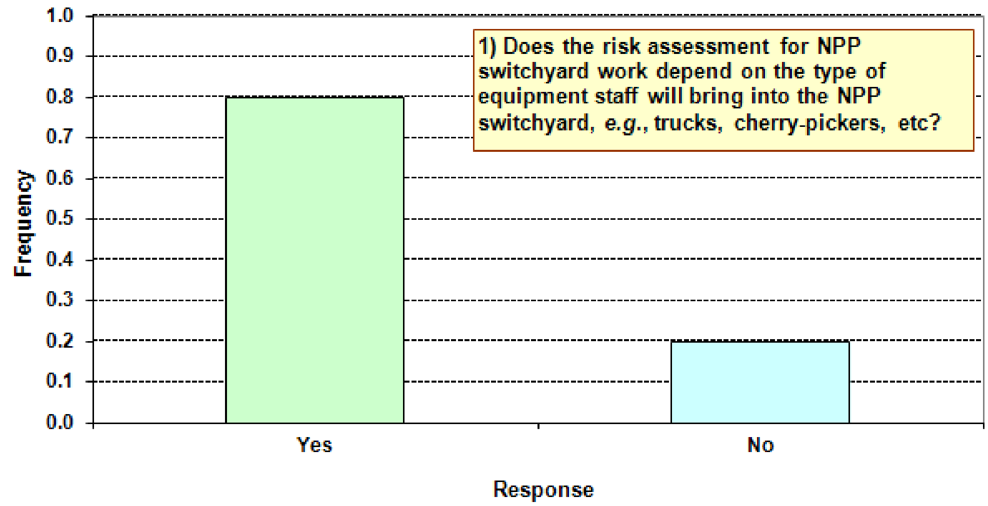

Figure A-1
NPP (PRA Staff) Response to Survey Question 1

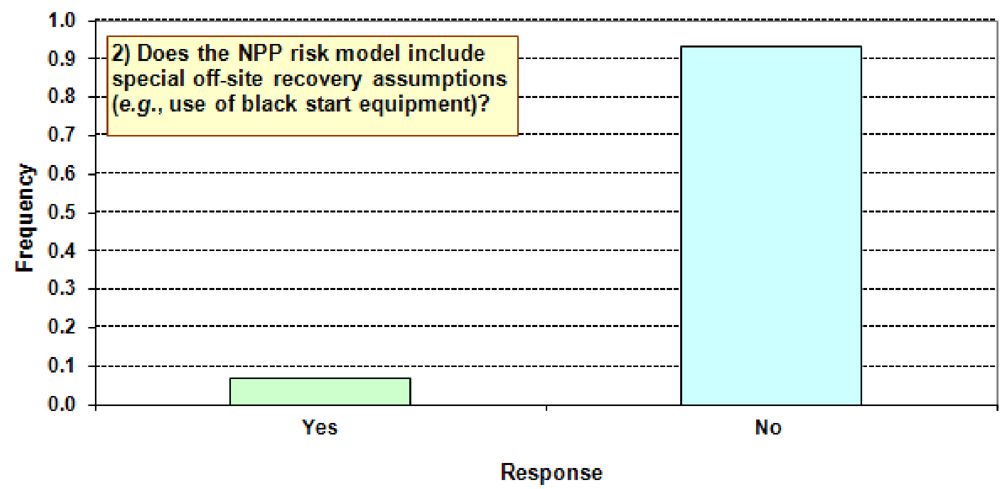

Figure A-2
NPP (PRA Staff) Response to Survey Question 2

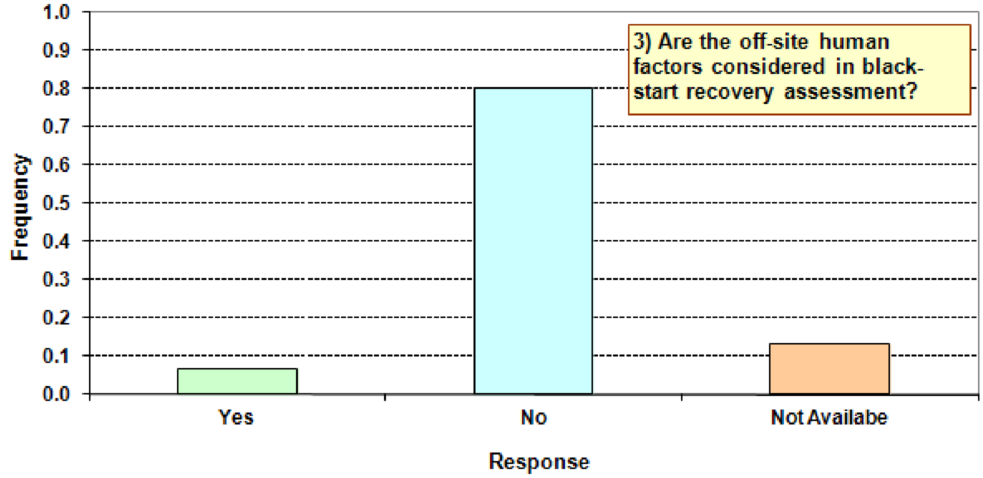

Figure A-3
NPP (PRA Staff) Response to Survey Question 3

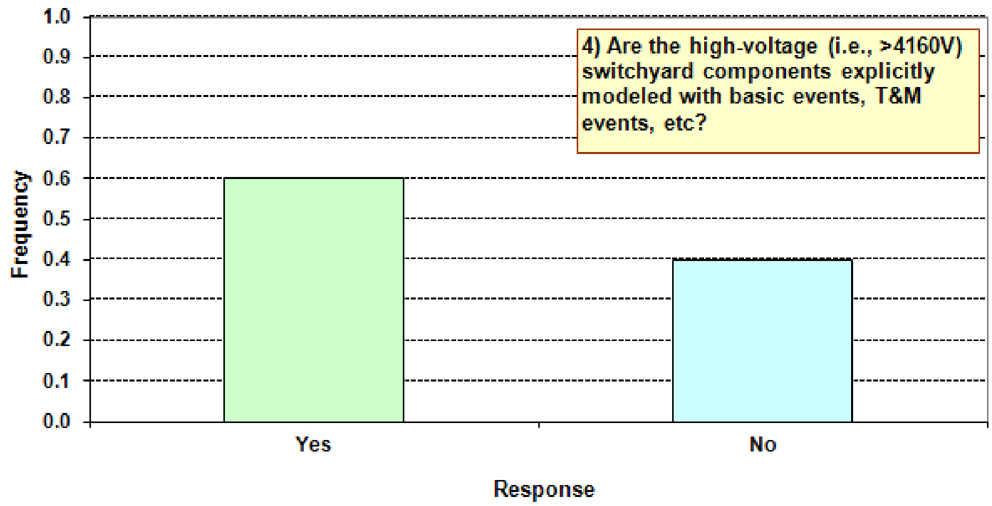

Figure A-4
NPP (PRA Staff) Response to Survey Question 4

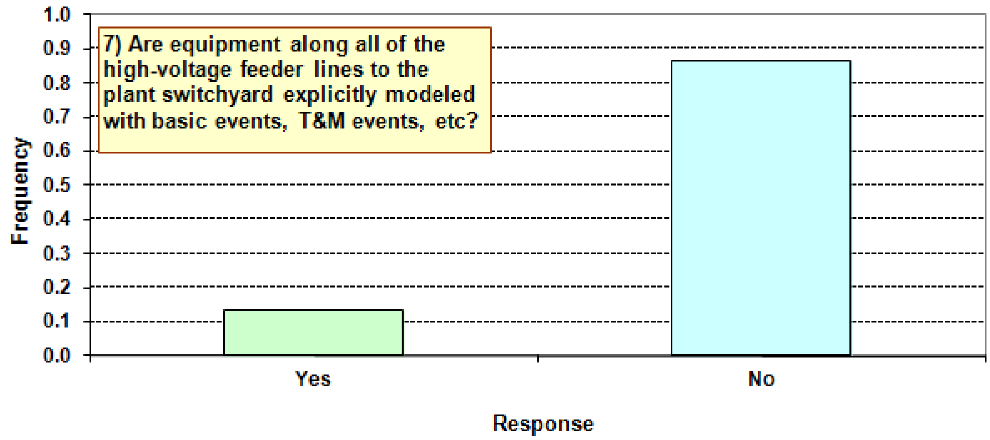

Figure A-5
NPP (PRA Staff) Response to Survey Question 7

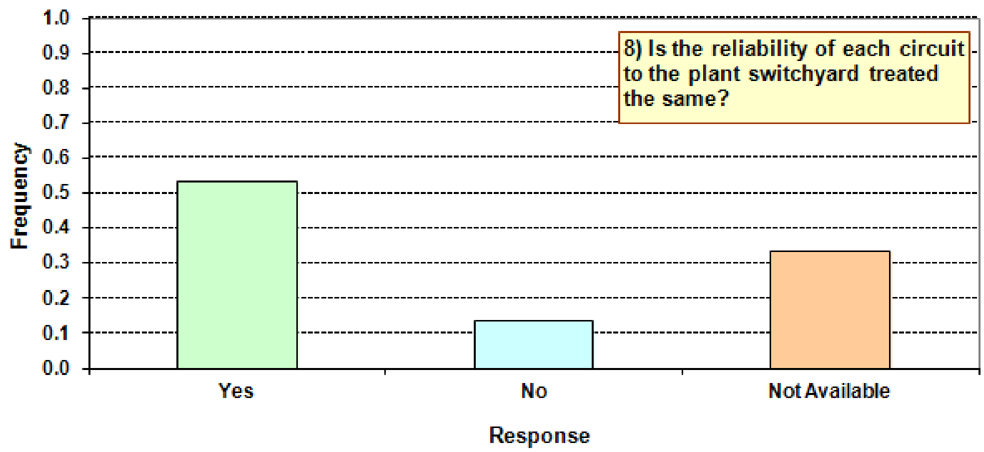

Figure A-6
NPP (PRA Staff) Response to Survey Question 8

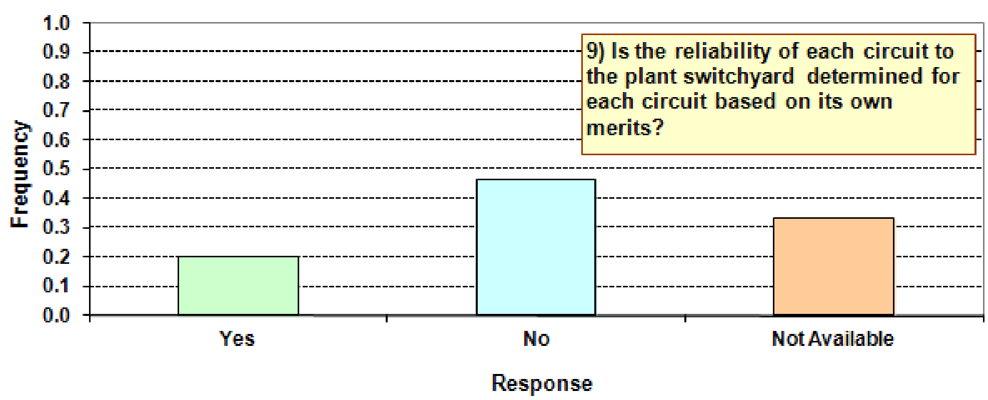

Figure A-7
NPP (PRA Staff) Response to Survey Question 9

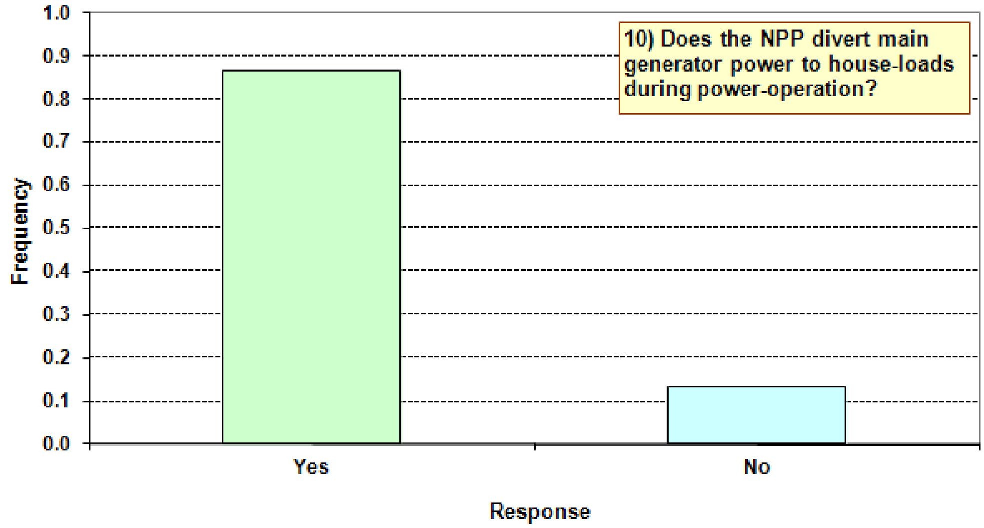

Figure A-8
NPP (PRA Staff) Response to Survey Question 10

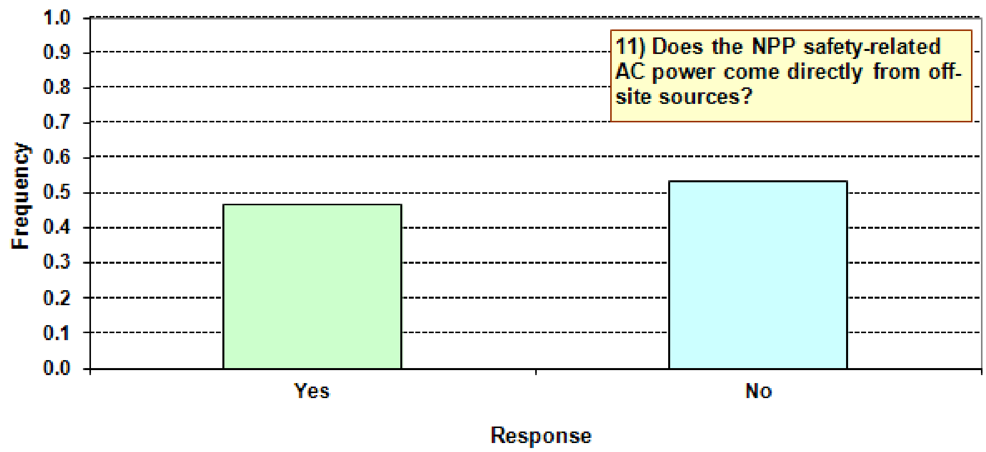

Figure A-9
NPP (PRA Staff) Response to Survey Question 11

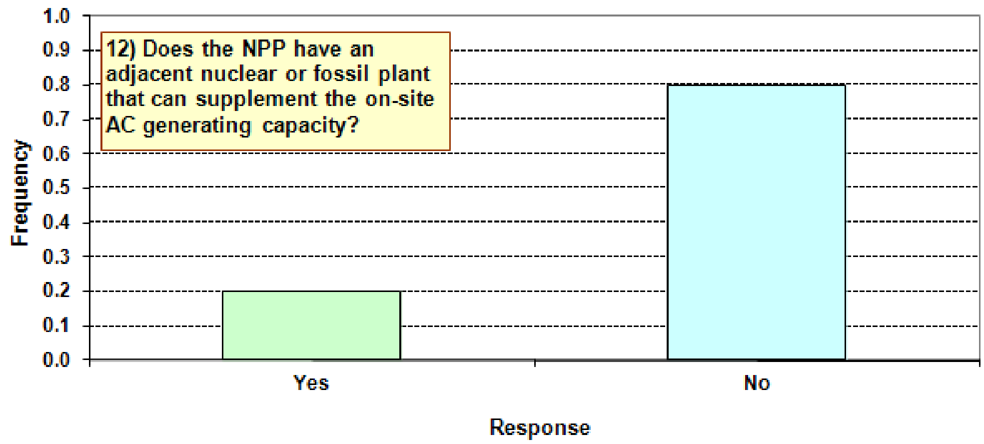

Figure A-10
NPP (PRA Staff) Response to Survey Question 12

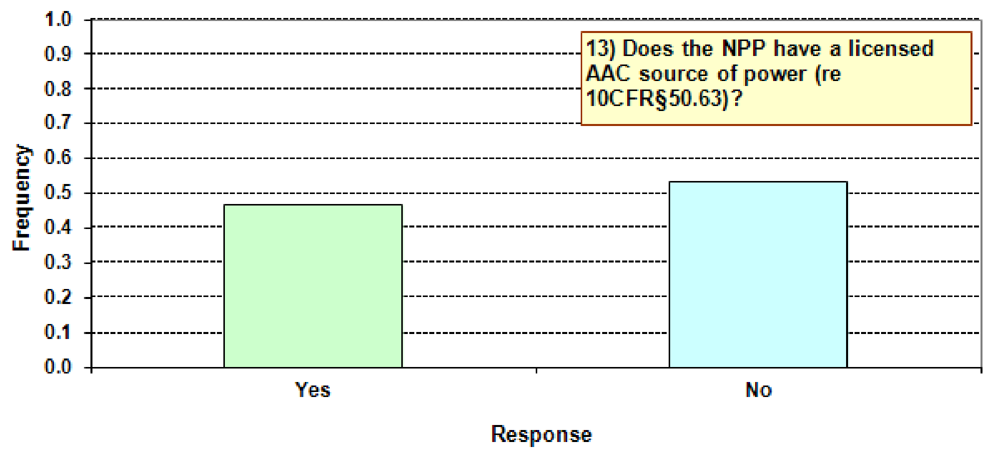

Figure A-11
NPP (PRA Staff) Response to Survey Question 13

Appendix B: Total Loss Of Offsite Power Events from Power Op or HSB Conditions at U.S. NPPs, 1986-2007

