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Support System Initiating Events

Identification and Quantification Guideline

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Technical Update, December 2008

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PRODUCT DESCRIPTION

This report documents current methods to identify and quantify support system initiating events (SSIEs) used in probabilistic risk assessment (PRA). This report updates the guidance provided in an EPRI report published in 2006, *Support System Initiating Events: Identification and Quantification Guideline* (1013490), and has been developed with input from a broad spectrum of the PRA community. Cooperation with the U.S. Nuclear Regulatory Commission (NRC) and Idaho National Laboratory (INL), under the provisions of the EPRI-NRC Research memorandum of understanding (MOU), has been a key element of the success of this effort. A particular focus of this report is the methods used for the development of SSIEs. State-of-the-art concepts involving the treatment of common-cause failures (CCFs) and the use of the explicit event and point-estimate fault tree methods are addressed in detail.

Results and Findings

This report documents the latest research efforts to improve the PRA modeling of SSIEs. Specifically, the report presents acceptable methods and revised approaches to known issues.

This report offers a critical examination of modeling methods, such as the explicit event, point-estimate fault tree, and multiplier methods. Of these, the explicit event method is recommended as a result of this effort because the basic event contributions to the initiating event total frequency are clear. Visibility improves the traceability and defensibility of the model because one can easily see whether the applied recovery and mitigation terms are appropriate. It should be noted, however, that both the explicit event and point-estimate fault tree methods provide the ability to define unique basic events with a year-long mission time that are used only in the initiating event fault tree, and each provides better results than the multiplier method. The third method—the multiplier method—violates the rare-event approximation because of the presence of a large (typically, 365-day) multiplier in the model.

Included in the report are specific recommendations for the treatment of CCFs. In the past, a common practice was to remove events from the INL CCF database by screening, using the "remove event" command. However, this practice does not properly address both the numerator and denominator of the alpha factor calculation. The current version of the INL CCF database allows the user to filter the data based on date. This report recommends filtering data so that only data used since 1995 are included in order to reflect data obtained since full implementation of the Maintenance Rule. This will eliminate older data that could skew results conservatively. As a result of this research effort, the INL CCF database was changed to provide the capability to calculate CCF parameters for systems that have no recorded historical events. In the past, this was treated as an error condition in the database. The CCF database now uses the independent failure event counts and related operational history to perform a Bayesian update of the CCF database prior distribution and will produce alpha factor results that are system specific.

The final issue addressed in this report is importance measures. The report recommends excluding SSIEs from the calculation of importance measures based on issues related to consistency of computation and consistency of treatment with other plant systems.

Challenges and Objectives

Implementation of ASME PRA Standard requirements has been a challenge to the nuclear industry. In many cases, consistent approaches to particular Standard requirements have been lacking, and there has been little or no guidance available. EPRI has sought to meet the need to provide quality guidance for PRA analysts in the industry through the EPRI PRA Scope and Quality Initiative. This report provides the guidance necessary for the identification and quantification of SSIEs and is based on the collective input of a wide spectrum of the industry, NRC, and INL.

Applications, Value, and Use

The guidance in this report provides sound methods for the identification and quantification of SSIEs, which is needed in the industry to support PRA model updates in accordance with Regulatory Guide (RG) 1.200. This report has been prepared to provide more mature guidance for PRA analysts in the nuclear industry than was available when the original report was published in 2006. In addition, this report is intentionally forward looking because there are possible future developments in the area of CCFs that could provide additional refinement of the methods. Examples include the possible elimination of CCF database records that represent only equipment degradation (not failures) and addressing alpha factor conservatisms for systems with no history of demand failures.

EPRI Perspective

SSIEs are an important element of PRA development. This report describes advancements in the understanding of the best techniques and application of available data, supporting utilities refining their PRA models in accordance with the ASME PRA Standard and RG 1.200. This report also represents the consensus of a broad spectrum of the industry through the EPRI PRA Scope and Quality Initiative and the NRC and INL under the provisions of the EPRI-NRC MOU.

It is expected that this technical update report will be widely used for its lessons learned. In addition, this report identifies several areas of potential research for consideration in a potential future update to this report.

Approach

This report provides an update on the state-of-the-art methods for SSIE development. Comments on the previous report were reviewed and considered. Significant issues identified by EPRI and NRC were discussed, and technically sound resolutions were developed. The result is that the existing guidance for SSIE identification and quantification has moved forward; opportunities for future advancements, especially in the treatment of CCFs, were also identified.

Keywords

Common-cause failure (CCF)
Fault tree
Probabilistic risk assessment (PRA)
Support system initiating events (SSIEs)

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1
INTRODUCTION

1.1 Objectives and Issue Summary

Probabilistic risk assessment (PRA) insights are used by the nuclear industry and the United States Nuclear Regulatory Commission (USNRC) to assess the level of safety of plant operations and to support changes in nuclear power plant operating requirements. These activities are used both on an exception basis (i.e., one to several days) and as long-term changes to a plant's licensing basis. The use of PRA insights to modify plant operations or a plant's licensing basis requires the PRA to demonstrate a level of quality commensurate with the prospective change, using recently developed PRA standards.

A series of standards addressing PRA quality has been developed by industry groups, and the standards are continuing to develop and evolve. These standards establish the technical adequacy for each technical element of a PRA used for risk-informed applications. The internal events PRA standard for full power operations was published by the American Society of Mechanical Engineers (ASME) in April 2002 [1], then updated in 2003 [2], in 2005 [3], and again in 2007 [4]. The USNRC implements the requirements for internal events during full power operations via the ASME PRA Standard using the endorsement in Appendix A of Regulatory Guide 1.200 [5]. The American Nuclear Society (ANS) developed a PRA Standard for External Events PRAs in 2003 [6] and a standard for Fire PRA [7]. ANS standards for shutdown PRA and Level 2/Level 3 PRA are under development.

As these standards were being written and updated, the Nuclear Regulatory Commission reviewed and updated the support system initiating event models and the process for modeling support system initiators, primarily for use in standardized plant analysis risk (SPAR) models. Similarly, industry conducted model updates and subsequent PRA peer reviews of the internal events PRAs. Owner's Groups peer reviews (conducted before the ASME PRA Standard was written), and more recently peer reviews and gap analyses conducted when implementing risk-informed applications, noted consistency issues with the modeling of support system initiating events. Specifically, the identification and quantification of Support System Initiating Events (SSIE) analyses revealed inconsistencies and issues as identified below.

- Identification. The definition of what constitute a support system initiating event is not consistent between plants, especially with respect to inclusion of support system initiating events resulting in administrative shutdown, manual shutdown, or delayed reactor trip.
- Quantification – Modeling Systems with Redundant Trains. Techniques used to model and quantify the unavailability of a support system for the 24-hour mission time following a reactor trip (post-initiator system model where repair or restoration is not

credited) are not always suitable for quantification of the complete loss of an operating system over the course of a year. The process for support system initiating event frequency quantification must accommodate factors such as removal of a train from service, restoration and repair of failed components, consideration of multiple operating configurations, and transitory environmental factors potentially degrading system performance.

- Quantification – Incorporating Common Cause Failure Data. Current models and data for common cause failure (CCF) of operating components are often based on minimal data that have been evaluated and developed for use in a post-initiator, 24-hour mission time model (which typically involves some conservatism). While the conservatism may be acceptable for a 24-hour mission time, extrapolation of this data to model common cause failure frequencies for the year-long mission time used in initiating event modeling often results in frequencies exceeding those observed in industry experience.
- Quantification – Initiating Event Frequency Results. In order to derive a representative initiating event frequency for a support system initiating event, a plant-specific reliability evaluation is often performed. The most common technique is fault tree analysis. The resulting frequency, although plant-specific, is often significantly different (higher or lower) from the industry experience of similar systems at other plants.

EPRI started a project in 2005 to examine these issues and to develop a recommended approach on how to address each, culminating in an interim report [14]. In 2008, the EPRI support system initiating event project merged with the NRC in a joint project to re-visit the issues and to address developments in the following three areas.

- General treatment of common cause failures for support system initiating event models – This topic relates to issue #3 above, focusing on the development of common cause failure data specific to the systems being modeled from the INL common cause database [16] and also providing common cause alpha factor data for systems that have zero failures.

- Modeling Methods – This topic relates to issue #2 above, first addressing the different types of fault tree modeling techniques for support system initiators, and also presenting the recommended treatment of the different mission times involved with modeling the running and standby train(s).

- Treatment of Initiating Event Precursors – This topic relates to issue #1 above, providing amplifying information based on the current ASME PRA Standard requirements.

- Dependencies – This topic relates to the extent and the level of detail that support systems are included within a support system initiating event model.

- Importance Measures - The final issue addressed in this report is importance measures. Because initiating events are measured in units of frequency they consequently do not have the value of “one” as an upper bound, so importance measures such as Risk-Achievement are essentially meaningless, and Birnbaum measures have difficulty in certain frequency ranges.

The general purpose of this project is to research all aspects of support system initiating event modeling, and then to develop modeling guidance. The specific focus on the research to date has been to address the issues identified above. The project plans on continuing to address additional research needs after this report is published. This report presents a technical update of the current state-of-the-art in support system initiating event modeling as of 2008. The objective of the modeling guidance in this report is to present a consistent approach to support system initiating events (i.e., selection / identification, grouping, quantification, and documentation) in order to produce initiating event frequencies consistent with actual reactor industry experience. Implementation of the support system initiating event modeling guidance of this report is intended to improve PRA model quality by providing an industry-consensus approach to satisfying the requirements of the ASME PRA Standard. In short, this report describes the "how to model" support system initiating events in response to the ASME PRA Standard requirements of "what to model".

This project is one of several EPRI initiatives to improve the scope and quality of probabilistic risk assessments. Since 2004 EPRI has developed and published reports addressing aspects such as PRA quantification (truncation level and convergence), treatment of uncertainty, and aggregation of risk metrics, with several more in research for publication at a later date.

1.2 Project Scope

This investigation applies to Level 1 probabilistic risk assessments of internal initiating events during full power operations. While this report focused on PRAs of full power operations, similar modeling considerations are expected to apply during low power and shutdown conditions but would require re-examination to ensure the resulting initiating event frequencies were consistent with industry experience. The investigation started, and focused, on the issues listed above [14], then was expanded in this report to address current developments: common cause modeling data changes, initiating event pre-cursors and modeling methods.

A support system initiating event is a *subcategory* of initiating events consisting of initiators where the failure not only causes a loss/challenge to a safety function, but also adversely affects one or more systems needed to respond to the reactor shutdown.

Failures of a component, train, or system leading to reactor trip, but which do not affect any of the systems normally available for safe shutdown (as defined by the PRA), are not considered a support system initiating event, and should be grouped in the reactor trip initiator category. For example, a loss of reactor letdown in a pressurized water reactor (PWR) or loss of reactor water cleanup system in a boiling water reactor (BWR) would be grouped with reactor trip since they do not impact safety systems needed to mitigate the initiating event.

1.3 Project Background

The project started with research, including a review of several PRAs. Then, a survey questionnaire was distributed to all EPRI members to investigate the current methods and techniques used by utility PRA staff in analyzing support system initiating events. Insights from the PRA reviews and the survey responses were used to develop a draft report. The draft report received widespread review, and review comments were received from utilities, consultants, and vendors. The responses to these comments were presented, discussed, and dispositioned at a technical meeting; then summarized in an interim technical report in 2006. The methods and considerations presented in the interim report were then examined through test application at pilot plants by the PWR Owner's Groups [13]. Next the EPRI project merged with an NRC effort to standardize the approach to support system initiating event modeling in SPAR models. The results of the pilot studies and the Idaho National laboratory SPAR model updates were used to refine the methods presented in this report. Thus, this report presents an industry consensus view of the current state-of-the-art in support system initiating event modeling.

1.4 Report Organization

This report provides the following PRA modeling guidance related to support system initiating events (with the associated report section shown in parentheses).

- The approach and methodology used in modeling of support system initiating events is provided in Section 2, specifically:
    - A *definition* for the term "support system initiating event" is presented, including a discussion of the subtleties in the definition.
    - *ASME PRA Standard* high-level requirements associated with initiating events, and those supporting requirements related to support system initiating events help define the process and tasks used in support system initiating event modeling.
    - *Concepts* and *issues* involved with modeling initiating events using fault tree modeling techniques are discussed, including a summary of current developments.
    - *Examples* of support system initiating events in current PRAs are listed.
- A description of the tasks associated with the development of support system initiating event models are described in Section 3, including:
    - *Identification* of support system initiating events (Section 3.1).
    - *Grouping (also called categorization)* of support system initiating events (Section 3.2).
    - *Quantification* of support system initiating events (Section 3.3).
    - *Model incorporation* of support system initiating events (Section 3.4).
    - *Uncertainty and Importance* of support system initiating events (Section 3.5).
- *Modeling considerations* specific to different types of systems, such as differences between electrical and mechanical systems, and water quality issues related to service water systems are provided in Section 4.

- *Conclusions* of this report, consisting of a summary of the current state-of-the-art in support system modeling, along with topics where future research is being considered, are summarized in Section 5.
- *References* used in this report are in Section 6.
- Acronyms and abbreviations are provided in Appendix A.
- Survey/Questionnaire used to collect data for this report is in Appendix B.
- Fault trees and resulting equations for examples using different modeling methods are documented in Appendices C, D, and E.

2
APPROACH / METHODOLOGY

This section describes the approach and methodology used in the modeling of support system initiating events, as follows.

- A *definition* for the term "support system initiating event" is presented, including a discussion of the subtleties in the definition.
- *ASME PRA Standard* high-level requirements associated with initiating events, and those supporting requirements related to support system initiating events help define the process and tasks used in support system initiating event modeling.
- *Concepts* and *issues* involved with modeling initiating events using fault tree modeling techniques are discussed, including a summary of current developments.
- *Examples* of support system initiating events in current PRAs are listed.

2.1 Definition of Support System Initiating Event

In the ASME PRA Standard [3], an initiating event (IE) is defined as follows:

> "Any event either internal or external to the plant that perturbs the steady state operation of the plant, if operating, thereby initiating an abnormal event such as a transient or LOCA within the plant. Initiating events trigger sequences of events that challenge plant control and safety systems whose failure could potentially lead to core damage or large early release."

A support system initiating event is a *subcategory* of initiating events consisting of initiators where the failure not only causes a loss/challenge to a safety function, but also adversely affects one or more systems needed to respond to the reactor shutdown. In this report, "support systems" are defined as those trains and/or components needed to start, operate, or control a front-line system, where the front-line system is fulfilling a critical safety function. Applying this definition to support system initiating events would result in the following (lengthy) definition of a support system initiating event: any event (such as a component, train, or complete system failure) typically internal to the plant (but can be external such as offsite power or the ultimate heat sink) perturbing the steady state operation of an operating plant, thereby initiating an abnormal event or plant condition such as a transient or LOCA within the plant. Support system initiating events not only trigger sequences of events that challenge plant control and safety systems whose failure could potentially lead to core damage or large early release, they also fail all or part of those systems used for mitigation.

This report reduces the lengthy text definition provided above and considers a “Support System Initiating Event” (often labeled SSIE) to have the following attributes.

> A **Support System Initiating Event is defined** as:
> “Any event such as a component, train, or complete system failure (or causing the failure of a component, train, or system) that:
>
> a. challenges a reactor safety function, then
>
> b. leads to a reactor trip, and also
>
> c. fails a train or complete front-line system normally available to respond to the reactor trip or reactor shutdown and successfully mitigate the loss of critical safety function.”

Failure of an operating front-line system usually causes a reactor trip in a short time period, e.g., within minutes. The initial (early) failure of a train or component in a support system, however, may not result in a reactor trip in a short time period, and instead may be delayed up to several hours. In these cases, initial failure of a train or component in a support system that ultimately leads to reactor trip through a subsequent loss of the complete support system or through loss of front-line systems is considered to be a support system initiating event per ASME PRA Standard supporting requirements IE-A5 and IE-A9. Initial failures of trains or components that lead to a reactor administrative shutdown due to Technical Specification violation may be considered as low power and shutdown events where transition risk may be important, but are excluded from consideration as an initiating event as described below in Section 2.3.1.

Loss of an operating component, train, or system whose impact is limited to a single front-line system is not considered to be categorized as a support system initiator since it can be grouped with the front-line system initiator. An example would be loss of electro-hydraulic control system or turbine control system which is part of the turbine trip initiating event. Another example is a loss of condensate system since this is typically grouped with a loss of feedwater.

Failures of a component, train, or system leading to reactor trip, but which do not affect any of the systems normally available for safe shutdown (as defined by the PRA), are not considered a support system initiating event, and should be grouped in the reactor trip initiator category. For example, a loss of reactor letdown in a pressurized water reactor (PWR) or loss of reactor water cleanup system in a boiling water reactor (BWR) would be grouped with reactor trip since they do not impact safety systems needed to mitigate the initiating event.

A support system initiating event can be caused by a single failure, or a series of failures. When the support system initiating event is a single failure, then the loss of a single component of single train directly causes reactor trip. More common, however, is the case where multiple failures are required to cause the failure of a support system (a system with redundancy). In this case, e.g., the operating train and the standby train(s) must fail in order to result in reactor trip or reactor shutdown. The definition of support system initiating event is further complicated by the time interval between system loss and reactor shutdown. Loss of a support system function may cause immediate reactor trip or may lead to a delayed reactor trip See Section 2.3 below for additional details regarding the modeling of multiple failures (e.g. the running train and the standby trains).

2.2 Process and Tasks

2.2.1 PRA Standard Requirements Associated with Support System Initiating Events

A series of standards addressing PRA quality have been developed by industry groups, and are continuing to be developed. These standards establish the technical adequacy for each technical element of a PRA used for risk-informed applications. The internal events PRA standard for full power operations was published by the American Society of Mechanical Engineers (ASME) in April 2002 [1], then updated in 2003 [2], in 2005 [3], and in 2007 [4]. The USNRC endorsed and implemented the ASME PRA Standard as part of risk-informed regulation using Appendix A of Regulatory Guide 1.200 [5].

The high level requirements for the initiating events (IE) portion of the ASME PRA Standard [4] are reproduced below in Table 2-1. The applicability of these high-level requirements and their consideration in this report are summarized in this table. There are several supporting requirements in "IE" PRA element for initiating events that explicitly mention support system initiating events. These are reprinted below and integrated into the subsequent discussion. There are several other requirements in PRA elements initiating events (IE), accident sequence (AS), data (DA), and systems modeling (SY) that must also be followed in the evaluation of fault trees and accident sequences incorporating support system initiating events; although the term "support system initiating event" may not be explicitly referenced in the requirement.

Table 2-1
ASME PRA Standard High Level Requirements Applicable to Initiating Events

Designator	Requirement	Consideration in this Report
HLR-IE-A (Identification)	The initiating event analysis shall provide a reasonably complete identification of initiating events.	Supporting requirements IE-A4, IE-A5, IE-A7, IE-A8 and IE-A9 apply specifically to support system initiating events and are considered in this report.
HLR-IE-B (Grouping)	The initiating event analysis shall group the initiating events so that events in the same group have similar mitigation requirements (i.e., the requirements for most events in the group are less restrictive than the limiting mitigation requirements for the group) to facilitate an efficient but realistic estimation of core damage frequency (CDF).	None of the supporting requirements is applied uniquely to support system initiating events. Typically, due to their nature, support system initiating events are unique and not amenable to grouping. The support system failures which are grouped with others are typically those which lead to plant trip or shutdown but do not degrade any post-initiator mitigation systems; these are not considered to be support system initiating events.

Table 2-1
ASME PRA Standard High Level Requirements Applicable to Initiating Events

Designator	Requirement	Consideration in this Report
HLR-IE-C (Quantification)	The initiating event analysis shall estimate the annual frequency of each initiating event or initiating event group.	Supporting requirements IE-C6, IE-C7, IE-C8, IE-C9, IE-C10, and IE-C11 apply specifically to support system initiating events and are considered in this report.
HLR-IE-D (Documentation)	The initiating event analysis shall be documented consistent with the applicable supporting requirements.	None of the supporting requirements is applied uniquely to support system initiating events.

The ASME PRA Standard initiating event PRA element defines the process, and the associated high level requirements define the tasks for modeling support system initiating events.

The following supporting requirements for the initiating events (IE) portion of the ASME PRA Standard [4] are reproduced below and apply directly to the identification of support system initiating events. The requirements below cover Capability Categories I, II, and III. Category II is the level generally needed for risk-informed licensing applications. In some cases the requirements are the same for all capability categories. In those cases, no category is listed or "all capability categories" is listed.