Table B-1
Total LOOP Events from Power Op or HSB Conditions at U.S. Nuclear Power Plants, 1986-2007

Site Name	Unit	Date	Condition	LOOP Category	EPRI Category	References	Notes
Robinson	2	28-Jan-86	Power Op	Plant-Centered	Ia	EPRI TR-110398, NUREG/CR-6890, LER-2611986005	Event called a HI event because this failure was related to on-going maintenance of the "B" EDG output breaker.
Salem	2	26-Aug-86	Power Op	Plant-Centered	Ib	no EPRI TR, NUREG/CR-6890, LER-3111986007	EPRI category based on info in NUREG/CR-6850 and the LER.
Brunswick	1	13-Sep-86	Power Op	Plant-Centered	Ib	no EPRI TR, NUREG/CR-6890, LER-3251986024	EPRI category based on info in LER.
Palisades	0	14-Jul-87	Power Op	Switchyard-Centered	Ia	EPRI TR-110398, NUREG/CR-6890, LER-2551987024	

Table B-1
Total LOOP Events from Power Op or HSB Conditions at U.S. Nuclear Power Plants, 1986-2007 (continued)

Site Name	Unit	Date	Condition	LOOP Category	EPRI Category	References	Notes
Calvert Cliffs	1	23-Jul-87	Power Op	Grid-Related	Ia	EPRI TR-110398, NUREG/CR-6890, LER-3171987012	Switchyard-centered per NUREG/CR-6890; however, recategorized based on info in EPRI TR and LER. Not associated with any maintenance activity.
Calvert Cliffs	2	23-Jul-87	Power Op	Grid-Related	Ia	EPRI TR-110398, NUREG/CR-6890, LER-3171987012	Switchyard-centered per NUREG/CR-6890; however, recategorized based on info in EPRI TR and LER.
Beaver Valley	2	17-Nov-87	Power Op	Plant-Centered	Ib	no EPRI TR, NUREG/CR-6890, LER-4121987036	Switchyard-Centered per NUREG/CR-6890; however, recategorized based on info in LER.EPRI Category based on info in the LER.
Diablo Canyon	2	17-Jul-88	Power Op	Plant-Centered	Ia	EPRI 1000158, NUREG/CR-6890, LER-3231988008	Switchyard-centered per NUREG/CR-6890; however, recategorized based on info in EPRI TR and LER.
Palo Verde	2	03-Jan-89	Power Op	Switchyard-Centered	Ia	EPRI 1000158, NUREG/CR-6890, LER-5291989001	
Crystal River	3	16-Jun-89	Power Op	Switchyard-Centered	Ib	EPRI 1000158, NUREG/CR-6890, LER-3021989023	
Brunswick	2	17-Jun-89	Power Op	Switchyard-Centered	Ia	EPRI 1000158, NUREG/CR-6890, LER-3241989009	
Summer	0	11-Jul-89	Power Op	Plant-Centered	Ia	EPRI 1000158, NUREG/CR-6890, LER-3951989012	Grid-centered per NUREG/CR-6890; however, recategorized based on info in EPRI TR and LER.