IE-A4 "PERFORM a systematic evaluation of each system, including support systems, to assess the possibility of an initiating event occurring due to a failure of the system." (All Capability Categories) Additionally:

> "**PERFORM a qualitative review of system impacts to identify potential initiating events**."
> (Capability Category I)
>
> **"USE a structured approach (such as a system-by-system review of initiating event potential, or an FMEA [failure modes and effects analysis] or other systematic process) to assess and document the possibility of an initiating event resulting from individual systems or train failures**." (Capability Category II).
>
> **"DEVELOP a detailed analysis of system interfaces. PERFORM an FMEA (failure modes and effects analysis) to assess and document the possibility of an initiating event resulting from individual systems or train failures**.
> (Capability Category III)

(Note that fault tree analysis, by its nature, accounts for multiple failures. If Capability Category II is all that is required it is not necessary to model the random failures as individual events, and instead a simplified fault tree with only common cause failures will meet the criterion. However to fully integrate the model and account for all the dependencies between the initiating event and the post-initiator system response the initiating event fault tree model should be developed at the same level of detail as the system fault trees. In general these models will then meet the Capability Category III requirements for IE-A4.)

IE-A4a: "When performing the systematic evaluation required in IE-A4:

"INCLUDE initiating events resulting from multiple failures, if the equipment failures result from a common cause."
(Capability Category I)

"INCLUDE initiating events resulting from multiple failures, if the equipment failures result from a common cause, **and from routine system alignments**."
(Capability Category II).

"INCLUDE initiating events resulting from multiple failures, **including equipment failures resulting from random and common causes, and from routine system alignments.**"
(Capability Category III)

IE-A5 (All Capability Categories) "In the identification of the initiating events, INCORPORATE

(a) events that have occurred at conditions other than at-power operation (i.e., during low-power or shutdown conditions), and for which it has been determined that the event could also occur during at-power operation.

(b) events resulting in a controlled shutdown that include a scram prior to reaching low-power conditions, unless it is determined that an event is not applicable to at-power operation."

IE-A7 "No requirement for precursor review." (Capability Category I)

"REVIEW plant-specific operating experience for initiating event precursors, for the purposes of identifying additional initiating events. **For example, plant-specific experience with intake structure clogging might indicate that loss of intake structures should be identified as a potential initiating event**." (Capability Category II)

"REVIEW plant-specific **and industry** operating experience for initiating event precursors, for the purposes of identifying additional initiating events." (Capability Category III)

IE-A8 DELETED

IE-A9 DELETED

IE-A10 <u>"For multi-unit sites with shared systems, INCLUDE multi-unit site initiators (e.g., multi-unit LOOP events or total loss of service water) that may impact the model."</u>

The following supporting requirements apply directly to the **quantification** of support system initiating events, and are reproduced from the ASME PRA Standard [4].

IE-C6 "Some initiating events are amenable to fault-tree modeling as the appropriate way to quantify them. These initiating events, usually support system failure events, are highly dependent upon plant-specific design features. If fault-tree modeling is used for initiating events, USE the applicable systems-analysis requirements for fault-tree modeling found in the Systems Analysis section (para. 4.5.4)."

IE-C7 "If fault tree modeling is used for initiating events, QUANTIFY the initiating event frequency (as opposed to the probability of an initiating event over a specific time frame, which is the usual fault tree quantification model described in the Systems Analysis section, para. 4.5.4.). MODIFY, as necessary, the fault tree computational methods that are used so that the top event quantification produces a failure frequency rather than a top event probability as normally computed. USE the applicable requirements in the Data Analysis section, para. 4.5.6, for the data used in the fault-tree quantification."

IE-C8 "If fault-tree modeling is used, CAPTURE within the initiating event fault tree models all relevant combinations of events involving the annual frequency of one component failure combined with the unavailability (or failure during the repair time of the first component) of other components."

IE-C9 "If fault-tree modeling is used for initiating events, USE plant-specific information in the assessment and quantification of recovery actions where available; consistent with the applicable requirements in the Human Reliability Analysis (para. 4.5.5)."

IE-C10 "COMPARE results and EXPLAIN differences in the initiating event analysis with generic data sources to provide a reasonableness check of the results."

IE-C11 "For rare initiating events, USE industry generic data and **INCLUDE plant-specific functions**. For extremely rare initiating events, engineering judgment may be used; if used, AUGMENT with applicable generic data sources. Refer to para. 4.3, Use of Expert Judgment, as appropriate. For purposes of this Requirement, a "rare event" might be expected to occur one or a few times throughout the world nuclear industry over many years. An "extremely rare event" would not be expected to occur even once throughout the industry over many years." (Capability Category I/II)

"For rare initiating events, USE industry generic data and **AUGMENT with a plant specific fault tree or other similar evaluation that accounts for plant-specific features**. For extremely rare initiating events, engineering judgment may be used; if used, AUGMENT with applicable generic data sources. Refer to para. 4.3, Use of Expert Judgment, as appropriate. For purposes of this Requirement, a "rare event" might be expected to occur only a few times throughout the world nuclear industry over many years. An “extremely rare event” would not be expected to occur even once throughout the industry over many years. **INCLUDE in the quantification the plant specific-features that could influence initiating events and recovery probabilities. Examples of plant-specific features that sometimes merit inclusion are the following:**

> **(a) plant geography, climate, and meteorology for LOOP and LOOP recovery**
>
> **(b) service water intake characteristics and plant experience**
>
> **(c) LOCA frequency calculation. “**

(Capability Category III)

2.2.2 Support System Initiating Event Modeling Tasks

The ASME PRA Standard initiating event (IE) PRA element defines the support system initiating event modeling process and the associated high level requirements define the tasks, but this is only up to the point of model incorporation. For example, one could complete all the tasks in the IE PRA element and the resulting product could be a fault tree whose solution is used to supply the data for an initiating event that is modeled as a single basic event in the PRA. The model incorporation task invokes requirements from the quantification (QU) PRA element of the ASME PRA Standard, including a treatment of dependency and uncertainty. Thus, the entire process of modeling support system initiating events within a PRA consists of the following tasks.

- *Identification* of support system initiating events.
- *Grouping (also called categorization)* of support system initiating events.
- *Quantification* of support system initiating events.
- *Model incorporation* of support system initiating events, including a treatment of dependencies.
- *Uncertainty and* Importance analysis of support system initiating events.

2.3 Concepts and Issues

This section describes the major concepts and issues applicable to using fault tree modeling techniques for the development of initiating event frequencies for losses of a support system. Since the publication of the initial EPRI Support System Initiating Event Report [14], several issues have received a broader review within the PRA community, including NRC-sponsored research by Idaho National Laboratory, resulting in refinement of the guidance in the areas listed below.

- Considerations for Initiating Event Precursors – This topic relates to issue #1 in the initial EPRI Support System Initiating Event Report [14], providing an approach for models to satisfy the current ASME PRA Standard quality requirements for initiating event precursors. (Section 2.3.1)

- Modeling Methods – This topic relates to issue #2 in the initial EPRI Support System Initiating Event Report [14], first addressing the different types of fault tree modeling techniques for support system initiators, and also presenting the recommended treatment of the different mission times involved with modeling the running and standby train(s). (Section 2.3.2)

- Treatment of Common Cause Failures in support system initiating event models – This topic relates to issue #3 in the initial EPRI Support System Initiating Event Report [14], focusing on the development of common cause failure data specific to the systems being modeled from the INL common cause database and also providing common cause alpha factor data for systems that have zero failures. (Section 2.3.3)

- Dependencies – This topic relates to the extent and the level of detail that support systems are included within a support system initiating event model (2.3.4).

- Importance Measures - The final issue addressed in this report is importance measures. Because initiating events are measured in units of frequency they consequently do not have the value of "one" as an upper bound, so importance measures such as Risk-Achievement are essentially meaningless (2.3.5).

The following general modeling issues in this section need to be addressed when constructing, updating, and/or maintaining models of support systems as initiating events. Following each issue there is a short discussion of the issue and a recommended treatment. Note that there is often more than one way to address modeling issues, and that other approaches than the ones outlined below may be equally valid.

2.3.1 Considerations for Initiating Event Pre-Cursors

Two fundamental schools of thought regarding initiating event precursors have emerged during the course of this research. The first is that an initiating event must lead to a plant trip. If it does not lead to a plant trip, then it does not meet the threshold for consideration as an initiating event. This is explicitly stated in ASME PRA Standard supporting requirement IE-A9 ("INCLUDE support system failures as initiating events quantitatively in the PRA in a realistic fashion. TREAT EXPLICITLY the individual support systems (or trains) that **can cause a plant trip**.")

The second view is that some events, such as loss of busses that do not result in a loss of offsite power, should be considered as a support system initiating event due to similarity of plant response. There are two relevant ASME PRA Standard supporting requirements related to the scope of initiating events to include in the model. Supporting requirement IE-A5 requires the incorporation of "events resulting in an unplanned controlled shutdown that includes a scram prior to reaching low power conditions…." Additionally, SR IE-A7 requires an accounting of initiating event pre-cursors. Supporting requirement IE-B3 then requires that grouping of initiating events can only occur when "events can be considered similar in terms of plant response, success criteria, timing, and the effect on the operability and performance of operators and relevant mitigating systems; or events can be subsumed into a group and bounded by the worst case impacts within the "new" group. Based on these supporting requirements, loss of some lower voltage safeguards ac and/or dc buses have often been included in the development of many PRAs since although they may not lead to an immediate plant trip, they often would be subject to short time frame (e.g. < 8 hour) technical specification action statements requiring shutdown of the plant while at the same time much of the mitigating equipment is rendered unavailable. Although IE-A5 could be interpreted to exclude these events if the general shutdown procedure at the site does not require a scram prior to reaching low power conditions, the requirements in IE-B3 would indicate that they should be included since they represent a unique mitigation challenge to the plant following the execution of the shutdown procedure. If these types of initiating events are included in the model, then the success criteria should be characterized consistent with other manual scram type of events so as to not be overly conservative in the subsequent accident sequence development.

Recommendation: While modeling of pre-cursor events as support system initiating events has been commonly practiced, the explicit statement in the ASME PRA Standard establishes that the appropriate and best practice is to model only those losses of support system that lead to reactor trip (with a loss of support systems or trains of systems used for safe shutdown) as support system initiating events.

When identifying support system initiating events, there are three general types of scenarios to be considered, as follows:

- Case 1 - Immediate (or Direct) Initiating Event. Support system initiating events causing an immediate reactor trip, such as is the case in some plants following the loss of a DC bus or an AC bus. For this type of scenario, recovery of the failed support system before reactor trip is not applicable and thus is not credited since the effect (reactor trip) is immediate. If the support system failure event was recoverable and not included as one of the systems mitigating the reactor trip, then it would be an initiator but not a support system initiator since it could be grouped with another initiating event such as reactor trip or turbine trip. An example is the SPAR treatment of loss of an electrical power bus initiating event. If the initiating event frequency is based on sustained losses of power from an AC electrical power bus and the associated event tree does not credit power from the AC electrical power bus then this is an example of a Case 1 SSIE. However, for the same electrical power bus, events that involved only momentary losses of power were placed in the general transient category and not treated as SSIEs.
- Case 2 - Delayed (Indirect) Initiating Event (Unrecovered). Support system initiating events involving loss of a support function that will ultimately cause reactor trip if not restored in some allowable period of time. The reactor continues to operate until a later reactor trip or administrative shutdown, typically for equipment protection. Examples of this type of support system initiating event include loss of switchgear room heating, ventilating, and air conditioning (HVAC) or a partial loss of service water. For this category of support system initiating event, the analytical basis should be available (or developed) defining the time available for restoration or mitigation of the failed function before the onset of adverse conditions. The event tree/fault tree modeling of this

category is the same as the first category, except there is a time period available for potential recovery of the failed support function (before reactor trip or shutdown), thereby reducing the initiating event frequency. Complete recovery of the function obviates the need for the support system initiating event since the conditions necessary to result in plant trip or force an administrative shutdown are alleviated. Partial recovery of the function leads to the third category.

- Case 3 - Delayed (Indirect) Initiating Event (Partially Functional). This case consists of support system initiating events involving a partial loss of a support system in a system with redundancy. Following the loss of an operating component, train or system, the standby train starts and maintains the required functions for reactor operation. If repair of the failed train is not possible within the allowed outage time (AOT), administrative shutdown will occur with a degraded, but operable support system. This type of support system initiating event may be treated as a unique initiator (if it leads to reactor trip) or more likely would be excluded from consideration during full power because it leads to administrative shutdown. An example of such a scenario would be pipe break in a component cooling water (CCW) header. While this scenario may cause a total loss of CCW for some plants, other plants with segregated headers would experience degradation in the overall system capability and redundancy. Repair of the break may not be possible within the AOT for the CCW train, resulting in administrative shutdown. CCW is being provided, although there is no backup train for CCW.

2.3.2 Modeling Methods for Running and Standby Trains

One of the principal tasks of developing support system initiating event models is to address modeling of the running and the standby trains. First, the running train must be developed to model faults occurring during the mission time of a year. In addition to being a mission time adjustment compared to the fault tree modeled used in the post-initiator plant response, this development also needs to consider the addition of events and failure modes that may have been ruled out as negligible for a 24-hour mission time. An example of this may be heat exchanger plugging. Next, the standby train(s) must also fail at the same time the running train is failed. Ultimately, modeling of multi-train support systems as initiating events leads to different mission times and major adjustments/developments to events such as the common cause failure events. Thus this topic consists of selection of modeling methods and also mission time issues.

<u>Modeling Methods</u>. The three modeling methods in use in the industry for support system initiating events are 1) the explicit event method, 2) the point estimate fault tree method, and 3) the multiplier method. These methods are described below in Section 3.3.

Recommendation: The current consensus method is to use either the explicit event method or a point estimate fault tree. The advantages of the explicit event method and the point estimate fault tree are that these methods include multiple mission times for the same component to address the initiating event fault tree and the post-initiator mission support tree. Typically, the multiplier method uses a stand-alone basic event of 365 days as a multiplier on the result of the mitigating event system fault tree. It has been shown that this practice can violate the rare event approximation, causing erroneous results. This report recommends the explicit event method because one can easily see the basic event contributions to the initiating event total frequency. Visibility improves the traceability and defensibility of the model, as one can easily see whether the applied recovery and mitigation terms are appropriate. It should be noted, however, that both the explicit event and point-estimate fault tree methods provide the ability to define unique basic events with a year long mission time that are used only in the initiating event fault tree, and each provides better results than the multiplier method.

Inclusion of Multiple Mission Times Within the Same Logic Model. The selection of modeling methods is typically influenced by the issue of dealing with multiple mission times within the same logic model. In general, it will not be possible to use one single support system fault tree for both initiating event and for post-trip mission support. For support system initiating events purposes, an initiating event fault tree will have to be designed with a different time basis in mind.

For the running portions of a support system, the first train fails some time during the reactor calendar year. Redundant train(s) also fail, but for these standby systems the mission time is shorter and can vary. Typically an interruption of the support function long enough to cause a plant trip is the basis for the initiating event fault tree. For example, interruption long enough to result in a possible RCP seal LOCA may define an early time frame requirement, while it may also be necessary to have a separate model for support of the post-initiating event decay heat removal function in the late time frame. For the late (post-initiating event) time frame it is likely that spare pump train realignments can be credited that should not be credited in either the initiating event or early time frame. For those systems where loss of one train leads to a technical specification allowed outage time limitation (a limiting condition for operation), the time available for recovery is typically longer (and may require additional deterministic data, such as a room heat-up calculation).

Recommendation: The issue with using different events to represent failure of a component in separate time periods (or overlapping time periods) results in difficulty of determining the true component importance from the separate time period events from an aggregated set of results. This report identifies that the process used to aggregate the basic event importance measures is an area for potential future research. Once accomplished, then model developers would be free to use as many events as they need to represent a component's frequency contribution, and support function in the various sequence time phases. Aggregation of the resulting component failure mode importance measures in a consistent way helps to resolve this issue. Use of the multiplier method does not solve this problem. Also, detailed time phasing of the models is generally considered beyond the state of the art, although many PRAs are now doing it to some degree (for example, BWR HPCI/RCIC/CRD early mission and late mission).

Methodologies Used to Model Different Mission Periods for the Same Component. Typically operating support system components have a nominal one-year mission when considered as part of an initiating event fault tree, and a 24-hour mission when considered as part of the post-trip support model. Furthermore, the result of interest is the rate at which the system fails (which theoretically could be a value greater than 1.0), not the probability of failure during a mission (which must be between 0.0 and 1) as described in Section 3.3.3. Multipliers (e.g., 365X under an AND gate) used in conjunction with existing nominal 24-hour fail-to-run events can be used to make a conversion, but a better approach is to create unique events that represent failure frequencies with units of per year.

Multiplier methods have more disadvantages than advantages. The primary advantage of using a multiplier approach is that success criteria differences associated with different time frames can be easily modeled. Another advantage is that the same basic failure events appear in both the initiating event Boolean equation as well as the post-initiator response equations, so that parametric data uncertainties and importance measures are correlated. This is a conservatism in that the failure to run for a year would most likely have additional failure modes when compared to those for a 24-hour mission time (but the model treats these as the same). A very minor advantage is that the multiplier method also reduces the overall number of basic events. A very large disadvantage of the multiplier method is the impact on importance measure calculations and the generation of potentially undefined or erroneous importance measures (specifically, Birnbaum and Risk Achievement Worth).

Recommendation: The current consensus method is to use either the explicit event method or a point estimate fault tree. Components in current PRAs are already represented by several events corresponding to different failure modes that may occur in separate time periods, conditional on specific operational modes, or initiators. Use of the multiplier method does not remove the need to aggregate component importance measures. What the multiplier method does do is reduce the under-estimation of some of the importance measures for a given component. However, users of the multiplier method must clearly define the limits of its accuracy. It is possible to show the multiplier method fails completely for failure rates on the edge of the range of values that might be encountered in support system initiating event development.

For example, it appears that a typical multiplier method cutset value must be less than 0.01, when any basic event in it is set to 1.0, in order for the multiplier method to be a reasonable approximation. At least that appears to be the case when the mincut approximation is used to combine cutset probabilities and to determine component importance. The range of values over which the method is valid is dependent on the quantification method used. Most industry PRA codes rely heavily on the mincut approximation for combining cutset probabilities and for calculating component importance measures. The range of values over which the multiplier method is valid is less when the mincut is used than when the rare event approximation is used.

Component Specific Mission Times. There are two groups, the normally running components and the standby components. Normally running components need to be represented with events that have frequency units of “per year”. One approximation approach (the multiplier method) uses a 365x multiplier event that is input to an AND gate with the existing 24-hour-based fail-to-run failure events. This approach facilitates using the same basic event in both the initiating event fault tree and the support system fault tree, which represents complete dependence between the initiating event and post-initiator failure modes. Another approach is to define unique basic events with a year long mission period that are used only in the initiating event fault tree, and this is accomplished in the explicit event method or the point-estimate method.

Recommendation: Use the explicit event or point-estimate methods as described in Section 3.3.

Mean Time To Repair (MTTR). Standby components should be assigned a mission time based on the mean-time-to-repair (MTTR) of the running component that failed or the limiting condition of operation (LCO) for that component. WASH-1400 [17] identifies mean time to repair values in the range of 20 hours for many components in the plant (diesel generators - 21 hrs, pumps - 19 hrs, valves 19 - hrs, etc). These mean time to repair values are supported by other studies (e.g., NSAC-161, Faulted Systems Recovery Experience [18]). To facilitate use of the existing failure events, a composite mean time to repair of 24-hours can be assumed for all failed components.

Recommendation: Use of a 24-hour mean time to repair in the IE fault trees simplifies the modeling while yielding results that are not excessively conservative. Also, use of a 24-hour MTTR mission period allows use of the same value in every model. Use of the Limiting Condition for Operation periods is also a viable option that typically yields somewhat more conservative results. These times vary from plant-to-plant and from component-to-component.

The 2006 version of this report relied more heavily on the multiplier method, and the multiplier approach makes this issue more important than it would be otherwise. The complexity involved in making sure that appropriate multipliers are applied to every cutset becomes very difficult if any option is chosen besides use of a 24-hour MTTR for all standby components. In most PRA models, post-initiator support events almost always use a 24-hour mission. Every component that is to credit a MTTR different from 24-hours needs a different multiplier (different from the unit conversion multiplier, and different among events with differing MTTRs).

It needs to be clear that any multiplier used to adjust the mission time of the probability-based component in a cutset is related to the MTTR of the frequency based component in the cutset (the initial failure). The confusion potential rises when two failure to run (FTR) elements of a cutset are based on different components with different MTTR values. Then extraction of the frequency approximation is not symmetric with respect to which component is assumed to fail first (assuming both normally running). This EPRI report demonstrates, using examples, (Appendices C, D, and E) how to accommodate different MTTR values. The examples provided in the appendices were set up to be simple enough to be scrutable, but complex enough to illustrate all the nuances required when there are multiple fail-to-run events in a cutset, and when each fail-to-run event is associated with a different MTTR. This situation will be expected in most PRA applications (e.g., failure of a service water pump and service water strainer), and it is likely that when models with SSIE fault trees are used for event evaluation, there will likely be requests to refine the MTTR values used, thereby moving away from the 24-hour standard MTTR.