Table B-1
Total LOOP Events from Power Op or HSB Conditions at U.S. Nuclear Power Plants, 1986-2007 (continued)

Site Name	Unit	Date	Condition	LOOP Category	EPRI Category	References	Notes
Nine Mile Point	1	12-Nov-90	Power Op	Switchyard-Centered	Ia	EPRI 1002987, NUREG/CR-6890, LER-2201990023	No plant trip but a LOOP; EDGs were the only source of power to safety buses until OSP recovered.
McGuire	1	11-Feb-91	Power Op	Switchyard-Centered	Ia	EPRI 1002987, NUREG/CR-6890, LER-3691991001	Plant-centered per NUREG/CR-6890; however, recategorized based on info in EPRI TR and LER.
Vermont Yankee	0	23-Apr-91	Power Op	Switchyard-Centered	Ia	EPRI 1002987, NUREG/CR-6890, LER-2711991009	Plant-centered per NUREG/CR-6890; however, recategorized based on info in EPRI TR and LER.
Cook	1	12-May-91	Power Op	Plant-Centered	Ib	no EPRI TR, NUREG/CR-6890, LER-3151991004	EPRI category based on info in LER.
Yankee Rowe	0	15-Jun-91	Power Op	Switchyard-Centered	Ib	EPRI 1002987, NUREG/CR-6890, LER-291991002	
Crystal River	3	27-Mar-92	Power Op	Plant-Centered	Ib	EPRI 1002987, NUREG/CR-6890, LER-3021992001	
Oyster Creek	0	03-May-92	Power Op	Grid-Related	Ib	EPRI 1002987, NUREG/CR-6890, LER-2191992005	Plant-centered per NUREG/CR-6890; however, recategorized based on info in EPRI TR and LER.
Robinson	2	22-Aug-92	Power Op	Switchyard-Centered	Ia	EPRI 1002987, NUREG/CR-6890, LER-2611992017	

Table B-1
Total LOOP Events from Power Op or HSB Conditions at U.S. Nuclear Power Plants, 1986-2007 (continued)

Site Name	Unit	Date	Condition	LOOP Category	EPRI Category	References	Notes
Oconee	1	19-Oct-92	Power Op	Switchyard-Centered	II	EPRI 1002987, NUREG/CR-6890, LER-2701992004	Plant-centered per NUREG/CR-6890; however, recategorized based on info in EPRI TR and LER.
Oconee	2	19-Oct-92	Power Op	Switchyard-Centered	Ia	EPRI 1002987, NUREG/CR-6890, LER-2701992004	Plant-centered per NUREG/CR-6890; however, recategorized based on info in EPRI TR and LER.
Oconee	3	19-Oct-92	Power Op	Switchyard-Centered	II	EPRI 1002987, NUREG/CR-6890, LER-2701992004	Plant-centered per NUREG/CR-6890; however, recategorized based on info in EPRI TR and LER.
Sequoyah	1	31-Dec-92	Power Op	Switchyard-Centered	Ib	EPRI 1002987, NUREG/CR-6890, LER-3271992027	EPRI category of "None" for this event was revised to "Ib".
Sequoyah	2	31-Dec-92	Power Op	Switchyard-Centered	Ib	EPRI 1002987, NUREG/CR-6890, LER-3271992027	EPRI category of "None" for this event was revised to "Ib".
LaSalle	1	14-Sep-93	Power Op	Switchyard-Centered	Ib	EPRI 1002987, NUREG/CR-6890, LER-3731993015	
Beaver Valley	1	12-Oct-93	Power Op	Switchyard-Centered	Ib	EPRI 1002987, NUREG/CR-6890, LER-3341993013	
McGuire	2	27-Dec-93	Power Op	Switchyard-Centered	Ia	EPRI 1002987, NUREG/CR-6890, LER-3701993008	

Table B-1
Total LOOP Events from Power Op or HSB Conditions at U.S. Nuclear Power Plants, 1986-2007 (continued)

Site Name	Unit	Date	Condition	LOOP Category	EPRI Category	References	Notes
Indian Point	2	26-Jan-94	Power Op	Grid-Related	IIa	EPRI 1009889, LER-2471994001	Categorized as Grid-Related based on info in EPRI TR and LER.
Braidwood	2	18-Jan-96	Power Op	Switchyard-Centered	IIa	EPRI TR-1013239, NUREG/CR-6890, LER-4571996001	EPRI TR-1013239 incorrectly reports event date as 1/1/1996; it is reported as 1/18/1996 in reference LER. No plant trip but a LOOP; safety buses remain powered by UAT.
Catawba	2	06-Feb-96	Power Op	Switchyard-Centered	Ia	EPRI TR-1013239, NUREG/CR-6890, LER-4141996001	
Prairie Island	1	29-Jun-96	Power Op	Weather-Related	Ia	EPRI TR-1013239, NUREG/CR-6890, LER-2821996012	
Prairie Island	2	29-Jun-96	Power Op	Weather-Related	Ia	EPRI TR-1013239, NUREG/CR-6890, LER-2821996012	Categorized as Grid-Related based on info in EPRI TR and LER.
Maine Yankee	0	09-Nov-96	Power Op	Grid-Related	IIa	EPRI TR-1013239, no LER	Categorized as Grid-Related based on info in EPRI TR.
Three Mile Island	1	21-Jun-97	Power Op	Switchyard-Centered	Ia	EPRI TR-1013239, NUREG/CR-6890, LER-2891997007	
Oyster Creek	0	01-Aug-97	Power Op	Plant-Centered	Ia	EPRI TR-1013239, NUREG/CR-6890, LER-2191997010	Switchyard-centered per NUREG/CR-6890; however, recategorized based on info in EPRI TR and LER.
Point Beach	1	08-Jan-98	Power Op	Switchyard-Centered	IIa	EPRI 1016484, NUREG/CR-6890, LER-2661998002	No plant trip but a LOOP; safety buses remain powered by UAT.

Table B-1
Total LOOP Events from Power Op or HSB Conditions at U.S. Nuclear Power Plants, 1986-2007 (continued)

Site Name	Unit	Date	Condition	LOOP Category	EPRI Category	References	Notes
Davis-Besse	0	24-Jun-98	Power Op	Weather-Related	Ia	EPRI 1016484, NUREG/CR-6890, LER-3461998006	
Byron	1	04-Aug-98	Power Op	Switchyard-Centered	IIa	EPRI 1016484, NUREG/CR-6890, LER-4541998017	No plant trip but a LOOP; safety buses remain powered by UAT. Plant-centered per NUREG/CR-6890; however, recategorized based on info in EPRI TR and LER.
Diablo Canyon	1	20-Nov-98	Power Op	Switchyard-Centered	IIa	EPRI 1016484, LER-2751998013	Categorized as Switchyard-Centered based on info in EPRI TR and LER. No plant trip but a LOOP; safety buses remain powered by UAT.
Diablo Canyon	2	20-Nov-98	Power Op	Switchyard-Centered	IIa	EPRI 1016484, LER-2751998013	Categorized as Switchyard-Centered based on info in EPRI TR and LER. No plant trip but a LOOP; safety buses remain powered by UAT.
Fort Calhoun	0	21-Jan-99	Power Op	Switchyard-Centered	IIa	EPRI 1016484, no LER	Categorized as Switchyard-Centered based on info in EPRI TR. No plant trip but a LOOP; safety buses remain powered by UAT. EPRI TR states that "construction work" was a contributor to the event. This work is equated to "heavy maintenance".
Oyster Creek	0	05-Jul-99	Power Op	Switchyard-Centered	IIa	EPRI 1016484, LER-OE-10156	Categorized as Switchyard-Centered based on info in EPRI TR. No plant trip but a LOOP; safety buses remain powered by UAT.
Callaway	0	12-Aug-99	HSB	Grid-Related	IIb	EPRI 1016484, LER-4831999005	Categorized as Grid-Related based on info in EPRI TR and LER. No plant trip. Offsite sources of power to safety buses remain energized but in question especially if an accident were to occur.

Table B-1
Total LOOP Events from Power Op or HSB Conditions at U.S. Nuclear Power Plants, 1986-2007 (continued)

Site Name	Unit	Date	Condition	LOOP Category	EPRI Category	References	Notes
Indian Point	2	31-Aug-99	Power Op	Switchyard-Centered	Ia	EPRI 1016484, NUREG/CR-6890, LER-2471999015	
Diablo Canyon	1	15-May-00	Power Op	Plant-Centered	Ia	EPRI 1016484, NUREG/CR-6890, LER-2752000004	
Diablo Canyon	1	05-Apr-01	Power Op	Grid-Related	IIa	EPRI 1016484, LER-2752001001	Categorized as Grid-Related based on info in EPRI TR and LER. No plant trip but a LOOP; safety buses remain powered by UAT.
Diablo Canyon	2	05-Apr-01	Power Op	Grid-Related	IIa	EPRI 1016484, LER-2752001001	Categorized as Grid-Related based on info in EPRI TR and LER. No plant trip but a LOOP; safety buses remain powered by UAT.
Quad Cities	2	02-Aug-01	Power Op	Switchyard-Centered	Ib	EPRI 1016484, NUREG/CR-6890, LER-2652001001	
Diablo Canyon	1	04-Aug-01	Power Op	Switchyard-Centered	IIa	EPRI 1016484, LER-2752001002	Categorized as Switchyard-Centered based on info in EPRI TR and LER. No plant trip but a LOOP; safety buses remain powered by UAT.
Diablo Canyon	2	04-Aug-01	Power Op	Switchyard-Centered	IIa	EPRI 1016484, LER-2752001002	Categorized as Switchyard-Centered based on info in EPRI TR and LER. No plant trip but a LOOP; safety buses remain powered by UAT.

Table B-1
Total LOOP Events from Power Op or HSB Conditions at U.S. Nuclear Power Plants, 1986-2007 (continued)

Site Name	Unit	Date	Condition	LOOP Category	EPRI Category	References	Notes
Cooper	0	07-Sep-01	Power Op	Grid-Related	IIb	EPRI 1016484, LER-2982001004	Categorized as Grid-Related based on info in EPRI TR and LER. No plant trip. Offsite sources of power to safety buses remain energized but in question especially if an accident were to occur.
Watts Bar	1	27-Sep-02	Power Op	Grid-Related	IIa	EPRI 1016484, NUREG/CR-6890, LER-3902002005	No plant trip but a LOOP; safety buses remain powered by UAT.
Nine Mile Point	1	01-Nov-02	Power Op	Grid-Related	IIb	EPRI 1016484, NUREG/CR-6890, LER-2202002001	No plant trip. Offsite sources of power to safety buses remain energized but in question especially if an accident were to occur. Switchyard-centered per NUREG/CR-6890; however, recategorized based on info in EPRI TR and LER.
Salem	1	29-Jul-03	Power Op	Switchyard-Centered	Ia	EPRI 1016484, NUREG/CR-6890, LER-2722003002	No plant trip and no loss of safety buses, but loss of offsite power to safety buses.
Fermi	2	14-Aug-03	Power Op	Grid-Related	Ia	EPRI 1009889, NUREG/CR-6890, LER-3412003002	
Fitzpatrick	0	14-Aug-03	Power Op	Grid-Related	Ia	EPRI 1009889, NUREG/CR-6890, LER-3332003001	
Ginna	0	14-Aug-03	Power Op	Grid-Related	Ia	EPRI 1009889, NUREG/CR-6890, LER-2442003002	

Table B-1
Total LOOP Events from Power Op or HSB Conditions at U.S. Nuclear Power Plants, 1986-2007 (continued)

Site Name	Unit	Date	Condition	LOOP Category	EPRI Category	References	Notes
Indian Point	2	14-Aug-03	Power Op	Grid-Related	Ia	EPRI 1009889, NUREG/CR-6890, LER-2472003005	
Indian Point	3	14-Aug-03	Power Op	Grid-Related	Ia	EPRI 1009889, NUREG/CR-6890, LER-2862003005	
Nine Mile Point	1	14-Aug-03	Power Op	Grid-Related	Ia	EPRI 1009889, NUREG/CR-6890, LER-2202003002	
Nine Mile Point	2	14-Aug-03	Power Op	Grid-Related	Ia	EPRI 1009889, NUREG/CR-6890, LER-4102003002	
Perry	0	14-Aug-03	Power Op	Grid-Related	Ia	EPRI 1009889, NUREG/CR-6890, LER-4402003002	
Dresden	3	05-May-04	Power Op	Switchyard-Centered	Ia	EPRI 1016484, NUREG/CR-6890, LER-2492004003	
Palo Verde	1	14-Jun-04	Power Op	Grid-Related	Ia	EPRI 1016484, NUREG/CR-6890, LER-5282004006	
Palo Verde	2	14-Jun-04	Power Op	Grid-Related	Ia	EPRI 1016484, NUREG/CR-6890, LER-5282004006	
Palo Verde	3	14-Jun-04	Power Op	Grid-Related	Ia	EPRI 1016484, NUREG/CR-6890, LER-5282004006	

Table B-1
Total LOOP Events from Power Op or HSB Conditions at U.S. Nuclear Power Plants, 1986-2007 (continued)