<u>Modeling of Component Failures Contributing to Initiators as Well as Mitigative Functions, Due to Common Cause Impacts.</u> Failures that lead to an initiator (e.g., AC bus failure) can also have potential impact in mitigative systems through common cause modeling. For example, failure of a specific AC bus can lead to a plant trip. This bus may be included in common cause groups along with other AC buses in mitigative logic. The general question is, should the failure of other buses in the common cause group be conditional on the original failure that resulted in the plant trip? If so, the issue is how should this conditionality be modeled given the constraints of most of the PRA quantification codes?

Recommendation: There appears to be no industry consensus on the proper approach. Therefore this report recommends this area as a potential research topic, considering the guidelines provided in Appendix E of NUREG/CR-5485 (Section E.3.1) for conditional common cause given the observation of a total failure event (implies potential for common cause). Note - recent industry comments on this approach feel the default is overly conservative in modeled potential for common cause, and in response developed the considerations listed in Table 3-1.

2.3.3 Treatment of Common Cause Failures

Common cause failures (CCF) of operating (running) equipment must be included as appropriate in fault trees for support system initiating events. In the context of a support system initiating event application, a common cause failure is only of concern if the failures of the redundant equipment occur before the first failed component has completed repairs. For convenience, this time should be considered to be at least 24-hours.

Data Sources. The most common sources for common cause factor data are the Idaho National Engineering Laboratory (INEL, later named the Idaho National Engineering and Environmental Laboratory or INEEL, and still later named the Idaho National Laboratory or INL) documents [9, 10]. Reference 9 was the original common cause failure document published by INL, and reference 10 is an update through year 2000 for diesel generators, pumps, motor-operated valves (MOV), and circuit breakers. These data reports were developed from Licensee Event Reports (LERs) and INPO's Nuclear Plant Reliability Database System (NPRDS) reports, primarily based on data from equipment in standby systems. Industry experience has shown that this has the potential to introduce conservatisms and thus, the results do not always comport with actual plant experience. In analyzing the plant failure incidents, these reports considered an event a common cause failure if two failures occurred within the testing interval of the components due to the same cause. The redundant components in the system were considered susceptible to the same common cause until they were successfully tested (either at their regular test interval or a special test to determine operability). It was not necessary for two or more components to be failed at the same time for an event to be classified as a common cause event. The operating experience of Reference 10 is broader and it correlates CCF in terms of causes, partial or complete failures and CCF location. Reference 10 indicates the failures occurred over a short period of time, but does not provide a specific time frame. In the particular application for support system initiating event quantification, common cause is only a concern if the failure of the redundant train occurs prior to repair of the first component. Should a second component fail after the first is restored, the incident may technically be a common cause failure, but it does not have impact on the support system initiating event frequency calculation.

Filtering Common Cause Data. In response to the CCF data conservatisms, analysts have sometimes implemented an ad hoc screening of events from the database (using the "remove event" command) that do not appear applicable at the plant for which the calculations are being performed. This is an error-prone approach to resolving the problem. First, the details of the original events may be too poorly reported to judge accurately whether a past event at another plant is applicable now and in the future at a different plant. Also, when screening events that do not appear applicable to a given plant, it is necessary to address both the independent and common cause events in the database at the same time. This is necessary so that the screening process affects both the numerator and denominator in the alpha factor calculation concurrently. Thus, analysts that have used the screening technique to 'improve' or 'fit' CCF events to match the target plant's experience and operating philosophy are guaranteed to overly reduce the resulting CCF alpha factors since only the numerator is affected (i.e., reduced) by screening and not the denominator.

The research effort in this report focused on two features of the INL CCF database that can improve the data without the disadvantages of the screening approach. First, the ability to filter the data base on date range may be used. Note that this is not the same thing as screening. Analysts should filter the data to use only the data collected after the period of full implementation of the maintenance rule, starting in 1995, when determining alpha factors and failure rates. The second (a recent change as part of this research effort) involves the development of common cause alpha factor data based on systems where there were no recorded CCF events but there were independent failures. This is discussed in the following section.

<u>Zero Events CCF Data</u>. The INL CCF database provides the capability to calculate CCF parameters for systems for which there are no recorded historical events. Prior to September 2008, this was treated as an error condition in the database. For these systems the CCF database now uses the independent failure event counts and related operational history to perform a Bayesian update of the CCF database prior, and will produce alpha factor results that are system-specific. The system-specific results output by the CCF database program are strongly influenced by the database prior in cases where the operational history recorded for the system of interest is short compared to the total operational history contained in the database. As of this writing, additional steps are under consideration for future research, such as the elimination of records that represent degraded components (as opposed to failed components) and unavailability events.

<u>Service Water System Water Quality</u>. In addition to the above, cooling water systems have unique CCF considerations. While there is a consensus regarding the common cause modeling of the majority of cooling water system components, intake structures are an exception and may be best modeled as a separate event. This is an open issue that will require further study to resolve.

2.3.4 Dependencies

Dependencies are a concern for any of the modeling methods chosen. Support system dependencies should capture sufficient detail and scope of systems that an accurate initiating event frequency can be calculated. However, if the dependency modeling is taken too far, it could overstate the impact of systems already modeled. The recommended method to address dependencies is to quantify the post-initiator mission fault tree, and review the importance measures of support systems to determine which dependencies to include in the SSIE tree. Section 3 of this report describes that the candidate support system initiating events can be reviewed against the list of initiating events developed in the PRA. In some cases, the candidate support system initiating events are within the boundary of an initiating event that is already modeled. In these cases, the boundary conditions of the initiating event are noted as the basis for removing the candidate support system initiating event from further consideration. This approach requires analyst judgment and numerical tests can be employed to support determination of the inputs to include.

The real issue in the review of the cutsets is to capture failure events that could also impact other systems. It is difficult to define numerical criteria that could accurately account for the fact that some second order failures for the SSIE could also have a first or second order effect on other systems. The only way to capture all dependencies would be to expand all of the dependencies in the initiating event fault tree until all interfaces with support systems are included or are otherwise distinctly modeled in another initiating event that is separately represented in the model. That would be equivalent to the "Detailed Explicit Event Method" from Table 3-2. On the other hand, the cutset review could be utilized to determine what makes sense for including in a "Limited Explicit Event Method" from Table 3-2. So rather than numerical criteria, the focus of the review should be on determining what dependencies need to be included in the "Limited Explicit Event Method" approach – not because they are important for this SSIE, but because the review determined that they could also impact other systems.

2.3.5 Importance Measures

This report does not recommend calculating importance measures for support system initiating events based on current methods available. Several challenges exist to understand and properly address importance measures for SSIEs. Among these are:

- Consistency of computation. Importance measures for mitigating events are calculated as ratios using the computed risk with an event value set to either 1 or 0 and the baseline risk of the PRA model with the same event set to its nominal value. In the case of SSIEs, the calculation is different because the mission time has either an 8760 hour or 365 day component to it. Thus, an arguably non-rare event has been introduced into the importance calculation. In addition, since initiating events are frequencies, they do not have a value of 1 as an upper bound, as in the case of mitigating events. Only the Risk-Reduction measure may be considered, as zeroing out the initiating event (or portions thereof) eliminates mission time issues; however there are other issues associated with Risk-Reduction as noted below in consistency of treatment with other plant systems.
- Consistency of treatment of plant systems. There are many plant components and systems that are not SSIEs whose failure can cause a reactor trip. However, these systems are only considered for event mitigation. For example, if the Main Steam Isolation Valves (MSIVs) in a BWR fail closed, a reactor trip will result. Since MSIV closure is not an SSIE, annualized importance measures are not calculated. This calls into question the need to calculate importance measures for SSIEs or how such calculations could be done consistently throughout the PRA model.

Recommendation: This is an area for potential future research. A consensus needs to be established concerning the definition of SSIE importance measures to ensure meaningful results.

2.4 List of Typical LWR Support System Initiating Events

A list of typical support system initiating events for light-water reactors constructed before the year 2000 is shown in Table 2-2. The "specific examples" on this list may have a different voltage or the specific system name may vary from plant to plant. Additionally, this list may have one or two additions based on plant-specific factors or features, but it generally provides a representative set of common support system initiating events, as categorized by NUREG/CR-5750 [8]. Table 2-2 is not an all-inclusive list of those SSIEs that need to be included in each plant's PRA model. Rather, this list represents the full set of SSIEs that have been found to be included across all plants – and each plant/site will have a subset of these events based on the plant-specific and site-specific SSIE identification process, and determination of which ones are applicable (as described in Section 3.1).

Table 2-2
Typical List of LWR Support System Initiating Events

General Category	Specific Examples
Loss of Electrical Bus	Loss of 4160V AC Bus
	Loss of 480V AC Bus
	Loss of 125V DC Bus
	Loss of 120V AC Bus
	Loss of Instrumentation Power
Loss of Heating, Ventilation, or Air Conditioning (HVAC)	Loss of Switchgear HVAC
	Loss of Control Room HVAC
Loss of Cooling Water System	Loss of Normal Service Water
	Loss of Essential Service Water
	Loss of Service Water
	Loss of Component Cooling Water
	Loss of Reactor Building Closed-Cycle Cooling Water
	Loss of Turbine Building Close-Cycle Cooling Water
Miscellaneous	Loss of Pneumatics or Instrument Air
	Loss of Ultimate Heat Sink
	Loss of Drywell Coolers
	Reactor Water Level Reference Line Break

3
TASKS

This section describes the tasks associated with the development of support system initiating event models approach and methodology used in the modeling of support system initiating events, specifically:

- *Identification* of support system initiating events (Section 3.1).
- *Grouping (also called categorization)* of support system initiating events (Section 3.2).
- *Quantification* of support system initiating events (Section 3.3).
- *Model incorporation* of support system initiating events (Section 3.4).
- *Uncertainty and Importance* analyses of support system initiating events (Section 3.5).

Fault trees and associated results for example systems are documented in Appendices C, D, and E.

3.1 Identification

The first task in the development of support system initiating events is to identify those systems whose failure could lead to an initiating event and simultaneously fail plant equipment needed for safe shutdown. The definition of what constitutes a support system initiating event and modeling considerations associated with the identification task are provided in Section 2. Also presented in Section 2 are the ASME PRA Standard requirements associated with identification (high level requirement A with associated supporting requirements), and a list of typical support system initiating events.

The principal method for identification of support system initiating event is to perform an FMEA or equivalent analysis such as a system-by-system review of initiating event potential on all normally operating systems in the plant. An FMEA is an excellent approach. However, given the extensive modeling that has already been done at all licensed reactors in the USA, one can assume that the significant failure modes have already been uncovered. These failure modes most likely exist in the support system models of current licensee PRAs. Therefore a reasonable alternative or cross-check is to review the existing plant model importance measure lists. Post-initiator basic events representing support system component failures that have high Birnbaum importance measures, should be (or point to) candidates for support system initiating events. An additional argument along these lines is that ongoing data collection and evaluation efforts would have already identified initiators probable enough to have been seen in the current plant operating histories. This implies any as-yet undiscovered initiators will have very low frequency.

The general steps in the process of conducting an FEMA are summarized below. Similar process and steps would be considered for a system-by-system review of initiating event potential.

Steps to Identify Support System Initiating Events

Step #1) Perform an FMEA or equivalent evaluation (hereafter referred to as an FMEA) on all operating systems to identify the effect of system failures. The FMEA should be performed at the train or subsystem level of each operating system. The level of detail needs to be sufficient to determine if reactor shutdown will occur, either through direct reactor trip or administrative shutdown.

a. For partial system failures that do not cause a direct reactor trip (i.e., train failures), identify the remedial actions that must occur to maintain the support function and thereby avoid reactor trip or administrative shutdown.

b. For the identified remedial actions, confirm with operations staff that the remedial actions are proceduralized and trained. Develop time windows (meaning the time available for recovery, before equipment damage or core damage occurs) for remedial actions to ensure feasibility of these actions in recovering the loss of function before reactor trip or administrative shutdown is required.

Step #2) From step 1, develop an inclusive list of candidate support system initiating events. This list should include partial and total system failures, the remedial actions for each, whether the action is proceduralized, whether the action is trained, and the time required for the remedial action. Examples of candidate support system initiating events are:

- Component or train failure that causes immediate reactor trip (e.g., loss of DC Bus leads to main steam isolation valve closure)
- Component or train failure that causes reactor trip if not recovered by redundant train within some specified time (e.g., loss of instrument air if not recovered by redundant train)
- Component or train failure that leads to administrative shutdown for equipment protection (e.g., loss of switchgear room HVAC)
- Component or train failure that lead to administrative failure for exceeding limiting condition of operation (LCO) (e.g., loss of component cooling water train and inability to repair in 72 hours)
- Complete system failure that causes immediate reactor trip (e.g., loss of instrument air or loss of pneumatic controls)
- Complete system failure that leads to reactor trip if not recovered within some specified time (e.g., loss all service water)

Step #3) Eliminate any candidate support system initiating event that is included within the boundary of another non-support system initiating event initiating event and does not affect more than one system.

Step #4) Group support system initiating events as appropriate and develop system boundaries for each support system initiating event to ensure they are unique.

Step #5) Check the selection of support systems by examining the importance measures of those support systems used in the post-initiator response model. Since the objective of support system models is to identify those systems with an impact on plant mitigation response, those systems with a higher risk achievement worth and/or Birnbaum importance measures should be included as support system initiating events.

<u>Considerations in the Identification</u> of support system initiating events:

The FMEA should be performed on all systems that normally operate during plant operation. This method is applicable to all plants, although the results and process will be determined by the site/plant characteristics. Multi-unit plant sites with shared systems will have different grouping and results than for a single unit site. This method will identify which failures become immediate reactor trips and which failures result in delayed reactor trips corresponding to the second and third category of events discussed in Section 3.

The following considerations should be included when performing an FMEA for the identification of support system initiating event candidates:

a. For failure of a single train, the FMEA should identify the back-up actions and systems that must occur to maintain system function. Operator actions should be identified if required for a redundant train to start and run.

b. The possibility that the back-up train is in maintenance must be considered (if allowed by the Technical Specifications).

c. The possibility of CCF events between operating and standby trains should be considered.

d. All commonly encountered system functions and configurations shall be considered in the FMEA.

e. The effects evaluation identifies mitigating requirements and should be carried forward to the point that reactor trip is either guaranteed or prevented. Criteria for treating administrative shutdown for repair or to meet Technical Specifications must be developed for the FMEA, based on plant operating procedures.

f. Events that have significantly long time horizons, (e.g., events that will not result in an automatic or manual shutdown without human intervention in less than 24-hours) can be screened out from the candidate list of support system initiating events. The very long time windows (meaning well beyond the 24-hour mission time) essentially mean the loss of the normal operating component, train, or system has effectively been recovered such that it will not lead to reactor trip or administrative shutdown.

The screening of long duration events should be documented including the basis for the time horizon and methods for event discovery and mitigative actions.

g. The results of the FMEA used in the identification of support system initiating events should be documented in accordance with the ASME Standard supporting requirements.

In step #3, the candidate support system initiating events are reviewed against the list of initiating events developed in the PRA. In some cases, the candidate support system initiating events are within the boundary of an initiating event that is already modeled. In these cases, the boundary conditions of the initiating event are noted as the basis for removing the candidate support system initiating event from further consideration. This evaluation should be performed with care and the basis documented.

After the final list of support system initiating events is defined, it must be compared with generic industry lists and lists from plants of similar design. Differences should be resolved and documented. In addition, the list of candidate support system initiating events should be reviewed against the plant-specific trip experience collected in support of the PRA initiating event analysis. Other good sources include the plant's Abnormal, Off-Normal, and Emergency Operating Procedures. Any historical loss of support systems that resulted in a plant trip or significant transient should be considered as a potential support system initiating event. As an example, consider the potential for seasonal influx of materials causing blockage of the plant's service water intake structure. This has been a historical occurrence at several plants and can be caused by debris from flooding or storms, or environmental sources such as mussels, marsh grass, or frazzle ice. While other plants may not have experienced a plant trip during the lifetime of the plant, what needs to be examined is whether a heavier influx of blocking materials could have caused loss of circulating water and simultaneously impaired service water. This type of potential failure should be considered in the identification of support system initiating events.

After the list of support system initiating events is finalized, the need for thermal-hydraulic analysis or other defining criteria for restoration is considered. It will be necessary to define success criteria and to identify allowable periods for operation without a function being performed. The Owners Group PRA peer reviews found that success criteria for fluid cooling systems, such as HVAC and service water are generally not developed in detail and lead to imprecise definition of the support system initiating event. Items to consider are:

- Use of best estimate component success criteria.
- Use of best estimate temperatures for component damage to determine heat up times.
- Success criteria for service water could include variability in the ultimate heat sink temperature. Success criteria for HVAC systems could include variability in the ambient temperature. This may produce different success criteria for summer and winter operation.

It is necessary to define a support system initiating event narrowly enough to ensure it is unique and only accounted for in one support system initiating event. During the Owners Group PRA peer reviews and self assessments, it was found that if a single failure in one system will cause multiple other system failures, each leading to a reactor trip, the single failure was sometimes counted in more than one initiating event. Use of a master logic diagram will facilitate this distinction of support system initiating events into unique categories. If the PRA uses a support system method, unique identification will be facilitated by the support system matrix.

Use of these techniques will provide a comprehensive definition of initiating events at the functional failure level, consistent with other plants of similar design.

3.1.3 Single Train and Dual Train Initiating Events

Special consideration must be given for essential support systems where loss of a single train will cause a support system initiating event. Simultaneous loss of both trains will have a lower initiating event frequency, but may have a distinctly more severe effect on plant response than loss of a single train. It must be considered, on an individual plant basis, whether simultaneous loss of both trains should be included as an additional, distinct initiating event. Reviews of many PRAs have shown that, when train-level initiators are modeled, the dominant core damage cutsets tend to look like total loss of the system. Therefore most train-level initiator models will be redundant to total loss of system initiator models. This is most pronounced in fluid system models. The most common industry practice appears to be to model loss of ac or dc bus initiators at the train level (because of asymmetries in train importance), and to model loss of cooling water systems and loss of air systems at the system level. Exceptions to this are generally associated with cooling water systems that have separate headers that cannot be cross-tied quickly enough to avoid core damage.

Loss of DC power is an example of such an initiator. At some plants, failure of either train of DC will cause immediate reactor trip. For loss of each DC train initiator, an individual event tree is developed. Failure of the redundant train of DC within a 24-hour period after failure of the first train is included in the plant response model for the initiator, and represents all subsequent losses of the redundant train, even those due to common cause. The question involves the need for a "dual train initiating event." To be distinct as a dual train initiator, both trains must fail at the same time, which can only occur by a common cause failure. Typically, in the rank order of cutsets, right behind the common cause failure cutsets will be the cutsets where train A (or B) fails, and then train B (or A) is unavailable. Maintenance on electrical buses during power operation is not a standard practice, thus the cutsets involving maintenance are typically not modeled (since maintenance is disallowed).

The quantification of the dual train support system initiating event however, must be true to the definition of the event and that is loss of both trains at the same time (meaning the redundant train fails within the mean time to repair of the running train). Common cause failures as a means of triggering multiple train failures at the same time should be relegated to those either actually observed, or those for which a credible mechanism can be identified. Table 3-1 can be used as an aid for identifying components susceptible to common cause failure. For contributors that are common cause failure related, however, these events are so rare, that there is not usually sufficient historical information upon which to base a frequency. Thus, a more appropriate approach is to use the existing CCF data (alpha factors) as is. If this results in a support system initiating event frequency inconsistent with operating experience, then refine the data as described in Section 2.3.3 until the result is consistent with operating experience.

Table 3-1
Suggested Checklist for Identifying Components Susceptible to CCF

#	Susceptibility Considerations	Yes	No
	Is the cause or symptoms for the event well known and impacts a single component? (See Note 1 below)	☐	☐
	Do other components (inter or intra-system) similar to the identified failed component exist? (See Note 2 below.)	☐	☐
	Design Based Similarity		
1	Are other similar components configured and arranged the same way?	☐	☐
2	Do other similar components have the same sub-component or internal parts?	☐	☐
3	Do other similar components have the same requirements for maintenance, test, and/or calibration?	☐	☐
4	Are other components of the same type, size, or model?	☐	☐
	Quality Based Similarity		
5	Do other similar components have the same physical appearance?	☐	☐
6	Are other components made by the same manufacturer?	☐	☐
	Operational Based Similarity		
7	Has the same crew operated the components?	☐	☐
8	Are other similar components governed by the same operating procedure?	☐	☐
9	Do other similar components start/operate for the same time period?	☐	☐
10	Do other similar components exhibit the same mode of operation?	☐	☐
	Maintenance Based Similarity		
11	Do other similar components have the same procedure for performing maintenance, test, and/or calibration?	☐	☐
12	Do other similar components have the same schedule for maintenance, test, and/or calibration?	☐	☐
13	Do other similar components have the same crew for performing maintenance, test, and/or calibration?	☐	☐
	Environment Based Similarity		
14	Are other similar components located within the same area or room?	☐	☐
15	Are other similar components exposed to the same working medium (e.g., borated water, compressed air)?	☐	☐
16	Does the working medium satisfy quality requirements?	☐	☐
Notes: 1. If “Yes” is provided as a response, the event is an independent failure. 2. If yes, identify the group of components that may be susceptible to CCF. Otherwise, the failure is not a potential CCF event. Judgment will be needed to determine which of the			

Table 3-1
Suggested Checklist for Identifying Components Susceptible to CCF

above attributes are applicable. Susceptible components within the same system are referred to as a common cause component group.

3.1.4 Plant-Specific Data Review

The FMEA or equivalent analysis provides a structured, systematic approach to analytically identify trains and systems as potential initiating events. Additional ASME PRA Standard supporting requirements such as operator interviews, accounting for precursors, and system alignments (IE-A6, IE-A7, and IE-A8, respectively) focus on the plant-specific aspect of this task and are needed in order for this portion of the PRA to be Capability Category II compliant. A best practice in accomplishing this task is to review Licensee Event Reports, especially those that are referenceable, historical data that complement the analytical FMEA approach.

3.1.5 Comparison with Generic Data

The generic list of support system initiating events provided in Section 2.4 can be used to help satisfy the ASME PRA Standard requirement IE-D1, to "DOCUMENT the approach for assessing completeness and consistency of initiating events with plant-specific experience, industry experience, other comparable PRAs and FSAR initiating events."

3.2 Grouping (including IE pre-cursors)

Supporting requirement IE-B3 of the ASME PRA Standard [4] requires grouping of initiating events to only occur when

> "GROUP initiating events only when the following can be assured:
>
> (a) Events can be considered similar in terms of plant response, success criteria, timing, and the effect on the operability and performance of operators and relevant mitigating systems; or
>
> (b) events can be subsumed into a group and bounded by the worst case impacts within the "new" group." (Capability Categories I/II)

The main consideration in grouping of support system initiating events is that the dependencies with potential mitigating systems are captured.

Section 2.3.1 above provides a summary of the considerations for initiating event precursors. For example, loss of safeguards ac and/or dc buses have often been included in the development of many PRAs since although they may not lead to an immediate plant trip, they often would be subject to short time frame (e.g. < 8 hour) technical specification action statements requiring shutdown of the plant while at the same time much of the mitigating equipment is rendered unavailable.

3.3 Quantification

The two common modeling approaches for support system initiating event quantification are:

1) use of historical data to develop an overall frequency for a support system initiating event, or

2) development of a system-specific reliability evaluation to derive a frequency.

Use of historical data will result in a single basic event for support system initiating event, which will limit the ability to use the event for plant specific risk applications. In general, historical system experience is better suited to quantify a support system initiating event where it can be determined that a single failure within the system will dominate the support system initiating event characteristics.

For cases of a complex system of multiple trains, the preferred method of quantification of a support system initiating event frequency is through fault tree analysis. The use of a fault tree can lead to a single basic event in an approach called the point estimate, or the fault tree can be incorporated directly into the PRA in an approach called the explicit events method. There are several considerations which must be accommodated in the support system initiating event model development (as listed below), both in identifying which modeling method to use and also in constructing the support system initiating event fault tree.

- The system boundary for the support system initiating event may be different than the system boundary for the post accident fault tree model. For example, some cooling loads which are isolated following an initiating event may be required during normal operation and their loss may lead to shutdown. Also, failure modes, such as passive failures, and backflow or flow diversion failures, which may be excluded from the post-initiator model may be dominant in the support system initiating event model.
- For systems with redundancy, modeling recovery of a failed train or system by starting and/or aligning another train/system must be modeled considering human reliability performance shaping factors such as cues, instrumentation, procedures, skill-of-the-craft and the time available for action.
- All system configurations must be represented in the support system initiating event model. The fractional time spent in each configuration should be assigned, based on plant experience.
- Unavailability of standby trains / components due to routine maintenance and standby failure potential
- Appropriate mission times and failure rates for running equipment.
- Common cause failures of running equipment must be included and must have appropriate mission times (for example, the common cause failure to run for two

operating pumps may be about one year, but the common cause failure associated with the standby pumps may be for 24-hours.)

PRA peer reviews and self-assessments revealed the support system initiating event frequencies derived from fault tree models are often significantly different than other plants and the industry in general. The most common reasons for these differences are:

- Lack of appropriate CCF factors for annual frequency calculations
- Lack of sufficiently detailed success criteria for building the model
- Inability to accurately model recovery, repair, and operator actions to align a second system. A common modeling issue is to try to apply human reliability analysis to recover components for which the data collection has already screened events that were considered "recoverable". For support system initiating event calculations it is particularly important to make sure the data collection policies are not circumvented by later addition of inappropriate recoveries. The two should be developed together. The independent failure rates in NUREG/CR-6928 (EPIX data over 1998 - 2002) and any data within the associated INL failure data software (RADS) have not been screened for recoverable events. All failures are included, whether they are recoverable or not. The same is true for the CCF database [16].
- Misclassifying a component problem as a failure, when in reality in operates successfully until a replacement is made ready.
- Use of historical experience from plants of significantly different design.

3.3.1 Method Overview

General considerations, concepts and modeling issues associated with methods are described above in Section 2.3.2. The following table provides a summary comparison between methods, followed by guidance in implementing these types of models. A more detailed comparison of the explicit event method and the multiplier method is presented in Appendix B.

Table 3-2
Assessment of Support System Initiating Event Quantification Methods

SSIE Method	Pros	Cons
Historical data – modeled as a single basic event in the PRA.	Defensible, based on empirical data Works well for something which is dominated by a single failure mode like a loss of an electrical bus.	Difficult to capture changes in configuration Can limit the ability to support some PRA applications
Explicit Method - Detailed (All Fail-To-Run terms changed to Initiating Events with 8760 mission time as appropriate)	Captures all dependencies Importance Measures ~OK for non-initiator basic events	Full accountability of all dependencies would be extremely difficult to implement
Explicit Method – Limited (Only FTR terms directly included in support system model changed to Initiating Events with 8760 mission time as appropriate)	Importance Measures ~OK for non-initiator basic events Not too difficult to implement	Does not account for second order dependencies
Multiplier Method (Global 365x)	Captures all dependencies Relatively simple to implement	Error prone May not capture all dependencies appropriately Importance measures not right
Point Estimate Use of point estimate based on either of the methods above (or Bayes update of generic data) – modeled as a single basic event in the PRA.	Simple to implement Generates less cutsets	Does not account for second order dependencies Importance measures limited to mitigation impact, but can still be determined if a fault tree is used to develop the point estimate value.

Point Estimate Modeling Using Historical Operating Experience. Developing the frequency of a support system initiating event on the basis of historical data can be, where appropriate, straightforward and defensible. While plant-specific data should be used when available, losses of support systems are infrequent occurrences and thus the data population is expanded to include generic industry experience when modeling most basic event failures as point estimates. Examples would be Loss of a DC Bus, Loss of an AC bus, or Loss of all Instrument Air. In order for the blanket application of industry experience to be valid, the following considerations must be met:

a. The design of the system at the specific plant must be similar to the industry population.

b. The operation of the specific plant is similar to the industry population. The number of operating pumps, train configurations, and cross-connect capability must be similar.

c. The success criteria for the system at the specific plant are the same as the industry population.

When using industry experience to estimate the frequency of a support system initiating event, it is necessary to document the applicability of the historical experience to the specific plant being modeled. While it is typically not feasible to perform a formal survey of all the design features for all plants in order to more accurately gauge the applicability of the generic experience, a review of one's particular plant-specific features can either support or refute the assertion that the generic experience is relevant. The review of plant specific features should consider differences in design, instrumentation, or operation that significantly impact the likelihood of the support system initiating event. For example, plants with reciprocating air compressors are more susceptible to loss of instrument air than plants with screw-type air compressors. Additional examples are further described below.

Example 1: The support system being evaluated is a Component Cooling Water system at a PWR. This PWR has two redundant CCW headers, each supplied by a dedicated pump and heat exchanger. A spare train with a pump and heat exchanger is available and can be aligned to either distribution header. Suppose, in the industry data, the common plant has a two-train system without the spare train. In the industry experience, if one CCW pump is in maintenance and the other pump fails, then CCW is lost and there would be a recorded Loss of CCW. For the PWR with the third train, the same series of events would not necessarily cause a loss of CCW since the spare train could be aligned and used to maintain CCW, with no loss of service. In this case, the modeled PWR would likely have a lower initiating event frequency than the industry experience. Use of generic data in this example would likely overestimate the support system initiating event frequency for Loss of CCW unless some adjustment was made.

Example 2: The support system being evaluated is a Component Cooling Water system at a PWR. This PWR is on a dual unit site with a cross-tie of CCW systems. CCW configuration at each unit is the same as the typical, generic plant, but the inter-unit cross-tie serves as a completely redundant third train. The frequency for Loss of CCW at this plant could be an order of magnitude or more lower than the single unit plants.

Use of industry data will result in a single event for the initiator with an associated frequency. This limits the ability of the PRA model to explore the effect of different plant configurations and provides no information on plant specific features which may affect system operability. If the support system initiating event frequency is dominated by failure of a single component, use of generic frequencies may be acceptable, but the analyst relinquishes the ability to consider different operating configurations, relinquishes the ability to provide a specific basis for recovery, and can not capture the role of the operator in support system initiating events.

Example 3: The support system being evaluated is the Service Water system. The plant in question has three Service Water pumps with 2 of 3 normally in operation. The success criterion for continuing plant operation is also 2 of 3 Service Water pumps and during times of elevated river water temperature this success criterion changes to 3 of 3 Service Water pumps. The frequency of Loss of Service Water would thus increase during periods of elevated river water temperature. Use of a generic frequency for Loss of Service Water can not capture this situation.

For situations where an immediate support system initiating event is caused by failure of a single train and dominated by a single component failure (such as Loss of AC Bus), use of historical data is a good practice. It provides a reasonable frequency and because a single component failure dominates the support system initiating event, the component importance can be inferred from the support system initiating event frequency. Conversely, for support system initiating events that involve a multiple train system with normal equipment rotation between trains and other back-up mitigating systems, coarse modeling at the basic event level for support system initiating event should not be attempted. For this case, even if the plant configuration closely matches the generic data, important dependencies may be neglected and the importance of component could be obscured by the coarse modeling approach.

Detailed, Plant-Specific Reliability Evaluations Using Fault Trees. Detailed, plant-specific reliability evaluations most often take the form of a fault tree, and can produce a model capable of providing plant insights such are Risk-Reduction importance. It is the desired approach to use, if appropriate data are available for quantification. Fault tree analysis is the most common method for system reliability analysis and is recommended as the method of choice in this report. The advantages of using fault tree analysis for estimation of a support system initiating event frequency include the following:

- Allows different operating configurations to be modeled;
- Allows maintenance of redundant trains to be included;
- Allows modeling of human interactions; and
- Allows changes in success criteria to reflect transitory environmental conditions.

It should be emphasized that the models developed for the support system initiating event should be consistent with the applicable portions of the ASME PRA Standard such as systems modeling (SY), human reliability (HR), and data (DA). Each of these areas must be modeled realistically if a particular application needs this portion of the PRA to satisfy ASME Capability Category II. In the early years of PRA, simplifications were often made to offset computing limitations. The currently available tools are capable of handling complex models in a timely fashion.

The following considerations apply when performing support system initiating event frequency estimations using fault tree analysis:

1. All routine system alignments encountered in plant operation must be accommodated by the fault tree model.
2. Automatic start and manual start of redundant systems must be distinguished. Instrumentation, indication, and time lag to reach limiting conditions must be considered.
3. System failures must be representative of continuous operation of an operating system
4. Repair and use of alternate trains must be included.
5. For full power operations the result should represent an annual initiating event frequency based on a reactor year. The top event should produce the expected number of events in one year. This will not generally be different than frequency per year, but can be. While theoretically the expected number of failures is obtained by integrating the system unconditional failure intensity over the mission time (8760 hours maximum), for all realistic failure and repair rates this is the same as converting frequency terms from per hour to per year. Where it is potentially different is in the case of low power and shutdown modeling. In this case expected number of events can be significantly different (because component unavailabilities have not reached their asymptotic values)
6. The final result should be compared to generic frequencies.

This section summarizes the considerations in developing a support system initiating event fault tree. Specific considerations applicable to the explicit event method and the multiplier method are provided in Appendix C and Appendix E, respectively.

<u>Definition of Top Event</u>

The first step is to determine the minimal success criteria for the system during reactor operation. The normally operating system success criteria can be identified by examination of the plant operating procedures and records supplemented with discussions with plant personnel. The goal is to identify the normal operating configuration, and the minimum operational configuration. In the majority of cases the normal and minimum requirements are the same. If it is suspected that the minimum is less that the normal operational contingent, additional analysis would be required to justify the reduced configuration. In addition, the timing of events necessary to avoid plant trip/shutdown must be identified, either through plant experience or analysis. For example, for a fluid delivery system the normal number of operating pumps should be determined from plant records and discussion with plant personnel, and the plant process, including time constraints, for coping with a failure. This information forms the basis for the definition of the top event for the support system initiating event.

For systems with no redundancy, the definition of the top event is straightforward. For systems with redundancy and systems that operate with surplus equipment, the definition of the top event must be developed carefully to result in a representative support system initiating event frequency. Examples are given below for fluid delivery systems to demonstrate the impact of success criteria and level of redundancy on fault tree development.

In some cases, the success criteria for a system differ between the normal, operating full-power plant state and the post-initiator state. When a fault tree model is used for the support system initiating event, these variations in success criteria are automatically handled through the Boolean logic. This is one of the essential reasons for the proper selection of basic event names in the support system initiating event fault tree and the post-initiator system fault trees. For example, assume the support system initiating event for loss of service water is modeled in a fault tree representing failure of 2 of 3 pump trains and the support function of the post-initiator systems require flow from one pump train (meaning 3 of 3 must fail).

The following examples are for fluid systems but the examples are equally applicable to all multi-trained support systems such as power, actuation, and HVAC. These examples are not intended to cover all possible combinations that may be encountered, but rather to illustrate how success criteria are treated.

Example 1: A simple 2-pump system is one requiring 1 pump to maintain operation, and only operates with one pump normally running. When the running pump fails, the standby pump starts and must run until the failed pump is restored. Because only one pump runs at a time, the frequency of failure of a running pump in one year is (8760*fractional multiplier for reactor-critical year)*λ. Failure of the second pump to start and run during the mean-time-to-repair mission time for the standby component is one of the contributors to the support system initiating event fault tree model. This example scenario can be found in the explicit event model, the point estimate support system initiating event fault tree, and the multiplier method.

Example 2: A more complex system would be a 3 pump system which requires 2 pumps to maintain operation, and normally has two pumps in operation. When either running pump fails, the standby pump starts and must run until the failed pump is restored. It is important to note that the frequency of a failed pump depends on the number of pumps running. For this case, the frequency of failure of a running pump in one year is:

$$(2)*(8760)*\text{fractional multiplier for reactor-critical year})*\lambda$$

Failure of the standby pump (the third pump in the system) to start and run during corrective maintenance (or other appropriate time) results in the support system initiating event. This example scenario can be found in the explicit event model, the point estimate support system initiating event fault tree, and the multiplier method.

Example 3: A service water system has four pumps, requires 2 for success, and normally operates with 3 pumps. When the running pump fails, the standby pump is started manually. A running pump can fail with no effect. Only if a second pump fails before the fourth pump is started or the failed pump is restored, will there be a support system initiating event. Because three pumps run at a time, the frequency of failure of a running pump is:

(3)*(8760)*fractional multiplier for reactor-critical year)*λ

In order for a support system initiating event to occur in this situation, one of the other running pumps must fail to run during corrective maintenance on the initially failed pump and either the third operating pump or the standby pump must also fail to run or start as applicable during corrective maintenance to repair the first two failures.

Fault Tree Development

In general, the support system initiating event fault tree is developed with a content and scope similar to the system fault tree used for response after an initiating event (often called the post-initiator or post-initiator system model). One exception is that the links to any systems which are identified as support system initiating events themselves should not be included. One of the first steps is to select the system configuration with respect to which train is running and which train is in standby. It is necessary to consider all routine operating configurations. If all configurations have symmetrical results, then a single configuration can be modeled and will meet the ASME supporting criteria for fault tree analysis. The alternative choice is to model all routine configurations with a split fraction for operating time in each configuration. The use of a single configuration is not recommended. If only one configuration is modeled, the values for valid importance measures for the operating equipment will be higher than for the standby equipment, even though in reality, both trains could have equal importance. Although the support system initiating event frequency and the core damage frequency will be correct, the importance values for risk informed initiatives may be artificially skewed towards the equipment chosen as operating equipment. If all configurations are modeled, the importance of each component will be correctly represented. Building a system model to accommodate the broadest spectrum of possible system configurations is very useful and provides a more realistic assessment, but adds complexity to the model.

As the starting point for the support system initiating event fault tree is the post-initiator fault tree, it is necessary to ensure that passive failures such as pipe leaks, heat exchanger leaks, and valve plugging are included in the fault tree. The same can be said of standby failures for pumps and other active components that are typically assumed to be represented in the demand failure model associated with the component. It is more important to represent component standby failures, and do it in way that takes credit for real repair times and test intervals. Also, data for passive failure modes are typically problematic.

Passive failures are often removed from the post accident fault trees, but can be important contributors to the support system initiating event given the longer mission times. Passive failures such as large system leaks that are modeled in the internal flooding analysis are excluded from the SSIE boundary since they are modeled explicitly in another portion of the PRA.

The failures for each train must be segregated into demand-related failures and time-dependent failures. The probabilities of the time dependent failure events are adjusted to address the appropriate mission time. In a real system this can involve massive rearrangement of the post-initiator support system fault tree. Given the massive re-configuring that may be required, it is typically better to abandon attempts to maintain the resemblance to the post-initiator fault tree, and instead design and build a new initiator fault tree in order to produce the required result. The design should strive for accuracy of result and clarity of expression. This will give better long-term usability and maintainability of the results.

The initial failure will generally have a mission time of 8760 hours (adjusted for a reactor critical year) and the subsequent failure(s) will have a mission time related to the repair time (or the Allowed Outage Time, AOT) of the failed equipment. There are two techniques for modeling the extended mission time for the initial failure. One method is to use a basic event with a mission time of 8760 hours. The analyst must be sure the result is a frequency, not a probability, as described below in Section 3.3.3. The other method is to use the basic event for the 24-hour mission time multiplied by a basic event with a value of 365. Both of these methods will yield the correct support system initiating event frequency and lead to the correct core damage frequency. However, the risk-achievement worth (RAW) and Birnbaum importance measures will not be calculated the same for both methods. In the case where the basic event with the extended mission time is used, the Birnbaum value will be correct if the frequency of failure is less than 1.0. However, the RAW importance of the basic event for the 24-hour mission time will be greater than the RAW importance for the same component for the 8760 hour mission time. If the frequency is greater than 1.0, the RAW will be meaningless and the Birnbaum questionable. This is also the case with the “multiplier method”, because the initiating event frequency is artificially increased to one failure per day.

The support system initiating event frequency will be calculated accurately, regardless of which pump is selected as running or standby for symmetric systems. Since all of the fluid systems modeled as support system initiating events have at least one pump/loop running during power operation, the final cutsets will always have at least one running failure. Since the failure rates for PRA components typically are assumed to be constant in time, assuming a single configuration will run for one year is mathematically equivalent to modeling two configurations for 6 months each (or 4 configurations for 3 months each) for symmetric systems where the redundant trains are routinely rotated to balance out the duty.

The fault tree will model the initial failure followed by subsequent failure(s) for a given mission time. The mission time for component failures after the first component failure is related to the repair time of the first component. When the failed component is restored to operability, the system configuration is restored to the base case. Three possibilities for the mission time of subsequent failures are: 1) the average repair time of the initial failed component, 2) the allowed outage time (AOT) for the initial failed component, or 3) the same 24-hours as for the post-initiator fault trees. As demonstrated in Section 2.3.2 above, the use of a 24-hour mission time for the standby train is justified by generic data. In a system with multiple running pumps and higher order success criteria, (such as a 3 out of 6 service water system), one may want to model the mission time of the 5th pump as half of the mission time of the 4th pump, reflecting the assumption that the failures are randomly distributed in time. In practice, it is recommended that the same mission time be used for all standby components. This is reasonable and supported by what little recovery data are available today. However, this assumption may be challenged as the support system initiating event models are used for specific event evaluation, as there is often debate over what constitutes a best estimate repair time. A better way to build repair time into the model using a more detailed basic event failure calculation such as a SAPHIRE calculation type 5, CAFTA type 6, or equivalent, calculated as follows (and may be useful to address as a future research opportunity).

$$\frac{\lambda\tau}{\lambda\tau+1}\left(1-e^{-(\lambda+1/\tau)T}\right)$$

Where:

λ = operating failure rate, in hours
τ = mean time to repair

T = mission time

However, these calculation types are not a valid choice when the multiplier method is used.