Site Name	Unit	Date	Condition	LOOP Category	EPRI Category	References	Notes
Brunswick	1	14-Aug-04	Power Op	Weather-Related	Ia	EPRI 1016484, NUREG/CR-6890, LER-3252004002	
Dresden	2	23-Jun-05	Power Op	Grid-Related	IIb	EPRI 1016484, LER-2372005003	Categorized as Grid-Related based on info in EPRI TR and LER. No plant trip. Offsite sources of power to safety buses remain energized but in question especially if an accident were to occur.
Dresden	3	23-Jun-05	Power Op	Grid-Related	IIb	EPRI 1016484, LER-2372005003	Categorized as Grid-Related based on info in EPRI TR and LER. No plant trip. Offsite sources of power to safety buses remain energized but in question especially if an accident were to occur.
Diablo Canyon	2	19-Nov-05	Power Op	Switchyard-Centered	IIa	EPRI 1016484, LER-3232005002	Categorized as Switchyard-Centered based on info in EPRI TR and LER. No plant trip but a LOOP; safety buses remain powered by UAT.
San Onofre	2	03-Feb-06	Power Op	Grid-Related	IIb	EPRI 1016484, LER-3612006002	Categorized as Grid-Related based on info in EPRI TR and LER. No plant trip. Offsite sources of power to safety buses remain energized but in question especially if an accident were to occur. LER not available on NRC website.
San Onofre	3	03-Feb-06	Power Op	Grid-Related	IIb	EPRI 1016484, LER-3612006002	Categorized as Grid-Related based on info in EPRI TR and LER. No plant trip. Offsite sources of power to safety buses remain energized but in question especially if an accident were to occur. LER not available on NRC website.

Table B-1
Total LOOP Events from Power Op or HSB Conditions at U.S. Nuclear Power Plants, 1986-2007 (continued)

Site Name	Unit	Date	Condition	LOOP Category	EPRI Category	References	Notes
Catawba	1	20-May-06	Power Op	Switchyard-Centered	Ia	EPRI 1016484, LER-4132006001	Categorized as Switchyard-Centered based on info in EPRI TR and LER.
Catawba	2	20-May-06	Power Op	Switchyard-Centered	Ia	EPRI 1016484, LER-4132006001	Categorized as Switchyard-Centered based on info in EPRI TR and LER.
Ginna	0	01-Aug-06	Power Op	Grid-Related	IIb	EPRI 1016484, LER-2442006002	Categorized as Grid-Related based on info in EPRI TR and LER. No plant trip. Offsite sources of power to safety buses remain energized but in question especially if an accident were to occur.
Ginna	0	02-Aug-06	Power Op	Grid-Related	IIb	EPRI 1016484, LER-2442006002	Categorized as Grid-Related based on info in EPRI TR and LER. No plant trip. Offsite sources of power to safety buses remain energized but in question especially if an accident were to occur.
Surry	1	07-Oct-06	Power Op	Switchyard-Centered	Ia	EPRI 1016484, LER-2812006002	Categorized as Switchyard-Centered based on info in EPRI TR and LER, i.e., affected equipment was in the switchyard.
Brunswick	2	01-Nov-06	Power Op	Switchyard-Centered	Ia	EPRI 1016484, LER-3242006001	Categorized as Switchyard-Centered based on info in EPRI TR and LER.
Diablo Canyon	2	12-May-07	Power Op	Grid-Related	IIa	EPRI 1016484, LER-2752007001	Categorized as Grid-Related based on info in EPRI TR and LER. No plant trip but a LOOP; safety buses remain powered by UAT.

Table B-2
EPRI LOOP Category Definitions

EPRI Category	Definition in EPRI TR-110398	Definition in EPRI 1002987	Definition in EPRI 1009889, 1013239, 1016484
Ia	No off-site power available for 30 minutes or longer to the safety buses.	No off-site power available for 30 minutes or longer to the safety buses.	No off-site power available for 30 minutes or longer to the safety buses.
Ib	No off-site power available for less than 30 minutes to the safety buses.	No off-site power available for less than 30 minutes to the safety buses.	No off-site power available for less than 30 minutes to the safety buses.
II	Loss of startup (or shutdown or reserve) off-site power but if on-line, the main generator remained connected to the normal off-site system and the plant received power from the unit auxiliary transformer or its equivalent.	Loss of startup (or shutdown or reserve) off-site power but if on-line, the main generator remained connected to the normal off-site system and the plant received power from the unit auxiliary transformer or its equivalent.	(not used)
IIa	(not used)	(not used)	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	(not used)	(not used)	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.

Table B-2
EPRI LOOP Category Definitions

EPRI Category	Definition in EPRI TR-110398	Definition in EPRI 1002987	Definition in EPRI 1009889, 1013239, 1016484
III	The unit trips off-line with a loss of feed through the unit auxiliary transformer, but off-site power remains available, or can be made available, from a startup/shutdown source. The startup power may require a fast transfer or manual switching from the control room. A loss of unit auxiliary power this is caused by a unit trip is not a category III event. To be a category III event the loss of power must be the initiating event and precede the unit trip.	The unit trips off-line with a loss of feed through the unit auxiliary transformer, but off-site power remains available, or can be made available, from a startup/shutdown source. The startup power may require a fast transfer or manual switching from the control room. A loss of unit auxiliary power this is caused by a unit trip is not a category III event. To be a category III event the loss of power must be the initiating event and precede the unit trip.	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 off-site power available during cold shutdown because of special maintenance conditions that do not occur during or immediately following operations.	Off-site power lost during cold shutdown because of special maintenance conditions that do not occur during or immediately following operation.	No offsite power available during cold shutdown because of special maintenance conditions that do not occur during or immediately following operations.
None	Typically, a plant trip occurred but no loss of all offsite power occurred.	Typically, a plant trip occurred but no loss of all offsite power occurred.	Typically, a plant trip occurred but no loss of all offsite power occurred.

Appendix C: Switchyard-Centered Total Loss of Offsite Power Events from Power Op or HSB Conditions at U.S. NPPs, 1986-2007

Figure C-1
Switchyard-Centered Total LOOP Events from Power Op or HSB Conditions at U.S. Nuclear Power Plants, 1986-2007

Site Name	Unit	Date	Condition	EPRI Category	References	Notes	Type 1 (SWYD Battery Mtce)	Type 2 (SWYD I&C Mtce)	Type 3 (SWYD Heavy Mtce)	Type 4 (SWYD Other Mtce)	Type 0 (No SWYD Mtce)
Palisades	0	14-Jul-87	Power Op	Ia	EPRI TR-110398, NUREG/CR-6890, LER-2551987024		No	No	No	Yes	No
Palo Verde	2	03-Jan-89	Power Op	Ia	EPRI 1000158, NUREG/CR-6890, LER-5291989001		No	No	No	No	Yes

Table C-1
Switchyard-Centered Total LOOP Events from Power Op or HSB Conditions at U.S. Nuclear Power Plants, 1986-2007 (continued)