In general, the advanced calculation of mean time to repair (described above) does not significantly affect the calculated results. However, if this simplification introduces excessive conservatism in the model, the actual mission times should be examined to select the most representative value. While the use of a 24-hour mission time may simplify modeling as it is consistent with the basic events as in the post-initiator fault trees, the better reason to use 24-hours is that if fits with the available recovery data as described in Section 2.3.2.

If postulating repair of two or more components at the same time, it is necessary to assure that equipment, personnel and space are available to work on two or more components simultaneously. For systems with multiple redundant components, the impact of independent failures is small, and increasing the mission time of one of the redundant components is not expected to have a large impact.

One other issue is the treatment of degraded systems which may be taken out of service. Although not technically a "failure" this type of event does place the plant in one of the states defined as potentially leading to a support system initiating event. Ideally, the failure rates for the running equipment should reflect not only complete failures, but also the probability of degraded operation that would require the component to be taken out of service. If the running train is taken out of service, the standby train is required to function, regardless of the reason the running train was deemed "inoperable". This type of treatment is highly dependent upon the plant specific operational data available and should be included if there are sufficient data.

In order to apply the most current common cause failure data, the approach outlined in section 2.3.3 should be applied. This approach allows filtering of events that are not applicable from the data used to quantify common cause alpha factors. Additionally, a provision has been added such that systems with 0 failures can now be quantified.

Quantification and Results

As with any other PRA analysis, the support system initiating event cutsets quantifying the frequency of the initiating event need to be checked for validity. This check must consider the appropriateness of the standby train (or additional recovery action) to maintain sufficient operability of the system such that a reactor trip is avoided. For example, if the system has a leak then cross-tying to Unit 2 may not be a viable recovery mechanism.

Supporting Requirement IE-C3 for all initiating events requires that frequencies should be calculated on a reactor-year basis. There are two issues that must be considered:

- The numerical result must represent a frequency, not a probability.
- The frequency must be for a reactor critical year, not a calendar year

Quantification of a fault tree results in minimal cutsets, each representing the probability of occurrence in a year. In order for each cutset to be representative of a frequency, rather than a probability, the rare event approximation must hold for each cutset event. Note that typical codes currently use the minimum cutset approximation for sequence quantification, and that this can introduce very large errors in component frequency calculations and component importance calculations. This area is an opportunity for future research.

The next issue concerns how the cutsets are added to derive a top event probability. If the cutsets are added arithmetically, the top event is a frequency. This may result in a top event number greater than 1.0. It the cutset probabilities are combined in a “min-cut” method, or an exponential approximation, in order to derive a probability, the result may not be suitable for a support system initiating event frequency. If the top event is on the order of .01 or less, the difference between probability and frequency is generally not important. If the top event probability is .1 or greater, the difference between the annual frequency and the annual probability of occurrence must be considered and adjusted if necessary.

The second issue can be resolved by ensuring that each cutset has one event with an 8760 hour mission time and the top event in the support system initiating event fault tree is combined with Boolean AND logic with an event representative of the plant availability factor.

The simple example above only listed two basic events associated with a component. In a typical PRA model, a given component may have several more basic events associated with it such as fail-to-start, fail-to-run, test and maintenance, fail-to-restore, and common cause failure events. Of these, the first four will generally have the same importance. But this is not always the case. A true component importance calculation requires aggregation of all these failure modes. The mission time issue is just one more contribution to the aggregation problem. Use of the multiplier method does not solve the problem. The best solution is to develop and code an appropriate algorithm for aggregation into the quantification codes (future research).

Explicit Event Approach

A detailed example presenting the explicit event approach to support system initiating event modeling is provided in Appendix C. The example provided in Appendix C represents the current state-of-the-art in support system initiating event modeling. The advantages and disadvantages of this approach are summarized in Table 3-2.

Point Estimate Fault Tree

An example of support system initiating event modeling using the point estimate fault tree approach is provided in Appendix D. The example provided in Appendix D follows the same approach as used in the explicit event approach (shown in Appendix C) but instead of directly incorporating this fault tree, the top event is solved separately and incorporated into the model as a separate basic event representing the support system initiating event. The advantages and disadvantages of this approach are summarized in Table 3-2.

Multiplier Method

Appendix E contains a summary of the considerations for modeling a support system initiating event fault tree. This appendix provides a procedure for model development and integration into the plant PRA model. Plant-specific modeling issues may be more or less complex than the procedure example. The intention is to identify the principles which are important to the development of a coherent and realistic model for any type of support system.

3.3.3 Data

Common Cause Failure (CCF) Data

Concepts and issues related to common cause failure modeling in support system initiating events are provided above in Section 2.3.3, including recent changes in the INL CCF database [16]. The improvements to the INL CCF database described below are a step in the right direction towards addressing the common cause failure data issue associated with support system initiating event modeling. Note that the CCF database screening function (using the “remove event” command) only removes events and does not properly treat both the numerator and denominator. It is recognized that situations may arise in which results from the filtering method and the calculation of alpha factors for systems with no failures still does not comport with reality and in these cases the PRA analyst may need to go outside of the INL CCF database, especially for cases where the INL data do not apply to your plant’s particular system. This is an area of consideration for future research.

The issue associated with common cause failure data development for use in support system initiating event models is that attempts to calculate the common cause failure contribution to support system initiating event frequencies have often produced initiating event frequencies that are higher than observed system failure rates. Typically, the CCF contributions are the largest factors in these high frequencies. The CCF contribution to initiating event frequency comprises two separate calculations: 1) calculation of the total component failure rate, and 2) the calculation of the CCF alpha factors, which are ratios of CCF events to all failure events.

In an attempt to determine the source(s) of these inaccuracies, the INL recently investigated key data in these databases related to closed-cycle cooling water systems. A preliminary investigation of the databases used in generating the failure rates (RADS) and CCF parameters (CCF database) [17] suggests that outdated and potentially inapplicable data are being used in these calculations. Therefore, a more thorough approach to addressing this issue is recommended.

It is known that there has been a significant improvement in equipment reliability over the years, both in terms of independent failures and in the number of common cause failures reported. Figure 3-1 shows a trend analysis of ‘complete’ (sometimes erroneously referred to as ‘lethal’) CCF events decreasing significantly since the beginning of the CCF data collection effort in 1980. (Note that these are *Events per year*, not alpha factors.) Alpha factors are the ratio of CCF events to total (mostly independent) failure events. Figure 3-2 and Figure 3-3 show the most recent total failure probability trending done for normally running motor-driven pumps; both of these trends are statistically significantly decreasing.

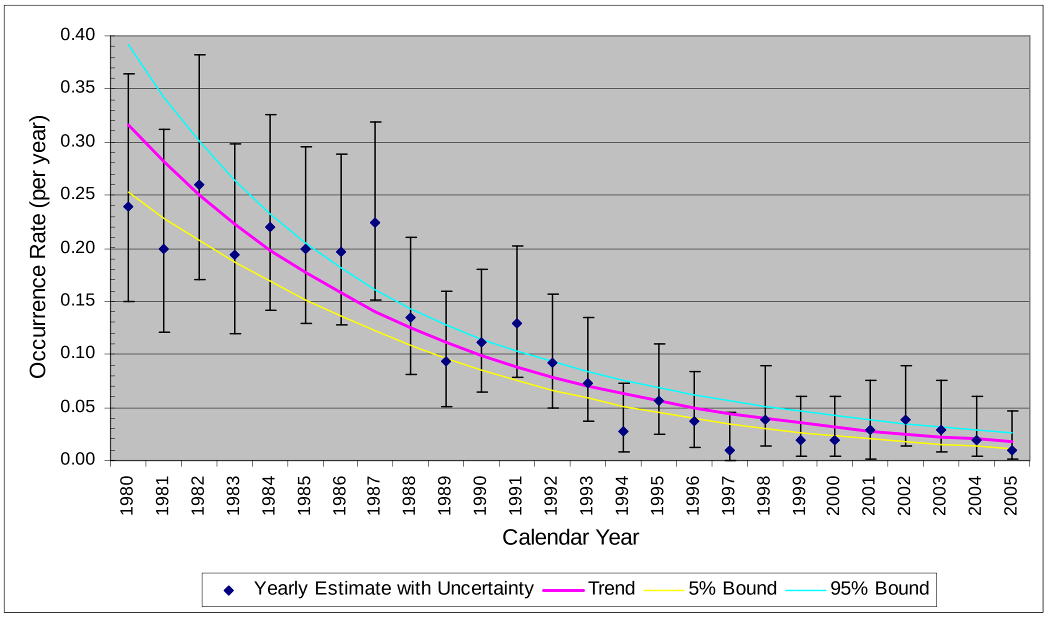

Figure 3-1.
Long-term trend for complete common-cause failure events (p-value = 0.0001)

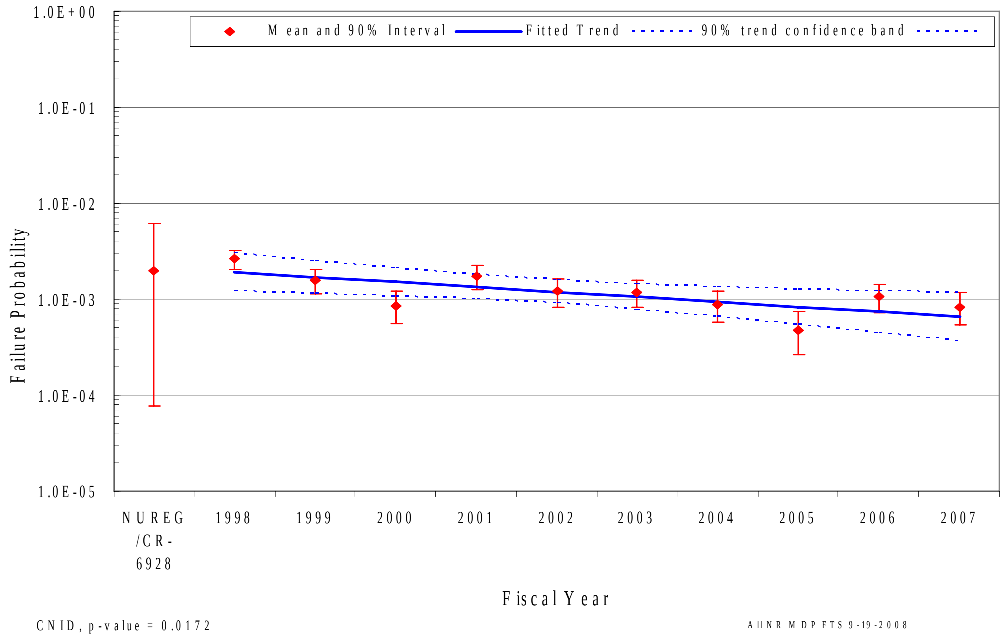

Figure 3-2.
Normally running systems, industry-wide MDP FTS trend.

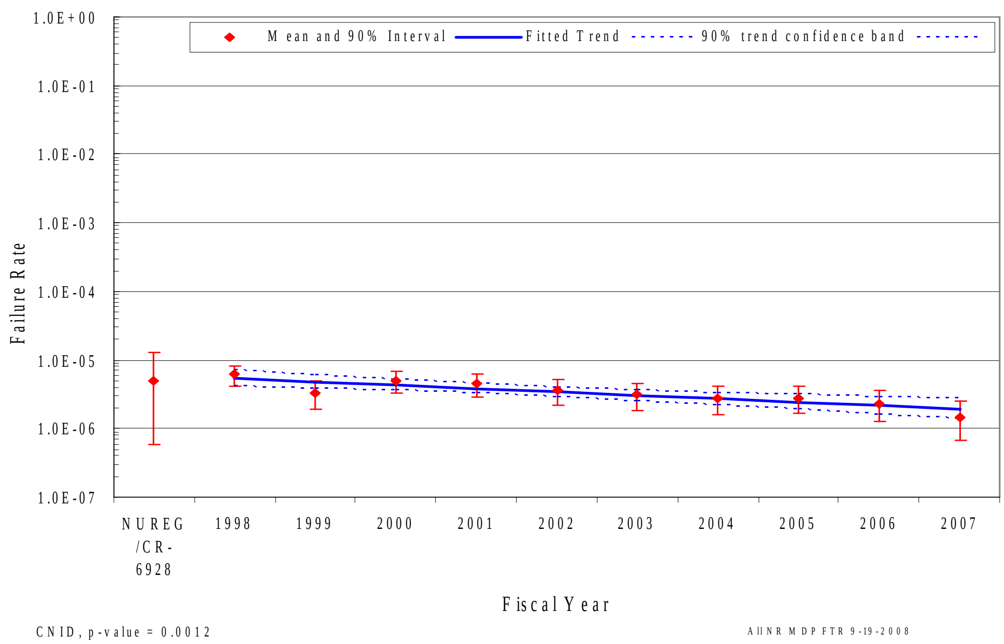

Figure 3-3.
Normally running systems, industry-wide MDP FTR trend.

A series of progressive steps are recommended to reduce potential conservatisms in the CCF calculations. The first recommended step is to use only data collected after full implementation of the Maintenance Rule (1995) when determining alpha factors and failure rates. This recommendation needs to be supported by a review of the data, to show that the Maintenance Rule had an impact on CCF event reduction. It appears that the CCF curve was dropping long before the Maintenance Rule came into effect. However, the year 1995 appears to be a reasonably good starting year for calculating CCF parameters.

If using only recent data does not result in credible frequency results, then an additional step to eliminate CCF Database records (both independent and common cause) that represent degraded components (as opposed to failed components) is under consideration by NRC. (The INL is anticipating performing this step for specific key systems/components in 2009.) Many of the 'failure' records contained in the CCF Database actually document incipient issues that do not immediately challenge the function of the component. Examples of these records include cooling degradation, and unavailability events. The affected components might have performed their design function but were included in the database because, as a consequence of their degradation, they may not have survived the 24-hour mission time and/or were subsequently removed from service for maintenance. (Note that the degraded and incipient events in the CCF Database do not carry the same weight as actual failure events. However, because there are typically many more degraded and incipient events than actual failure events, their inclusion in CCF parameter calculations can have a significant impact.) Also, with the recent implementation of the Mitigating System Performance Index (MSPI) program, these maintenance outages are now explicitly included in the unavailability calculations. Their inclusion also as failures essentially results in a double counting of the events. Therefore, these records should not be included in (i.e., removed from) the tally of failures in both RADS and the CCF database. (Note that information on collection of data in a manner consistent with the MSPI program and its use in PRA should be addressed and provided to the utilities.)

For some of the systems of interest there is the possibility that there will be no recorded CCF events, or that there will be no CCF events that survive the filtering process described above. Previous versions of the CCF database treated this circumstance as an error condition and, for these systems, would produce no results. In this case, the initiating event fault tree model would have to depend on generic alpha factors instead of system-specific ones. A recent modification to the CCF database has partially addressed this problem by enabling the database to calculate CCF parameters for systems for which there are no recorded CCF events. For these systems the CCF database now uses the independent failure event counts and related operational history to perform a Bayesian update of the CCF database prior, and will produce alpha factor results that are system-specific. The system-specific results output by the CCF database program are strongly influenced by the database prior in cases where the operational history recorded for the system of interest is small compared to the total operational history contained in the database. If after using the screening approaches described above, the CCF failure rates computed from the failure rates obtained from the INL failure data software associated with EPIX data (RADS), and using the alpha factors output by the CCF database are not consistent with observed system failure rates, then the prior used in the CCF database should be reviewed for applicability to the system of interest and if necessary a new, informed, system-specific prior should be developed.

In the past analysts have focused on the nature of the events stored in the CCF database as the primary contributor to unrealistic results. Specifically, these analysts propose and are currently using an *ad hoc* screening of events from the database that do not appear applicable at the plant for which the calculations are being performed. This is an error-prone approach to resolving the problem. First, the details of the original events may be too poorly reported to judge accurately whether a past event at another plant is applicable now and in the future at a different plant. Also, when screening events that do not appear applicable to a given plant, it is necessary to address both the independent and common cause events in the database at the same time. This is necessary so that the screening process affects both the numerator and denominator in the alpha factor calculation concurrently. Using the "remove event" command, the CCF database software only allows the user to screen events affecting the numerator, not the denominator. Analysts that use the screening technique to 'improve' or 'fit' CCF events to match plant-specific experience and operating philosophy are guaranteed to reduce the resulting CCF alpha factors since only the numerator is affected (i.e., reduced).

Therefore, if an analyst desires to model the improvements in reliability in both the CCF and total failure probability of the equipment, the most appropriate method is to filter (not screen) the data in the CCF database by date, which affects the counts of both the numerator and the denominator. It should be noted again that the alpha factor is a ratio. That is, when more recent data is used, both the numerator and denominator should decrease.

An internal INL demonstration study of initiating event fault tree methods was performed using the recommended approach for data evaluation. The resulting component failure rate data were collected for and used in a generic component cooling water system model. This model produced a system failure frequency result of 7.9E-4 failures per year. The predicted frequency of 7.9E-4 failures per year is for a system having three pump trains and two heat exchanger trains. The system was assumed to have a 1-of-3 pump success requirement half the time, a 2-of-3 pump success requirement half the time, and a 1-of-2 heat exchanger success requirement all the time. Assuming system failure events are Poisson-distributed with characteristic rate 7.9E-4 per year, the probability of seeing zero failure events over the operational exposure represented in Table 3-3 is about 0.37. This result is compatible with the observation that no such system failures have occurred in the system operating history that generated the failure rate information used in the study. About 80 percent of the predicted system failure frequency resulted from common cause failure (CCF) events. The pump and heat exchanger failure rate data used in this example are shown in Table 3-3. The pump and heat exchanger failure rates were extracted from the EPIX database. The total failure rates (λ_H, λ_P) are based on a sufficient number of failure events to provide reasonable confidence in their values. The alpha factors were extracted from the NRC CCF database with no observed system level component cooling water CCF events, and are therefore largely determined by the priors used in the CCF database.

Table 3-3
Failure Rates and Alpha Factors for Component Cooling Water System Components.

Parameter	Description	Mean	Alpha Factor	Distribution
λ_H	CCW heat exchanger failure rate	3.68E-7/hr		Gamma (8.50, 2.3E+7)
$\acute{\alpha}_{H21}$	Alpha 1 for 2 component group		0.978772	Beta (24.7, 0.535)
$\acute{\alpha}_{H22}$	Alpha 2 for 2 component group		0.021228	Beta (0.535, 24.7)
λ_P	CCW pump failure to run rate	2.58E-6/hr		Gamma (25.5, 9.9E+6)
$\acute{\alpha}_{P21}$	Alpha 1 for 2 component group		0.991912	Beta (56.4, 0.46)
$\acute{\alpha}_{P22}$	Alpha 2 for 2 component group		0.008080	Beta (0.46, 56.4)
$\acute{\alpha}_{P31}$	Alpha 1 for 3 component group		0.986713	Beta (84.1, 1.13)
$\acute{\alpha}_{P32}$	Alpha 2 for 3 component group		0.0101	Beta (0.865, 84.4)
$\acute{\alpha}_{P33}$	Alpha 3 for 3 component group		0.00314	Beta (0.268, 85.1)

1 This table is shown as an example of realistic data obtained from performing the recommended screening steps identified above.

The impact of this revised CCF approach was examined using the closed-loop cooling water system example model presented in Appendix D. Appendix D, Table D-2 shows the original basic event data and the revised data using the INL data described above. The data changes were based on applying the independent failure rates and alpha-factors shown in Table 3-3 above instead of the previous CCF factors used in the example. Table D-3 presents the revised cutsets. The impact of implementing these data changes reduces the calculated initiating event frequency from 3.3E-3 per year to 7.9E-4 per year. This represents more than a factor of four reduction in the calculated support system initiating event frequency.

Service Water Systems

One problem with support system initiating events is the issue of transient degradation of service water quality. Historical experience shows that transient degradation of water quality occurs sporadically and can be severe. Environmental phenomena that affect service water quality can significantly increase component failure rates and common cause factors over their nominal values. Averaging the water quality over a yearly basis will show only a small degradation, which is not sufficient to produce the effects on service water that have been seen in historical experience. Degraded water quality is plant specific. Reports of system failure due to degraded water quality are included in the generic data bases, but are commonly averaged in with other nominal operating data. Service water degradation has been shown to occur due to ice, seaweed, sea grass, and fish runs. Because these phenomena are plant specific, they should be quantified on a plant specific basis. Because of their short duration and severe affects, they should be modeled with separate common cause factors and split fractions for yearly exposure times.

Alpha Factor Conservatisms / Zero Demand Failures

As noted in Section 2.3.2, a recent change to the INL CCF database provides the capability to calculate CCF parameters for systems for which there are no recorded historical events. Prior to

September 2008, this has been treated as an error condition in the database. For these systems the CCF database now uses the independent failure event counts and related operational history to perform a Bayesian update of the CCF database prior, and will produce alpha factor results that are system-specific. The system-specific results output by the CCF database program are strongly influenced by the database prior in cases where the operational history recorded for the system of interest is small compared to the total operational history contained in the database. As of this writing, additional steps are under consideration for future research, such as the elimination of records that that represent degraded components (as opposed to failed components) and unavailability events.