Site Name	Unit	Date	Condition	EPRI Category	References	Notes	Type 1 (SWYD Battery Mtce)	Type 2 (SWYD I&C Mtce)	Type 3 (SWYD Heavy Mtce)	Type 4 (SWYD Other Mtce)	Type 0 (No SWYD Mtce)
Crystal River	3	16-Jun-89	Power Op	Ib	EPRI 1000158, NUREG/CR-6890, LER-3021989023		No	Yes	No	No	No
Brunswick	2	17-Jun-89	Power Op	Ia	EPRI 1000158, NUREG/CR-6890, LER-3241989009		No	No	No	Yes	No
Nine Mile Point	1	12-Nov-90	Power Op	Ia	EPRI 1002987, NUREG/CR-6890, LER-2201990023	No plant trip but a LOOP; EDGs were the only source of power to safety buses until OSP recovered.	No	No	No	No	Yes
McGuire	1	11-Feb-91	Power Op	Ia	EPRI 1002987, NUREG/CR-6890, LER-3691991001	Plant-centered per NUREG/CR-6890; however, recategorized based on info in EPRI TR and LER.	No	Yes	No	No	No

Table C-1
Switchyard-Centered Total LOOP Events from Power Op or HSB Conditions at U.S. Nuclear Power Plants, 1986-2007 (continued)

Site Name	Unit	Date	Condition	EPRI Category	References	Notes	Type 1 (SWYD Battery Mtce)	Type 2 (SWYD I&C Mtce)	Type 3 (SWYD Heavy Mtce)	Type 4 (SWYD Other Mtce)	Type 0 (No SWYD Mtce)
Vermont Yankee	0	23-Apr-91	Power Op	Ia	EPRI 1002987, NUREG/CR-6890, LER-2711991009	Plant-centered per NUREG/CR-6890; however, recategorized based on info in EPRI TR and LER.	Yes	No	No	No	No
Yankee Rowe	0	15-Jun-91	Power Op	Ib	EPRI 1002987, NUREG/CR-6890, LER-291991002		No	No	No	No	Yes
Robinson	2	22-Aug-92	Power Op	Ia	EPRI 1002987, NUREG/CR-6890, LER-2611992017		No	No	No	No	Yes
Oconee	1	19-Oct-92	Power Op	II	EPRI 1002987, NUREG/CR-6890, LER-2701992004	Plant-centered per NUREG/CR-6890; however, recategorized based on info in EPRI TR and LER.	Yes	No	No	No	No

Table C-1
Switchyard-Centered Total LOOP Events from Power Op or HSB Conditions at U.S. Nuclear Power Plants, 1986-2007 (continued)

Site Name	Unit	Date	Condition	EPRI Category	References	Notes	Type 1 (SWYD Battery Mtce)	Type 2 (SWYD I&C Mtce)	Type 3 (SWYD Heavy Mtce)	Type 4 (SWYD Other Mtce)	Type 0 (No SWYD Mtce)
Oconee	2	19-Oct-92	Power Op	Ia	EPRI 1002987, NUREG/CR-6890, LER-2701992004	Plant-centered per NUREG/CR-6890; however, recategorized based on info in EPRI TR and LER.	Yes	No	No	No	No
Oconee	3	19-Oct-92	Power Op	II	EPRI 1002987, NUREG/CR-6890, LER-2701992004	Plant-centered per NUREG/CR-6890; however, recategorized based on info in EPRI TR and LER.	Yes	No	No	No	No
Sequoyah	1	31-Dec-92	Power Op	Ib	EPRI 1002987, NUREG/CR-6890, LER-3271992027	EPRI category of "None" for this event was revised to "Ib".	No	Yes	No	No	No
Sequoyah	2	31-Dec-92	Power Op	Ib	EPRI 1002987, NUREG/CR-6890, LER-3271992027	EPRI category of "None" for this event was revised to "Ib".	No	Yes	No	No	No

Table C-1
Switchyard-Centered Total LOOP Events from Power Op or HSB Conditions at U.S. Nuclear Power Plants, 1986-2007 (continued)

Site Name	Unit	Date	Condition	EPRI Category	References	Notes	Type 1 (SWYD Battery Mtce)	Type 2 (SWYD I&C Mtce)	Type 3 (SWYD Heavy Mtce)	Type 4 (SWYD Other Mtce)	Type 0 (No SWYD Mtce)
LaSalle	1	14-Sep-93	Power Op	Ib	EPRI 1002987, NUREG/CR-6890, LER-3731993015		No	No	No	No	Yes
Beaver Valley	1	12-Oct-93	Power Op	Ib	EPRI 1002987, NUREG/CR-6890, LER-3341993013		No	Yes	No	No	No
McGuire	2	27-Dec-93	Power Op	Ia	EPRI 1002987, NUREG/CR-6890, LER-3701993008		No	No	No	No	Yes
Braidwood	2	18-Jan-96	Power Op	IIa	EPRI TR-1013239, NUREG/CR-6890, LER-4571996001	EPRI TR-1013239 incorrectly reports event date as 1/1/1996; it is reported as 1/18/1996 in reference LER. No plant trip but a LOOP; safety buses remain powered by UAT.	No	No	No	No	Yes

Table C-1
Switchyard-Centered Total LOOP Events from Power Op or HSB Conditions at U.S. Nuclear Power Plants, 1986-2007 (continued)

Site Name	Unit	Date	Condition	EPRI Category	References	Notes	Type 1 (SWYD Battery Mtce)	Type 2 (SWYD I&C Mtce)	Type 3 (SWYD Heavy Mtce)	Type 4 (SWYD Other Mtce)	Type 0 (No SWYD Mtce)
Catawba	2	06-Feb-96	Power Op	Ia	EPRI TR-1013239, NUREG/CR-6890, LER-4141996001		No	No	No	No	Yes
Three Mile Island	1	21-Jun-97	Power Op	Ia	EPRI TR-1013239, NUREG/CR-6890, LER-2891997007		No	No	No	No	Yes
Point Beach	1	08-Jan-98	Power Op	IIa	EPRI 1016484, NUREG/CR-6890, LER-2661998002	No plant trip but a LOOP; safety buses remain powered by UAT.	No	No	No	No	Yes
Byron	1	04-Aug-98	Power Op	IIa	EPRI 1016484, NUREG/CR-6890, LER-4541998017	No plant trip but a LOOP; safety buses remain powered by UAT. Plant-centered per NUREG/CR-6890; however, recategorized based on info in EPRI TR and LER.	No	No	No	No	Yes

Table C-1
Switchyard-Centered Total LOOP Events from Power Op or HSB Conditions at U.S. Nuclear Power Plants, 1986-2007 (continued)