Events Added for Long Mission Times

Post-initiating event response fault trees typically modeling a 24-hour mission time are often used as the starting point for the development of a support system initiating event fault tree. When the running train mission time is extended from 24-hours to a reactor critical year, consideration should be given to events that may have been screened out due to the short initial mission time. For example, heat exchanger plugging may have been assessed as negligible in a 24-hour mission time but could be significant over the course of a year.

Repair Data

Plant-specific mean time to repair components modeled in the standby train should be incorporated into a support system initiating event model if it is expected that the mean time to repair is more than 24-hours. Justification of the use of a generic 24-hour mission time is presented in Section 2.3.2. Mean time to repair data is needed to establish the mission time of standby trains.

Data Formulas

Care needs to be taken in the selection of formulas used for the basic events in the support system initiating event fault trees. The ASME PRA Standard supporting requirement IE-C7 relates to this issue. It was observed that some older PRAs used the following formula to calculate the unavailability for a failure to run event:

$$u = 1 - \exp(-f * t_m)$$

Where: u = basic event point estimate probability of failure

f = failure rate

t_m = mission time

This failure model effectively "caps" the maximum failure at 1.0 per year. This is theoretically incorrect as a system could potentially fail multiple times in a one year period. This was addressed by changing the failure model to the following:

$$\text{Frequency} = f * t_m$$

In one example case identified during the review, this change in formula resulted in an increase in the initiating event frequency by approximately 200%. The pump fails to run data were then reviewed and screened. The Maintenance Rule database was reviewed for pump events and the failure rate recalculated based on actual pump failures. These modifications resulted in a more accurate model with an overall reduction of the initiating event frequency by 7%.

3.3.4 Checking Results

When fault tree analysis is used to develop a support system initiating event frequency, it is necessary to compare the plant specific results with generic results from historical experience per ASME PRA Standard supporting requirement IE-C10. This section shows representative frequencies for typical support system initiating events from U.S. operational experience and discusses the limits of historical experience. It is useful to understand the limits of accumulated nuclear operational experience and how it affects the uncertainty in one's estimates of support system initiating event frequencies from plant specific analysis.

NUREG/CR-5750 [8] is a recent tabulation of reactor experience and initiating event frequencies. Based on the list of operating reactors and the reactor year data in NUREG/CR-5750, Table 3-4 was developed to show the total number of critical years of reactor operating experience. The page and table references in Table 3-4 refer to pages and tables in NUREG/CR-5750.

Table 3-4
Accumulated Experience in US Reactor Industry

	PWR Years	**BWR Years**	**Total**
Critical reactor years, in time period 1969-1997 (Page 10)	1019	525	1544
No. operating reactors as of 2004 (Table H-3)	69	34	103
Critical reactor years from 1998-2004 (assuming capacity factor of .8 from Page H-10)	386	190	576
Total Critical Years in time period 1969-2004	1405	715	2120

Table 3-5 shows the expected number of occurrences and the probability of having observed at least one event, assuming the event was applicable to all reactors in the U.S. for varying annual frequencies assuming 2000 reactor years of experience. The probabilities of observance in Table 3-5 are developed from a simple Poisson equation.

Table 3-5
Expected Occurrence Rate and Probability of Observation

Annual Frequency of Initiator (Per reactor year)	Expected Number of Occurrences in 2000 reactor critical years	Chance of observing one or more events in 2000 reactor years
1E-4	0.2	18%
5E-4	1	63%
1E-3	2	86%
5E-3	10	99.9%
1E-2	20	99.9%

Table 3-5 indicates that a support system initiating event with an expected frequency of 5E-3 per year is likely to have occurred in the US nuclear industry, even if the entire plant population is not susceptible to the support system initiating event. If the expected frequency of a support system initiating event is 1E-2 or greater, then it is very likely that multiple events of this type would have been observed in historical experience. For support system initiating events in the range of 1E-3 to 5E-4, one or maybe two events could have been expected to be observed. An initiator with an annual frequency of 5E-4 or less may not have occurred to date in the US nuclear experience. If a plant specific reliability evaluation results in a frequency less than 5E-4, it is not possible to validate that result from historical experience. Therefore, analysis for support system initiating events with projected frequencies less than 5E-4 must be of complete scope and content, not over-credit recovery, and accurately represent the actual system and its operation, because the results must be taken on their own. In this case it is not possible to compare the result to historical experience. This can be the case for Loss of All Service Water as discussed below.

NUREG/CR-5750 develops and calculates initiating event frequencies for typical support system initiating event, based on a compilation of experience from 1987-1995, and was the most recent generic data available when this report was first written [14]. Table 3-6 identifies the mean frequency, 5th percentile and the 95th percentile for five of the most common support system initiating events included in NUREG/CR-5750. The frequency estimates for the Initial Plant Fault (IPF) categories from Table D-12 were used.

NUREG/CR-6928 [19] was published in 2007, and it develops and calculates initiating event frequencies for typical support system initiating event based on a compilation of experience from 1998-2002. A column was added to Table 3-6 to list the mean frequency from NUREG/CR-6928 Table 8-1 for comparison purposes. This comparison shows the more recent experience is relatively close to the earlier data from NUREG/CR-5750.

Table 3-6
Initiator Frequencies from NUREG/CR-5750 and NUREG/CR-6928

Description	NUREG/CR-6928 Rounded Mean Frequency[3] (per year)	NUREG/CR-5750 Mean Frequency (per year)	5750 5^{th} Percentile (per year)	5750 95th Percentile (per year)	5750 Number of Observed Events 1987-1995	Expected number of Events based on 2120 years experience[4]
Loss of Vital Medium Voltage AC Bus (600 < V <10 kV)	Note 3	1.4E-2	8.0E-3	2.2E-2	10	30
Loss of Instrument or Control Air System (BWR)	1.0E-2	1.3E-2	3.9E-3	2.9E-2	13	91
Loss of Instrument or Control Air System (PWR)	1.0E-2	5.8E-3	1.8E-3	1.3E-2	13	82
Loss of Vital Low Voltage AC Bus (< 600 V)	Note 3	2.1E-3	2.4E-4	5.4E-3	1	4
Loss of Vital DC Bus	1.2E-3	6.9E-4	2.7E-6	2.6E-3	0	77% chance of an event

[1] Expected number of events has been adjusted based on the number of BWRs.
[2] Expected number of events has been adjusted based on the number of PWRs.
[3] Data from the rounded mean column of NUREG/CR-6928 Table 8-1; this data did not distinguish between voltage on loss of a vital AC bus, and only shows a 9.0E-3 per reactor critical year as the initiator frequency of loss of vital AC bus.
[4] 2120 reactor critical years from Table 3-4 of this report.

Total Loss of Service Water	4.0E-4 for Total Loss of Emergency Service Water or Total Loss of Component Cooling Water	3.2E-4	1.3E-6	1.2E-3	0	50% chance of an event

The following observations can be made from Table 3-6.

Loss of a Medium Voltage AC bus and Loss of Instrument Air have occurred several times. Using the 5th percentile values of the uncertainty range and considering the number of reactor years indicates these events would have been expected to be observed. The historical data base provides a reasonable collection of knowledge for development of a generic frequency, or comparison of a plant specific frequency. Use of experience models for the development of support system initiating event frequency is warranted provided plant-specific features (e.g., number of trains) do not preclude the applicability of the data.

Loss of a Low Voltage AC bus occurred once during the reporting period and may be expected to have occurred a few times in the total industry experience. Using the 95th percentile value of 5E-3 per year, we would have expected to see several of these events. Using the 5th percentile value of 2E-4 per year, the event would not have been expected to be observed. This event frequency is difficult to quantify, because only one event occurred in the reporting period. An updated search of the historical experience would provide a better data base for frequency calculation.

Loss of a DC bus and complete loss of Service Water are rare events as evidenced by a lack of event occurrences during the NUREG/CR-5750 observation period. Assuming all reactor operation to date is applicable to this event, they would not necessarily be expected to have occurred in the total U.S. nuclear experience. The values for the support system initiating event frequencies indicate it is recommended to develop plant specific reliability models for these events.

3.4 Model Incorporation (Addressing Dependencies)

The two recommended methods for incorporating support system initiating events into a PRA are the explicit event approach and the point estimate approach, for the reasons described in Section 2.3.2. Additionally the multiplier approach/method can be used. A short description of these approaches is summarized below, along with considerations regarding usage. The method for developing support system initiating event fault trees for each of these methods is presented in Section 3.3. The topic of model incorporation is significant for support system initiating events, because the model method and the approach to incorporation will affect the development of the dependencies between initiator and post-initiator systems.

As discussed in Section 2.3.4, dependencies are a concern for any of the modeling methods chosen. Support system dependencies should capture sufficient detail and scope of systems that an accurate initiating event frequency can be calculated. However, if the dependency modeling is taken too far, it could overstate the impact of systems already modeled. The recommended method to address dependencies is to quantify the post-initiator mission fault tree, and review the importance measures to determine which dependencies to include in the SSIE tree. Section 3 of this report describes that the candidate support system initiating events can be reviewed against the list of initiating events developed in the PRA. In some cases, the candidate support system initiating events are within the boundary of an initiating event that is already modeled. In these cases, the boundary conditions of the initiating event are noted as the basis for removing the candidate support system initiating event from further consideration. This approach requires analyst judgment and numerical tests can be employed to support determination of the inputs to include.

The real issue in the review of the cutsets is to capture failure events that could also impact other systems. It is difficult to define numerical criteria that could accurately account for the fact that some second order failures for the SSIE could also have a first or second order effect on other systems. The only way to capture all dependencies would be to expand all of the dependencies in the initiating event fault tree until all interfaces with support systems are included or are otherwise distinctly modeled in another initiating event that is separately represented in the model. That would be equivalent to the “Detailed Explicit Event Method” from Table 3-2. On the other hand, the cutset review could be utilized to determine what makes sense for including in a “Limited Explicit Event Method” from Table 3-2. So rather than numerical criteria, the focus of the review should be on determining what dependencies need to be included in the “Limited Explicit Event Method” approach – not because they are important for this SSIE, but because the review determined that they could also impact other systems.

3.4.1 Explicit Event Approach

In the explicit event approach, a support system initiating event fault tree (or cutsets produced by the support system initiating event fault tree) are linked directly into the appropriate PRA event trees. In this example, dependency could be ensured by providing the support system initiating event development under an OR gate at the top of the post-initiator system model. This is a good practice in order to ensure if the post-initiator models were linked the dependency would be captured. An example of a typical explicit event model that would be used in this approach is provided in Appendix C.

3.4.2 Point Estimate Approach

In this approach, a single basic event is added to the PRA to model the support system initiating event. The point estimate could be quantified using historical data or it could be quantified based on a support system initiating event fault tree. This is sometimes called the two-stage approach. In the first stage, the initiating event frequency is updated to reflect changes in configuration such as taking a pump out of service for maintenance. When a support system initiating fault tree model is used, this is a relatively simple change. If historical data have been used, then a data change such as using the upper bound may be needed. The second stage is to take the updated support system initiating event frequency and apply it to the PRA model. In this approach, the basic event used to represent the support system initiating event is typically included in the post-initiator systems model development in order to ensure if the post-initiator models were linked the dependency would be captured. An example of a typical point estimate model that would be used in this is provided in Appendix D.

3.4.3 Multiplier Approach

An example of a typical multiplier model that would use this approach is provided in Appendix E.

3.5 Uncertainty and Importance

3.5.1 Uncertainty

Sources of uncertainty need to be identified during the support system initiating event modeling process, similar to all other PRA elements [20].

3.5.2 Importance

The whole concept of explicit modeling of support systems as both initiating events and as post-initiator system models is to ensure that components that affect either plant trip as well as post-initiator plant response produce the appropriate level of calculated risk significance.

As described in Section 2.3.5, this report does <u>not</u> recommend calculating importance measures for support system initiating events based on current methods available. Several challenges exist to understand and properly address importance measures for SSIEs. Among these are:

- Consistency of computation. Importance measures for mitigating events are calculated as ratios using the computed risk with an event value set to either 1 or 0 and the baseline risk of the PRA model with the same event set to its nominal value. In the case of SSIEs, the calculation is different because the mission time has either an 8760 hour or 365 day component to it. Thus, an arguably non-rare event has been introduced into the importance calculation. In addition, since initiating events are frequencies, they do not have a value of 1 as an upper bound, as in the case of mitigating events. Only the Risk-Reduction measure may be considered, as zeroing out the initiating event (or portions thereof) eliminates mission time issues; however there are other issues associated with Risk-Reduction as noted below in consistency of treatment with other plant systems.
- Consistency of treatment of plant systems. There are many plant components and systems that are not SSIEs whose failure can cause a reactor trip. However, these systems are only considered for event mitigation. For example, if the MSIVs in a BWR fail closed, a reactor trip will result. Since MSIV closure is not an SSIE, annualized importance measures are not calculated. This calls into question the need to calculate importance measures for SSIEs or how such calculations could be done consistently throughout the PRA model.

Recommendation: This is an area for potential future research. A consensus needs to be established concerning the definition of SSIE importance measures to ensure meaningful results.

4 CONSIDERATIONS BASED ON SYSTEM TYPE

This section describes modeling considerations specific to different types of systems, such as differences between electrical and mechanical systems, and water quality issues related to service water systems. Fault trees and associated results for example systems are documented in Appendices C, D, and E.

4.1 Loss of Electrical Bus

There appear to be few special considerations for electrical bus support system initiators. There are several reasons for this. Electrical buses are in continuous use, therefore a fault is almost immediately known. When in normal operation, there are no active components associated with a bus. As a result, there are no potential common cause failures that are associated with the failure of a bus presuming that such redundant electrical busses are in separate compartments and not subject to the same internal hazard such as high-energy break or spatial events such as may occur during maintenance. However, common cause failures can contribute to the failure of a fast bus transfer, circuit breaker re-alignments, or other restoration/recovery actions.

As bus failures are fairly infrequent, there is little actual failure data. It is therefore presumed that data screening would likely not yield a benefit as could be the case with more frequent active failures.

4.2 Loss of Service Water System

Service water systems have several issues to be considered during the development of support system initiating event models as summarized below.

Consideration #1. Definition of loss of service water

Discussion: The loss of cooling water initiator definition can be constructed around the function that causes a plant trip that cannot be rectified by starting of alternate systems or it can be constructed around failure of cooling to a defined set of safety related functions (e.g., loss of service water to the component cooling water (CCW) heat exchangers). For example, service water typically cools balance of plant loads that will lead to a plant trip if cooling is lost. These loads are typically isolated from or bypassed by auto-starting standby/emergency systems. If the initiator is defined around the plant trip then failure of only the normally operating system is considered the initiating event. If the initiating event definition is constructed around the safety related cooling function both the normally operating system and the ‘emergency’ standby system must fail to be considered an initiating event and must be included in the initiating event fault tree.

Recommendation: It is recommended the initiator is defined around the plant trip, such that failure of only the normally operating system is considered the initiating event. In this case the normal cooling function of the system is contained in the initiating event development and the 'emergency' standby system support functions are developed in the event tree sequences.

Consideration #2. Water quality issues relating to loss of service water

Discussion: When developing initiating event fault trees for loss of service water system (LOSWS), a question immediately arises concerning the modeling of what are termed environmental events. These events can include storm surge impacts (excess debris accumulation in the intake structure) or other naturally occurring events such as fish runs, grass attacks, algae blooms, frazzle ice, etc. collecting in the circulating water and SWS intake area(s). These infrequent events have been observed to clog or fail inlet traveling screens and/or strainers for both the circulating water pumps and the Service Water System, resulting in plant trips or manual shutdowns. In a few cases, the events actually degraded the Essential Service Water (ESW) cooled by the SWS, although not to the extent such that ESW was totally unavailable. Also, when such events occur, they can affect many/all of the inlet strainers and/or traveling screens. Therefore, the common-cause failure (CCF) impacts from these environmental events can be significant.

To model environmental event impacts in the LOSWS initiating event fault tree, two different approaches have been identified. One approach is to develop a separate path in the fault tree to cover environmental-event-caused plant trips with resulting failures of the SWS, and to quantify this contribution based on historical data. This approach is outlined below:

1. Obtain plant trips caused by environmental event impacts on the circulating water system and/or SWS from the initiating event database. Analyze these data for trends and determine whether there are significant plant-specific differences. The result from this step would be a current industry average (or a plant-specific average, if applicable) frequency for circulating water system and/or SWS environmental events causing a plant trip. It is expected that the industry average frequency from this type of analysis will be approximately 3E-2/reactor critical year (rcry).
2. Use this same set of data to determine the probability of the SWS failing, given a plant trip from such an environmental event. Depending upon the interpretation of one or more events, there was at least one and possibly two such plant trips resulting in failure of the SWS. Assuming one failure, this probability is then approximately 0.05. (An alternative approach might be to model this probability with a human reliability analysis.)
3. Potential credit for recovery, given a plant trip with total loss of the SWS, could then be included. This might involve clearing of the traveling screen assemblies or the SWS strainers.

Another approach is to model the environmental event impacts within the LOSWS fault tree without adding a separate path within the tree. This alternative approach is described below:

1. Each LOSWS IE fault tree will generally include debris removal assemblies (trash racks or traveling screen assemblies (TSAs)) upstream of the SWS pumps and strainers (STRs) downstream of the pumps. To model environmental event impacts on the TSAs and STRs, failure rates under these conditions would be needed, and perhaps could be generated from the Equipment Performance and Information Exchange System (EPIX) data. The data would include only SWS and circulating water system components and associated failures. Most of the failures are the result of environmental events, so the resulting failure rates will appropriately include the effects of such events. Based on a preliminary review of EPIX data for the SWS and circulating water system TSAs and STRs, the plugging failure rates are 5E-6/h and 7E-6/h, respectively. Converting to a per reactor critical year basis, these two plugging rates are 3.9E-2/rcry and 5.5E-2/rcry, respectively (assuming a 90% factor for critical operations).
2. Failure of the remaining TSAs and/or STRs could be modeled using the CCF methodology, but with alpha factors generated from only environmental events impacting the SWS and/or circulating water system. (This recommendation assumes the alpha factors are higher for such events, compared with non-environmental events. If this assumption is not correct, then use all of the CCF data for these systems.) The alpha factor for a 2-component system using this approach would probably lie within the range 0.04 to 0.15.
3. Recovery of the TSAs and/or STRs could also be modeled. This recovery model could be developed based on observed recoveries in the Licensee Event Reports (LERs). This recovery event would probably look similar to step 3 in the first method described and is a potential opportunity for future research.

There are pluses and minuses to each approach. The first approach allows for plant-specific differences in plant trip frequencies to be identified (some plants appear to experience more environmental events than others). However, it would be difficult to account for plant-specific differences in the conditional probability of failing the SWS, given a plant trip. This is especially true for plants that have a backup ESW that takes over once the plant trips and SWS is unavailable. This is also true for plants with two diverse intake paths for the SWS (or ESW).

The second approach makes use of the LOSWS IE fault tree without structure changes. Also, plant-specific differences in SWS/ESW design (affecting the conditional probability of loss of the SWS/ESW given a failure in a TSA or STR) would be automatically handled within the fault tree. Recoveries (step 3) could then be developed based on the dominant failure modes observed in the cutsets. However, this approach depends upon the quality and quantity of the data within EPIX and the CCF database. Some additional work will be necessary to add the TSA and STR data from EPIX to RADS and to review the appropriate CCF events and may be considered as potential future research.

The bottom line is that water quality issues are known to affect service water, and these should be addressed in the support system initiating event model by explicitly modeling a separate basic event. The data for this event may be seasonal, would be likely be an undeveloped event based on generic data for similar plants, but the generic data currently requires development.

Consideration #3.   Coupling of spatially separated suction sources

Discussion: Coupling mechanisms like wind blown debris or flooding that fails multiple different suction sources should be considered (e.g., cooling tower and lake) <u>if</u> data are available. However, there may be minimal data and the application may be too complex for inclusion in the PRA models. This is an area for consideration as future research.

Consideration #4.   Modeling of recoveries of strainer and traveling screen plugging

Discussion: Should credit be allowed for backwash or is failure of the backwash implicit in the failure value for the strainer? Is credit for strainer cleaning a function of time to perform this task in relation to time to dependent failures (e.g., RCP seal failure)? Appropriate recovery values depend entirely on the events that determine the failure rate.

4.3 Loss of HVAC

Modeling the loss of switchgear room cooling requires specific considerations not relevant to other support systems. In addition to the general evaluation of the mechanical failure of the system the following must be considered and incorporated.

<u>Room Heat-up Rate</u>. The room heat-up rate is a function of numerous factors; the failure mode of the system (fan failure, damper failure, chiller failure, etc.), equipment heat load (generally constant during plant operation), and ambient temperature (varies by plant site and season). It is best to have actual plant data (one plant surveyed performed a room heatup test by allowing the switchgear room to heat up to its design basis maximum, which was found to take 2 hours. for the 15^{o}F increase above ambient temperature in winter conditions). A benchmarked room heat-up model could also be used if available.

<u>Impact of Heat-up on Equipment</u>. Uncertainty exists regarding the effects on, and the response of, electrical equipment to room heat-up. In switchgear and electrical rooms, it is generally believed that solid-state based components such as battery chargers, inverters, and certain relays are more susceptible to temperature related degradation than other equipment typically located in such rooms. Note that equipment failure would be related to equipment temperature rather than room temperature. This is an important distinction for components that generate a high heat load. Due to the heat loads generated it is possible that ac power transformers may be the first to degrade following a sustained HVAC problem. The order of equipment failure may well play a role in both the initiation and development of any resulting accident sequences. Manufacturers' equipment qualifications for specific components should be consulted.

For mechanical equipment such as pumps and valves, other considerations apply. For example, the heat load for a containment spray pump room would be increased if the system was reconfigured from operation in the injection mode to operation in containment sump recirculation. Thus, the equipment and the specific system function being performed have unique impacts.

Other Impacts of Loss of Ventilation. Some considerations for a loss of HVAC event are not related to heat-up. For example, consideration should be given to the potential build-up of hydrogen in a battery room on loss of battery room ventilation but with a continuing charge.

5
CONCLUSIONS

This project advanced the state-of-the-art in support system initiating event modeling for internal events PRAs during full power operations by identifying and addressing the following key issues.

- **Identification and Definition of Support System Initiating Events –** This report clarified the definition of what constitutes a support system initiating event. (Section 2.1)

    - Treatment of Initiating Event Precursors - While modeling of pre-cursor events as support system initiating events has been commonly practiced, the appropriate and best practice is to model only those losses of support system that lead to reactor trip (with a loss of support systems or trains of systems used for safe shutdown) as support system initiating events (Section 2.3.1).
    - Treatment of Dependencies – The issue of where to trim the support system initiating event models, or what portions to include in the fault tree such as lower level motor control centers is addressed (Section 2.3.4).

- **Modeling Systems with Redundant Trains**. The development of support system initiating event fault trees involves complexities that are not encountered in the development of system models used to mitigate initiating events (where a 24-hour mission time is typical for all trains), including the following issues addressed in this report. (Sections 2.3.2 and 3.3)

    - Modeling Methods – This report recommends using the explicit event method as it provides better visibility on the contributors. Additionally, a point estimate fault tree also provides a valid approach over the error prone multiplier method. This report provides examples for modeling each type of method.

    - Mission Times – This report presents the recommended treatment of the different mission times involved with modeling the running and standby train(s).

        - Inclusion of multiple mission times within the same logic model - with the mission time for the operating/running portions of the fault tree (typically a reactor calendar year) different than for the standby/redundant portions of the system (typically 24-hours).

        - Component specific mission times - defining unique basic events with a year long mission period that are used only in the initiating event fault tree, as accomplished in the explicit event method or the point-estimate method.

- Standby component mission time – mission time should be determined by the mean-time-to-repair (MTTR) of the running component that failed or the limiting condition of operation (LCO) for that component. This report provides justification of using a 24-hour mission time for standby components based on mean times to repair.

- **Updating and Incorporating Common Cause Failure Data**. Current models and data for common cause failure (CCF) of operating components are often based on minimal data that has been evaluated and developed for use in a post-initiator, 24-hour mission time model (which typically involves some conservatism). While the conservatism may be acceptable for a 24-hour mission time, extrapolation of this data to model common cause failure frequencies for the year-long mission time used in initiating event modeling often results in frequencies exceeding those observed in industry experience. (Section 2.3.3)

  - Common Cause Failure Data Sources – This report identified issues in older data sources [9, 10] potentially introducing conservatism in common-cause failure modeling of support system initiating events.

  - Filtering Common Cause Data - the ability to filter the records in the INL CCF database [16] based on date range is an important feature to be emphasized. Note that this is not the same thing as screening using the "remove event" command, which removes failures from the numerator but not the denominator of CCF factor calculations. Analysts should filter the data to use only the data collected after the period of full implementation of the maintenance rule, from 1995 when determining alpha factors and failure rates.

  - Zero Events CCF Data - as a result of this research effort, the INL CCF database [16] software has been modified to produce common cause alpha factor data for systems that have no (zero) historical failures. Prior to September 2008, this had been treated as an error condition in the database. Now for these systems the CCF database [16] uses the independent failure event counts and related operational history to perform a Bayesian update of the CCF database prior, and will produce alpha factors that system-specific.

  - Service Water System Water Quality – service water intake structures often have a common cause failure effect, but the frequency of failures may be affected more by environmental conditions such as detritus or frazzle ice than by hardware failures. The development of data for these conditions is an open issue for consideration in future research. The first step is to include a separate event in the PRA for service water intake failures in the PRA.

  - Importance Measures - The final issue addressed in this report is importance measures. This report recommends excluding support system initiating events from the calculation of importance measures based on issues related to consistency of computation, and consistency of treatment with other plant systems.

- Checking Initiating Event Frequency Results – developed historical data for use in checking the initiating event frequencies produced by support system initiating event fault trees, checking that they are within the range of observed industry experience.

The methods and considerations presented in this report will continue to be examined and tested as the commercial power industry conducts model updates and associated Regulatory Guide 1.200 peer reviews, and then expands PRA models into areas such as low power and shutdown. Simultaneously, the U.S. NRC and the national laboratories will review and update the SPAR models. The goal for support system initiating event modeling remains to develop realistic, best-estimate models of support system failures. Specifically, to quantify initiating event frequencies that comport with industry experience (based on a paucity of data due to the highly reliable nature of these systems), to integrate these initiating event models with the rest of the PRA such that the dependencies are captured, and to develop importance measures that realistically reflect the importance of components to plant safety.

This section presents the conclusions of this report, consisting of a summary of the current state-of-the-art in support system modeling (Section 5.1), along with topics where future research is being considered (Section 5.2).

5.1 State-of-the-Art

This project advanced the state-of-the-art in support system initiating event modeling in several areas as listed above. This section provides a more detailed summary of the project, including a list of the recommendations developed, based on the results and insights obtained in accomplishing the project.

This project started by surveying and reviewing several aspects of support system initiating event analysis to develop methods and guidelines for identification and quantification of support system initiating events. A support system initiating event is defined as a component or system failure in a support system that:

- results in a failure of a front line system which in turn leads to a reactor trip, and
- potentially affects the performance of one or more systems normally available to respond to the reactor shutdown.

The principal method for identification of support system initiating event is to perform a Failure Modes and Effects Analysis (FMEA) of all normally operating systems in the plant. The FMEA should be performed at the train or sub-train level and can be performed at a coarse level of detail. The candidate support system initiating events must be reviewed and condensed to result in a final list of support system initiating events. The list should be reviewed against support system initiating events from similar plants and, where appropriate, generic industry lists such as presented in Section 2.4.

There are two common approaches for support system initiating event modeling, differing principally in the level of detail in the systems evaluation. Support system initiating event models range from coarse models where a single basic failure event represents the support system initiating event, to a detailed fault tree model for failure of the system which shows individual component failures. The data used for quantification will depend on the level of modeling. Coarse modeling which represents the support system initiating event with a single basic event can use historical industry experience to develop an initiating event frequency. This method will provide an initiating event frequency reflective of industry experience, but provides little consideration of plant specific features, and provides minimal insight into the contributors at a specific plant.

Plant specific system reliability evaluations can derive an overall frequency for support system initiating events and will explicitly include individual contributors and their importance. This approach should use plant-specific failure data, where available, to quantify individual events. The following issues need to be addressed in the plant specific reliability evaluations:

- All important configurations of the system must be modeled unless all configurations can be shown to have the same reliability.
- Common cause failure for all combinations of operating and standby components must be included.
- Generic CCF data must be adjusted to filter events that are not applicable at a plant. CCF evaluation must also assess probability of degraded service water quality due to plant specific environmental factors. Generic CCF factors should be adjusted to account for the mission time in the CCF equations.
- Plant specific calculations for success criteria should be performed rather than relying on licensing based criteria or generic criteria. Success criteria should address variation in ambient temperatures for service water and outside air.
- The method for representing extended mission times should allow derivation of importance factors with the PRA software in use at the plant.
- The PRA software should allow calculation of a frequency for support system initiating event, not a probability. If the software does not allow frequency calculations, and the expected probabilities of basic events is close to 1.0, adjustments must be made as necessary.
- Results of plant specific reliability evaluations should be compared to historical industry experience to validate results. The lower verifiable limit of historical operating experience is in the range of 1E-4 to 5E-4/yr. support system initiating events postulated to have a frequency below this value can not be validated by historical experience. The quality and scope of the models must be adequate to support the results.

This project developed the following list of the recommendations based on the results and insights obtained in accomplishing this project.

- While modeling of pre-cursor events as support system initiating events has been commonly practiced, the appropriate and best practice is to model only those losses of support system that lead to reactor trip (with a loss of support systems or trains of systems used for safe shutdown) as support system initiating events.
- Losses of support system that lead to administrative shutdown due to Technical Specification violation may be considered as low power and shutdown events where transition risk may be important, but are excluded from consideration as an initiating event as described in Section 2.3.1.
- Modeling methods - This report provides a critical examination of the major modeling methods, such as the explicit event, point estimate fault tree, and multiplier method. Of these, the explicit event method is recommended as a result of this effort because one can easily see the basic event contributions to the initiating event total frequency. Visibility improves the traceability and defensibility of the model, as one can easily see whether the applied recovery and mitigation terms are appropriate. It should be noted, however, that both the explicit event and point-estimate fault tree methods provide the ability to define unique basic events with a year long mission time that are used only in the initiating event fault tree, and each provides better results than the multiplier method. The third method, the multiplier method violates the rare-event approximation due to the presence of a large (typically 365 day) multiplier in the model (Section 2.3.2).
- Mean time to repair for the standby train - use of a 24-hour mean time to repair in the initiating event fault trees simplifies the modeling while yielding results that are not excessively conservative. Also, use of a 24-hour mean time to repair mission period allows use of the same value in every model. Use of the Limiting Condition for Operation periods is also a viable option that typically yields somewhat more conservative results. These times vary from plant-to-plant and from component-to-component (Section 2,3.2)
- Common cause data – Section 2.3.3 describes the recommendation to filter events used in the calculation of common cause alpha factors, and specifically states to *not* use a screening approach.
- Common cause data – The treatment of systems with zero events is described (Section 2.3.3).
- Checking support system initiating event frequency results – see Section 3.3.4.
- Importance measures - This report recommends excluding support system initiating events from the calculation of importance measures. Only the Risk-Reduction measure may be considered, as zeroing out the initiating event (or portions thereof) provides a valid and often useful indicator of how sensitive the PRA results are to that particular initiating event. There are issues associated with the other importance measures as described in Section 2.3.5.

5.2 Future Research

As support system initiating event model development and application progresses, there are several issues affecting the model worthy of consideration as potential future research. Common cause data is the main area for potential future research, specifically to eliminate conservatisms in the data and to develop representative data for use in modeling such that when support system initiating event fault trees are developed the associated frequencies are within the bounds of observed historical data. Specific areas that should be considered are listed below.

- Zero Events CCF Data. In addition to providing the capability to calculate CCF parameters for systems for which there are no recorded historical events the INL CCF database, additional steps such as the elimination of records that that represent degraded components (as opposed to failed components) and unavailability events. This area also includes the possibility of development of improved prior distributions to support Bayesian updating.
- Importance Measures. Another opportunity for future research is importance measures. This is an area where limited work has been done, primarily by the NRC, and there is a need to examine all of the issues that could be included. Note that Appendix C describing the explicit events method discusses the unavailability method and critiques importance calculations used in the explicit event method.
- Aggregation of Event Importance Measures. Aggregation of event importance measures for events occurring as part of the initiating event as well as the post-initiator (mitigation) portion of the model, as these may have differing but correlated failure modes.
- Conditional Common Cause Modeling. The issue of whether, and how, running component failures modeled in the initiating event should be linked to the common cause failure of mitigating system components is an area for potential future research as described in Section 2.3.2.
- Service Water System Water Quality. In addition to the above, cooling water systems have unique common cause failure considerations. While there is a consensus regarding the common cause modeling of the majority of cooling water system components, intake structures are an exception. This is an open issue that will require further study to resolve. See Section 4.2 for details.

An additional area of potential research is to consider the development of time-phased models. Some have proposed that Markov modeling may be well suited for these types of models. Time-phased models should provide additional clarity on the timing involved such that additional recovery credit may apply to some scenarios.

The final area of research would be to extend the modeling into areas outside of the scope of this report. For example, to develop support system initiating event models for low power and shutdown systems. While there is typically more historical data for a loss of residual heat removal cooling or a loss of a bus during shutdown, there are also additional dependencies between the initiating event and post-initiator response. For example, the initiating event may operator-induced, and this may introduce dependencies with the post-initiating event plant response.

6
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A
ACRONYMS & ABBREVIATIONS

AOV	Air-Operated Valve
ASME	American Society of Mechanical Engineers
BS	Basket Strainer
CA	Compressed Air
CCF	Common Cause Failure
CCW	Component Cooling Water
CDF	Core Damage Frequency
CV	Control Valve or Check Valve
CW	Circulating Water
DC	Direct Current
EPS	Electrical Power System
EPRI	Electric Power Research Institute
ESFAS	Engineered Safety Features Actuation System
IA	Instrument Air
ICW	Intake Cooling Water
IE	Initiating Event
INL	Idaho National Laboratory
Kv	Kilo-volt
LER	Licensee Event Report

LOCA	Loss of Coolant Accident
LOOP	Loss of Offsite Power (sometimes called LOSP)
LOSW	Loss of Service Water
LWR	Light Water Reactor (BWR and PWR)
MOV	Motor-Operated Valve
MSIV	Main Steam Isolation Valve
NEI	Nuclear Energy Institute
NRC	U.S. Nuclear Regulatory Commission
POV	Power-Operated Valve
PORV	Power- (or pilot) Operated Relief Valve
PRA	Probabilistic Risk Assessment (synonymous with PSA in this report)
PSA	Probabilistic Safety Assessment (synonymous with PRA in this report)
PWR	Pressurized Water Reactor
PWROG	Pressurized Water Reactor Owners Group
RG	Regulatory Guide (sometimes called Reg Guide)
RWST	Refueling Water Storage Tank
SI	Safety Injection
SIRWT	Safety Injection and Refueling Water Tank
SSIE	Support System Initiating Event
SW	Service Water
TPCW	Turbine Plant Cooling Water
VDC	Volts - Direct Current

B
SUPPORT SYSTEM INITIATING EVENTS SURVEY

Background

PRA Certification reviews, both by the owner's groups and as part of the ASME process, show there are inconsistencies in the method and quantification of support system initiating events. The biggest concerns are summarized below.

a. Identification of risk-significant systems is being conducted systematically

b. Quantification through fault tree analysis produces a number that is different (higher or lower) than actual experience in the industry.

c. Quantification techniques developed for the 24-hour mission period (where repair or restoration is not possible) may not be suitable for the quantification of initiating event frequencies

d. Common cause failure of redundant components within a system (for the purposes of quantifying initiating event frequencies) is not well understood

Therefore, this project proposes to develop a consistent approach to initiating event selection and quantification that will produce initiating event frequencies consistent with actual reactor industry experience.

Scope

This project only applies only to a Level 1 probabilistic risk assessment (PRA) internal initiating event analysis during full power operations. The tasks developed during this project will keep in mind that the final guideline will be distributed to the industry at large and thus needs to be practical, easily implemented, and based on existing good practices.

System level initiating events are characterized by those systems whose function is necessary to maintain power operations. For these systems, the loss of the *system function* will cause a plant trip, either immediately or in a short time if the system function is not recovered. System failure which does not cause a plant trip, but results in an administrative shutdown must be addressed by this work. Some important aspects of initiating event initiator frequency are listed below:

1. System functions which can be lost by a single failure are relatively straight forward to quantify.

2. For a system with internal redundancy, loss of the total system function is more difficult to quantify and may need to be evaluated analytically.
3. For systems with internal redundancy, the analytical development of the initiating event frequency must consider the possible configurations of the system and the availability of the redundant components in each configuration.
4. For systems with internal redundancy, the analytical development of the initiating event frequency must consider whether the redundant components are started automatically or manually. For manually started components, the analytical development must consider the time lag between the loss of the function and the reactor trip and allow for recovery of system functions by operator actions.

The project consisted of two tasks, summarized below.

Task 1 – Develop guidance and a process to identify system level initiating events.

This task will address potential double counting of initiators through two avenues:

a) A plant may trip because of loss of an AC bus will cause instrumentation failure. The plant also may trip because loss of the same bus will fail instrument air. The loss of the DC should only be counted once.

b) Loss of a DC bus may cause reactor trip. On the event tree, after every reactor trip, the PRA questions DC power. The failures in the fault tree for DC power for the event tree are not necessarily the same as the failures in the fault tree for the initiating event.

Task 2 – Develop guidance and a process to quantify system level initiating events.

The overall objective of this task is to develop a procedure and set of guidelines which will enable the utilities to derive support system initiating event frequencies that are reasonable when compared with the plant experience and the industry experience in general. There are many instances of support system initiating event frequency quantification on systems with redundant trains, which are inconsistent with industry experience. This task will conduct a survey of methods and interview PRA representatives to document their methods. The resultant product is intended to be a consensus procedure. The procedure developed by this work will address the following items:

a) alignment and operability of redundant equipment at the time the first equipment failure

b) the manner in which redundant equipment is started and aligned – auto, manual

c) the time frame available to start redundant equipment

d) appropriate failure rates for running components which are routinely swapped on and offline.

e) assessment of common cause failure between the failed equipment and the standby equipment in the system.

f) The affect of normal plant operation (e.g., preventive maintenance, corrective maintenance, post maintenance testing, operator rounds and others) on the calculated system level initiating event frequency.

g) When to use generic frequencies and when to develop a plant specific fault tree

This questionnaire concerns techniques and methods for identification and quantification of support system initiating events in a Level 1 internal events PRA for full power operation. Attachment A provides background information regarding this project. You have been asked to complete this questionnaire, because you (or your organization) is a supplier of PRA services or has been instrumental in the development of methods for support system initiating event evaluation. In answering this questionnaire, please distinguish between:

a) methods and techniques you have used in past PRAs.

b) methods and techniques you consider promising, but have not yet implemented in a PRA.

SCOPE:

This questionnaire relates to support system initiating events in a Level I internal events PRA for full power operation, which could be:

a) Loss of an electrical system

b) Loss of a cooling water system

c) Loss of an air conditioning or room cooling system

d) Loss of a pneumatic supply system

e) Loss of an instrumentation system

QUESTIONAIRE FOR PRA METHODS SUPPORT SYSTEM INTIATING EVENTS

INTRODUCTION:

This questionnaire concerns techniques and methods for identification and quantification of support system initiating events (SSIE) in a Level 1 internal events PRA for full power operation. Attachment A provides background information regarding this project. You have been asked to complete this questionnaire, because you (or your organization) is a supplier of PRA services or has been instrumental in the development of methods for SSIE evaluation. In answering this questionnaire, please distinguish between:

a) methods and techniques you have used in past PRAs.

b) methods and techniques you consider promising, but have not yet implemented in a PRA.

SCOPE:

This questionnaire relates to support system initiating events in a Level I internal events PRA for full power operation, which could be:

a) Loss of an electrical system

b) Loss of a cooling water system

c) Loss of an air conditioning or room cooling system

d) Loss of a pneumatic supply system

e) Loss of an instrumentation system

SURVEY QUESTIONS:

1. Please list any support system you consider for SSIE which are not listed in the scope above.
2. Please select all of the methods used in your PRAs to select a system as an SSIE.
    a. Failure Modes and Effects Analysis
    b. Master Logic Diagram
    c. List of Initiating Events from Other Plants
    d. Other (Please Identify)
3. Provide a definition of Support System Initiating Event? Please address the following aspects:

    a. Time relationship between the support system failure and the reactor trip or administrative shutdown.

b. Are administrative reactor shutdowns (voluntary and Tech Spec forced) the same as a forced reactor trip for the purpose of identifying SSIE.

4. If a single train of a system will cause an SSIE (such as loss of DC power), is it necessary to consider loss of multiple trains of the system caused by common cause failure, if the plant response to the CCF initiator is different than the single initiator. What are appropriate data sources for CCF initiating event quantification?

5. What steps are taken to ensure that failure combinations which result in a support system initiating event are included in only one initiating event even though they may lead to losses of multiple support systems? For example, loss of an AC bus may lead to plant trip due to instrumentation failure as well as loss of instrument air. The loss of the bus should only be included for one support system initiating event.

6. Given the following conditions – (1) Loss of Service Water is an initiating event at a plant, (2) In the event tree for turbine trip, an event questions Loss of Service Water, and (3) The failure sequence is transferred to the Loss of Service Water event tree. What precautions (if any) are necessary to ensure the transferring sequence is unique from the initiator sequence. If the sequences are not unique, how do you prevent double counting of Service Water failures?