Site Name	Unit	Date	Condition	EPRI Category	References	Notes	Type 1 (SWYD Battery Mtce)	Type 2 (SWYD I&C Mtce)	Type 3 (SWYD Heavy Mtce)	Type 4 (SWYD Other Mtce)	Type 0 (No SWYD Mtce)
Diablo Canyon	1	20-Nov-98	Power Op	IIa	EPRI 1016484, LER-2751998013	Categorized as Switchyard-Centered based on info in EPRI TR and LER. No plant trip but a LOOP; safety buses remain powered by UAT.	No	Yes	No	No	No
Diablo Canyon	2	20-Nov-98	Power Op	IIa	EPRI 1016484, LER-2751998013	Categorized as Switchyard-Centered based on info in EPRI TR and LER. No plant trip but a LOOP; safety buses remain powered by UAT.	No	Yes	No	No	No
Fort Calhoun	0	21-Jan-99	Power Op	IIa	EPRI 1016484, no LER	Categorized as Switchyard-Centered based on info in EPRI TR. No plant trip but a LOOP; safety buses remain powered by UAT. EPRI TR states that "construction work" was a contributor to the event. This work is equated to "heavy maintenance".	No	No	Yes	No	No

Table C-1
Switchyard-Centered Total LOOP Events from Power Op or HSB Conditions at U.S. Nuclear Power Plants, 1986-2007 (continued)

Site Name	Unit	Date	Condition	EPRI Category	References	Notes	Type 1 (SWYD Battery Mtce)	Type 2 (SWYD I&C Mtce)	Type 3 (SWYD Heavy Mtce)	Type 4 (SWYD Other Mtce)	Type 0 (No SWYD Mtce)
Oyster Creek	0	05-Jul-99	Power Op	IIa	EPRI 1016484, LER-OE-10156	Categorized as Switchyard-Centered based on info in EPRI TR. No plant trip but a LOOP; safety buses remain powered by UAT.	No	No	No	No	Yes
Indian Point	2	31-Aug-99	Power Op	Ia	EPRI 1016484, NUREG/CR-6890, LER-2471999015		No	Yes	No	No	No
Quad Cities	2	02-Aug-01	Power Op	Ib	EPRI 1016484, NUREG/CR-6890, LER-2652001001		No	No	No	No	Yes
Diablo Canyon	1	04-Aug-01	Power Op	IIa	EPRI 1016484, LER-2752001002	Categorized as Switchyard-Centered based on info in EPRI TR and LER. No plant trip but a LOOP; safety buses remain powered by UAT.	No	No	No	No	Yes

Table C-1
Switchyard-Centered Total LOOP Events from Power Op or HSB Conditions at U.S. Nuclear Power Plants, 1986-2007 (continued)

Site Name	Unit	Date	Condition	EPRI Category	References	Notes	Type 1 (SWYD Battery Mtce)	Type 2 (SWYD I&C Mtce)	Type 3 (SWYD Heavy Mtce)	Type 4 (SWYD Other Mtce)	Type 0 (No SWYD Mtce)
Diablo Canyon	2	04-Aug-01	Power Op	IIa	EPRI 1016484, LER-2752001002	Categorized as Switchyard-Centered based on info in EPRI TR and LER. No plant trip but a LOOP; safety buses remain powered by UAT.	No	No	No	No	Yes
Salem	1	29-Jul-03	Power Op	Ia	EPRI 1016484, NUREG/CR-6890, LER-2722003002	No plant trip and no loss of safety buses, but loss of offsite power to safety buses.	No	No	No	No	Yes
Dresden	3	05-May-04	Power Op	Ia	EPRI 1016484, NUREG/CR-6890, LER-2492004003		No	Yes	No	No	No
Diablo Canyon	2	19-Nov-05	Power Op	IIa	EPRI 1016484, LER-3232005002	Categorized as Switchyard-Centered based on info in EPRI TR and LER. No plant trip but a LOOP; safety buses remain powered by UAT.	No	Yes	No	No	No

Table C-1
Switchyard-Centered Total LOOP Events from Power Op or HSB Conditions at U.S. Nuclear Power Plants, 1986-2007 (continued)

Site Name	Unit	Date	Condition	EPRI Category	References	Notes	Type 1 (SWYD Battery Mtce)	Type 2 (SWYD I&C Mtce)	Type 3 (SWYD Heavy Mtce)	Type 4 (SWYD Other Mtce)	Type 0 (No SWYD Mtce)
Catawba	1	20-May-06	Power Op	Ia	EPRI 1016484, LER-4132006001	Categorized as Switchyard-Centered based on info in EPRI TR and LER.	No	No	No	No	Yes
Catawba	2	20-May-06	Power Op	Ia	EPRI 1016484, LER-4132006001	Categorized as Switchyard-Centered based on info in EPRI TR and LER.	No	No	No	No	Yes
Surry	1	07-Oct-06	Power Op	Ia	EPRI 1016484, LER-2812006002	Categorized as Switchyard-Centered based on info in EPRI TR and LER, i.e., affected equipment was in the switchyard.	No	No	No	No	Yes
Brunswick	2	01-Nov-06	Power Op	Ia	EPRI 1016484, LER-3242006001	Categorized as Switchyard-Centered based on info in EPRI TR and LER.	No	No	No	No	Yes

Appendix D: Plant-Centered Total Loss Of Offsite Power Events from Power Op or HSB Conditions at U.S. NPPs, 1986-2007

Table D-1
Plant-Centered Total LOOP Events from Power Op or HSB Conditions at U.S. Nuclear Power Plants, 1986-2007

Site Name	Unit Number	Date	Condition	EPRI LOOP Category	EPRI Category	References	Notes
Robinson	2	28-Jan-86	Power Op	Ia	Plant-Centered	EPRI TR-110398, NUREG/CR-6890, LER-2611986005	
Brunswick	1	13-Sep-86	Power Op	Ib	Plant-Centered	no EPRI TR, NUREG/CR-6890, LER-3251986024	EPRI category was assumed based on the LER.

Table D-1
Plant-Centered Total LOOP Events from Power Op or HSB Conditions at U.S. Nuclear Power Plants, 1986-2007 (continued)

Site Name	Unit Number	Date	Condition	EPRI LOOP Category	EPRI Category	References	Notes
Diablo Canyon	2	17-Jul-88	Power Op	Ia	Plant-Centered	EPRI 1000158, NUREG/CR-6890, LER-3231988008	Switchyard-centered per NUREG/CR-6890 but recategorized based on EPRI TR and LER.
Summer		11-Jul-89	Power Op	Ia	Plant-Centered	EPRI 1000158, NUREG/CR-6890, LER-3951989012	Grid-related per NUREG/CR-6890 but recategorized based on EPRI TR and LER.
Cook	1	12-May-91	Power Op	Ib	Plant-Centered	no EPRI TR, NUREG/CR-6890, LER-3151991004	EPRI category determined based on LER.
Crystal River	3	27-Mar-92	Power Op	Ib	Plant-Centered	EPRI 1002987, NUREG/CR-6890, LER-3021992001	
Oyster Creek		01-Aug-97	Power Op	Ia	Plant-Centered	EPRI TR-1013239, NUREG/CR-6890, LER-2191997010	Switchyard-centered per NUREG/CR-6890 but recategorized based on EPRI TR and LER.
Diablo Canyon	1	15-May-00	Power Op	Ia	Plant-Centered	EPRI 1016484, NUREG/CR-6890, LER-2752000004	

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