7. There are two common practices for developing an initiating event frequency for SSIE; use of historical experience or development of a plant specific reliability model of the system. Please discuss under what conditions each method should be used. Relate this guidance to the following:

   a. The amount of operating experience available at the plant and in the industry

   b. The expected frequency of the event from historical experience

   c. The complexity of design of the plant system versus the common industry design.

   d. Does your SSIE process reconcile the initiating event frequency calculated from a fault tree model with the plant or industry observed experience?

   e. In what instances would it be considered acceptable to represent the support system initiating event as a single event rather than linking the entire support system initiating event fault tree in the solution of the accident sequences?

8. For support systems which have multiple operating configurations, how are these configurations addressed in the SSIE modeling?

9. Often, when a fault tree is developed for an SSIE frequency, the answer is significantly different than historical experience. Do you believe this is due to:

   a. Use of inappropriate failure rates for running components

   b. Omission of repair

   c. Omission of important failure combination or mechanisms, not captured by the fault tree

   d. Other

   How do you recommend coping with these shortcomings?

10. In a system with abundant redundancy (such as 6 pump service water system), how do you account for common cause failures (CCF) between the running equipment and the standby equipment? What mission time do you use for the CCF fail to run.
11. Technical Specifications often require that after a failure in one redundancy, a redundant pump must be shown to be "operable". If the redundant pump is started and run, at what point do you decide the "pump has been shown to be operable" and thus free from the failure cause that failed the first pump.
12. For development of a plant specific reliability analysis please discuss how you handle the following:
    a. In a system with redundant trains, change of state of the second train.
    b. Repair of failed components prior to reactor trip.
    c. Adjustment of a component failure rate to account for degraded components that are voluntarily taken out of service for repair.
    d. CCF of running components
    e. CCF of running and standby components
    f. Pipe leaks, heat exchanger leaks, and other passive failures.
    g. How is the influence of normal plant activity to discovering imminent failures in running systems included in the quantification of support system initiating events (e.g., preventive maintenance, corrective maintenance, post maintenance testing, operator rounds and status checklists, etc.)
13. Please provide any other discussion of support system initiating event analysis that you believe would be helpful in an industry guideline on the subject.

C
SSIE MODELING USING EXPLICIT EVENT METHOD

C.1 Introduction

Initiating event (IE) frequencies for nuclear industry probabilistic risk assessments (PRAs) and for the Nuclear Regulatory Commission (NRC) standardized plant analysis risk (SPAR) models are generally based on data collection efforts such as Reference C-1. For rare, but potentially high consequence initiators representing the failure of support systems, this approach has a number of shortcomings. First, there are no system failure events in the available data sets. For these initiators the resulting initiating event frequency is typically estimated using a Jeffreys prior, which amounts to one-half system failure during the data collection period. The amount of conservatism in this approach is unknown. Second, the frequency of these initiators might reasonably be expected to vary from plant to plant due to design variations and environmental factors. The data collection effort cannot estimate the resulting plant-to-plant variability in initiator frequency using such sparse data. Third, the importance with respect to core damage of components in these systems is underestimated when the PRAs and SPAR models represent only the event mitigation aspect of components in these systems, and do not include the event initiation contribution.

Another point in favor of calculating the system failure rates from suitable models is that, while system failure events might be too rare to appear in the data sets, component failure events are not. Component failures are relatively common, and the resulting rates are relatively well known. Therefore what is needed is a suitable method for calculating the system failure rate from the relatively well known component failure rates.

The possible ways of calculating the system failure rate for support systems include discrete event simulation, Markov models, and fault tree methods. Simulation and Markov methods may be suitable for calculating failure rates, but the software required is not currently part of the existing software packages used in industry PRAs or SPAR models. Markov methods also become unmanageable for systems as complex as many of those in question. Both simulation and Markov modeling do have value for benchmarking the fault tree methods that are considered most suitable for this purpose (Ref. C-2). Fault tree methods can be integrated into the existing PRAs and SPAR models using the existing software suites (CAFTA, etc.). Of the possible fault tree approaches there are three that either regularly appear in the literature, or are used in existing industry PRAs/SPAR models. These methods do not have proper names, but can be described as the unavailability method (Refs. C-3, C-4), the multiplier method, and the explicit event method. The unavailability method provides the most rigorous approach to the problem, but the existing quantification codes do not, at present, have the algorithms required to determine the system failure rate from a system unavailability model. The last two methods, multiplier and explicit event, each have their advocates in industry. The two methods are roughly equivalent, each with some advantages over the other. The purpose of this paper is to demonstrate the latter option, the explicit event method (and not to evaluate the relative merits of each).

There are two possible ways to apply the explicit event method. The first uses an IE fault tree to estimate the subject system failure frequency. The resulting failure frequency is then used as a point estimate input to an existing PRA. The second option takes the cutsets from the IE fault tree, instead of just the point value, and inserts them into the PRA model. With the first method a reading of the PRA cutsets will show only one event representative of the frequency of the subject system failure. With the second method a reading of the cutsets will show many events contributing to the frequency of system failure. Again, each option has some advantages and disadvantages that roughly balance out. Since the first option represents the least disruption to the structure of existing PRAs and SPAR models, it is the option described here. Note that most PRA codes such as CAFTA, WinNUPRA (where the code is used for SPAR model development) allow the initiating event fault tree to be fully integrated into the model with either option.

Existing industry PRAs and existing SPAR models will generally have fault tree models for the support system function of the systems in question. With some (possibly much) modification, these existing fault trees can be used to estimate the support system failure frequencies, and to some degree, the overall importance with respect to core damage of components in these systems.

Preliminaries

Consider the system represented by the reliability block diagram (RBD) in Figure C-1. The RBD represents a typical component cooling water system with pump trains PA, PB, PC, and heat exchanger trains HA and HB. It is not unusual for systems of this type to have different success criteria at different times during the year. Assume that for success this system requires 2-of-3 pump trains and 1-of-2 heat exchanger trains half the time, and 1-of-3 pump trains and 1-of-2 heat exchanger trains the rest of the time. Also assume that for a given success criterion, the required components are normally operating and the rest are in standby (meaning the standby failure rate is zero[3], except that common cause failures must be assumed to affect the standby train as well as operating train), and that the standby components are rotated from time to time to balance the wear on all components equally. These latter requirements complicate the example provided in Attachment A, but are necessary to provide a realistic example.

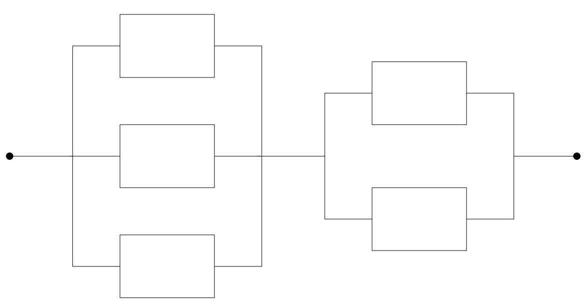

Figure C-1.

[3] This assumption may not be realistic. It does, however, illustrate a nuance of the method. If standby failure rates are available, they should be used. Standby rates are generally not available so fail-to-start events must typically be used to capture the standby failure contributions to system failure frequency.

Reliability block diagram for a typical component cooling water system.

An additional complication is that the system success criteria with respect to a plant trip will sometimes be different from the system success criteria with respect to the post-initiator plant response. It is a weakness of the explicit event method that it does not easily link the cutsets resulting from the initiating event fault tree with those resulting from the support system fault tree, and this is true of both versions of the explicit event method.

Industry PRA models will generally have to comply with the ASME PRA standard. The question will then arise: is the above RBD a sufficient representation of the system? Or at what level of detail is the model adequately developed? It is potentially a difficult task to answer these questions, except that industry PRAs/SPAR models already include support system models for systems with any significant impact on the core damage mitigation requirements for the plant.

The Birnbaum importance measures for components in support systems offer a reasonable guide to which components and component failure modes should be included. The fault tree illustrated in Attachment A does correspond to the RBD in Figure C-1, but includes more components and failure modes than just the pump fail-to-run and heat exchanger fail-to-function failure modes in the following discussions. Note that the fault tree in Attachment A includes only component cooling water system components. It does not include component cooling water system supports such as ac power, dc power, and service water cooling to the heat exchangers. This is not just a simplification to illustrate the method; it is a key aspect of initiating event fault tree development. The initiating event fault tree for one system should include no components from other systems that might be considered potential initiators in their own right.

The goal here is to determine the expected system failure frequency, $<F>$. References C-3 and C-4 demonstrate a method (the unavailability method) that estimates the expected system failure rate using an unavailability model for the system. The method has the advantages of being well documented in the literature, of incorporating component repair in a straight-forward way, of being fault-tree based, of being entirely probability based when manipulating cutsets and component importance, of providing an exact solution, and if needed, of providing a time-dependent solution. The method also works well with binary decision diagrams, providing large speed and accuracy advantages. However, as mentioned previously, the existing quantification codes do not have the required algorithms. (The two principal shortcomings are to calculate a quantity called the system unconditional failure intensity (Refs. C-3, C-4), and to integrate that quantity over the mission to get the expected number of system failures.) Therefore alternate, less well documented, methods are required. To illustrate an alternate method (the explicit event method), consider just the portion of the RBD representing the heat exchanger trains. If HA is normally operating and HB is in standby, and if HA fails it can be repaired with a mean repair time, τ, of 24-hours, then the frequency at which the heat exchange function is lost (i.e., both heat exchangers are failed at the same time) can be written as

$$< F > = \lambda_{HA} \cdot \Phi_{HB} \qquad (1)$$

Equation (1) above is an expression of the failure rate for a filtered Poisson process. The rate of failure challenge is represented by λ_{HA}, and is reduced by the "filter", Φ_{HB}. In this case the component-based initiating event "HA fails to operate" is represented by a failure rate, λ_{HA}, not a probability. The enabling event "HB fails to operate while HA is repaired" is represented by a probability, Φ_{HB}.

If both trains are normally operating and only one required, then the expected failure rate would be

$$< F > = \lambda_{HA} \cdot \Phi_{HB} + \lambda_{HB} \cdot \Phi_{HA} \qquad (2)$$

In this case, both components must have initiating event and enabling event representations. The distinction between initiating and enabling contributions is important and will be made clear in the fault tree example by using the prefix "IE-" for initiating event contributions. In the literature (Refs. C-3, C-4), enabling events are those events that are occurring and put the system in a state such that when the initiating event occurs, the system transitions from the operating state to the failed state. So, by the definition, the enabling events should be preexisting when the initiator occurs. This will be true if train HB is in test or maintenance when HA fails, or if HB fails to start because of a preexisting fault, etc. Strictly speaking, it is not true if the second train fails while the first is in repair, but for simplicity, this case can be treated like the others. Because support system failure events in existing PRAs/SPAR models are probabilities for component failure during 24-hours, and because 24-hours is a reasonable repair time for most components, the existing support system failure events can be used as enabling events, Φ, in the system failure frequency development. If this were not the case, new events would have to be introduced into the model for the enabling event aspect of the IE frequency calculation.

Typically some fraction of component failures will be common cause failures and must also be included. Equation (2) should then be rewritten as

$$< F > = \lambda_{Hc} + \lambda_{HA} \cdot \Phi_{HB} + \lambda_{HB} \cdot \Phi_{HA} \qquad (3)$$

Where λ_{Hc} is the rate at which heat exchanger common cause failures occur. The common cause term should not be treated like the other failure terms with respect to repair for two reasons; first, it may represent a shock that affects both trains at essentially the same time, leaving no time for repair before system failure. Second, if the common cause failure is not immediate, but just "within a typical PRA mission time", then the data collection effort includes an implicit repair credit which should not be counted twice.

Basic Events

In the example fault tree model basic events representing the enabling event contribution from failure of the heat exchange function will be

CCW-HTX-FC-A

CCW-HTX-FC-B

The event naming scheme used is from Reference C-5. These events are quantified as the probability of heat exchange failure during the repair time, τ, of the normally operating component

$$\Phi_{HA} = \Phi_{HB} = (1 - e^{-\lambda_H \cdot \tau}) \tag{4}$$

Basic events representing the initiating event contribution from failure of the heat exchange function will be

IE-CCW-HTX-FC-A

IE-CCW-HTX-FC-B

These events are quantified simply as λ_H.

The initiating event contribution from the common cause term in Equation (3) is

IE-CCW-HTX-CF-FCAB

Common cause failures may or may not have both initiating and enabling event contributions. In this case the common cause failure represents complete failure of the redundant trains, so the initiating event fault tree will include only the initiating event contribution. If there are CCF events that represent a partial failure of the redundant trains (e.g., pumps A and B fail from a common cause, but the success criterion is 1-of-3 pumps), then both initiating and enabling contributions must be represented. This will be the case for development of events and logic for the pump blocks in Figure 1. The CCF calculation for the heat exchanger block initiating event contribution uses the alpha factor method (Ref. C-6, pg. 40-41) as follows

$$\lambda_{Hc} = K_{H22} \cdot \alpha_{H22} \cdot \lambda_H \tag{5}$$

The constant K_{H22} depends on the testing scheme. For normally operating systems, use the non-staggered testing formulation

$$K_{H22} = \frac{k \cdot (k-1)! \cdot (m-k)!}{(m-1)! \cdot (1 \cdot \alpha_{H21} + 2 \cdot \alpha_{H22})} \qquad (6)$$

The constant K_{Hmk}, and alpha factor α_{Hmk} are subscripted according to component type, common cause group size, and number of failures occurring from a common cause. The *H* subscript in Equations (5) and (6) refers to component type, heat exchanger. The *m* refers to the group size, 2, and *k* refers to the number of failures occurring together because of a common cause, 2. The development is similar for the pump trains, except that both initiating event frequency and enabling event probability must be developed for all common cause event combinations possible in a common cause group of 3.

Table C-1 shows failure rates and alpha factors representative of component cooling water systems. Note that the fault tree described in the next section includes other events typically found in a component cooling water system models. Their quantification follows similar principles.

Table C-1.
Failure rates and alpha factors for the component cooling water system in Figure C-1

Parameter	*Description*	*Mean*	*Distribution*
λ_H	*CCW heat exchanger failure rate*	*4.59E-7 per hr*	*Gamma* *(0.50, 1.1E+6)*
α_{H21}	*Alpha 1 for 2 component group*	*0.9777*	*Beta* *(23.5, 0.5350)*
α_{H22}	*Alpha 2 for 2 component group*	*0.0223*	*Beta* *(0.5350, 23.5)*
λ_P	*CCW pump failure rate*	*1.68E-6 per hr*	*Gamma* *(1.00, 6.0E+5)*
α_{P21}	*Alpha 1 for 2 component group*	*0.9822*	*Beta* *(2.54E+1, 4.50E-1)*
α_{P22}	*Alpha 2 for 2 component group*	*0.0178*	*Beta* *(4.60E-1, 2.54E+1)*
α_{P31}	*Alpha 1 for 3 component group*	*0.9791*	*Beta* *(5.31E+1, 1.13E+0)*
α_{P32}	*Alpha 2 for 3 component group*	*0.0159*	*Beta* *(8.65E-1, 5.34E+1)*
α_{P33}	*Alpha 3 for 3 component group*	*0.0049*	*Beta* *(2.68E-1, 5.4E+1)*

The Fault Tree

The fault tree representing the RBD in Figure C-1 is provided in Attachment A. The fault tree was designed to illustrate either the multiplier method or the explicit event method. Either logic can be selected by setting the value of house event HE-USE-MULT-METHOD. The default setting for this house event is FALSE, which removes the multiplier method logic from the solution.

First consider the heat exchanger logic on page A-5. The common cause fault contribution (IE-CCW-HTX-CF-FCAB) is a single failure for the system. This is being treated as an immediate failure for which no repair is possible before the system fails. Other heat exchanger events depend on which train is currently aligned as operating, and which is in standby. Event CCW-HTX-FC-BSTBY is the probability H22 is in standby. The heat exchanger initiating event contribution for this operating configuration is then provided by IE-CCW-HTX-FC-A, and the enabling events are developed under transfer gate IEFT-LOCCW-HTXB-SBY. In this case the only enabling events correspond to heat exchanger test and maintenance on the standby train, or failure of the standby heat exchanger to function while the normally operating heat exchanger is repaired. The logic is developed in an identical way when HA is in standby.

Next consider the pump logic on page A-9. Since two different success criteria are required, two parallel logic developments must be used. The most efficient logic arrangement (requiring enumeration of the fewest cases) will depend on the success criterion modeled. For the 1-of-3 requirement, it is most efficient to arrange the fault tree logic around the running pump. For the 2-of-3 case it is most efficient to arrange the fault tree logic around the standby pump. The logic supporting both success statements requires some explaining. First the logic for one of the 1-of-3 cases as shown on page A-14. At the top of the logic is an event for the CCF of all three trains; it is independent of the operating lineup. Next is the logic for the independent initiator events. In this case, the explicit initiating event for the running pump is combined with its enabling events using “and” logic under gate IEFT-LOCCW-PA-RUN-1. If the pump discharge check valve fails to seat, a flow short circuit develops and the system fails. If there is a common cause of the standby trains to start or run, the system fails. Finally, if both standby trains independently fail to start or run, the system fails. Additional logic is required to develop the case where pump train A fails with pump train B in common cause (the initiator) and train C fails independently, and for the case where pump train A fails with pump train C in common cause (the initiator) and with train B independently. This somewhat complicated logic is repeated for the two other possible configurations (pump B normally running, or pump C normally running). Note that for systems with three redundant trains, working out the initiating event and enabling event contributions for all train combinations is error prone and tedious. For more than three redundant trains it may be prohibitively complicated.

For the case where success requires 2-of-3 trains the logic is arranged around which pump is in standby as shown on page A-16. The common cause failure combinations that can act as initiating events without accompanying enabling events are shown at the top of the page. These are independent of operating alignment. The CCF combinations that cause system failure without accompanying enabling events are CCF of trains A, B, and C, CCF of trains A and B, CCF of A and C, or CCF of B and C. The remaining logic on this page is configuration specific and requires event CCW-SYS-FC-ASBY to identify the probability this specific alignment exists at any given time. This logic must, of course, be repeated in an appropriate way for each of the other configurations.

Cutsets

The dominant cutsets for this system are shown in Table C-2. A complete listing is provided in Attachment B. Note that each cutset contains exactly one initiating event, and may contain one or more enabling events and configuration probabilities. Of the calculated 8.6E-4 expected system failure events per year, over 80 percent include common cause failures. This makes a strong case for accurate, and not excessively conservative, independent and common cause failure rate data.

Note that the predicted frequency is compatible with the observation that no such system failures have occurred in the operating history that generated the rate information in Table C-1. The rate information in Table C-1 was generated from approximately 10 years of operational history from about 100 plants. The number of similar systems operating at each plant is typically one and sometimes more. So the operational exposure for component cooling water systems can be estimated at about 1000 system-years. Based on the assumption of a Poisson process with characteristic transition rate of 8.6E-4 system failure events per year, the probability of seeing zero events is

$$P(X_t = 0) = \frac{(\nu \cdot t)^0}{0!} \cdot e^{-\nu \cdot t} = e^{-(8.6E-4) \cdot 1000} = 0.42 \qquad (7)$$

If uncertainty, shown if Figures 3 and 4, is factored into the above expression, the value shifts to about 0.50 or slightly higher, with the most probable number of failures being zero. Note that the pump and heat exchanger failure rates in Table C-1 are based on a relatively large number of failure events. The alpha factors, on the other hand, are based on no observed failures, and are therefore relatively more uncertain. Therefore the uncertainty distribution in the predicted system failure rate should be expected to be largely a result of uncertainty in the alpha factors.

One last point should be made about these results. Remember that the system in Figure C-1 was assumed to have both 1-of-3 and 2-of-3 success requirements for the pumps. The 1000 system years of operation in Equation (7) included systems with only two pump trains, and most likely included systems with three pump trains with either 1-of-3 or 2-of-3 pumping requirements, but not both. So the 8.6E-4 system failures per year are only generally representative of the systems in the 1000 system years of operating history.

Importance Measures

Consider the Birnbaum importance measure, or criticality function, for the heat exchanger blocks in Figure C-1. Formally, the Birnbaum is defined as the probability that the system is in a critical state for component *i*. It is calculated from the cutset for the heat exchanger portion of the RBD, {HA, HB}. Attachment C demonstrates the procedure. The important result from Attachment C is that the Birnbaum for component HA is just the unavailability of component HB, and vice versa. Using the failure rates in Table C-1, the Birnbaum importance for components HA and HB is 1.10E-5.

Now look at how would calculate the Birnbaum importance of HA when using the explicit event method. will be working with both the initiating event frequency and enabling event probabilities for components HA and HB, and will therefore calculate two Birnbaums for each component; one for the initiating event, and one for the enabling event. First consider the enabling events. Let Q be the system failure frequency, and q_i denote the probability that component i fails. Then the procedure for calculating the Birnbaum, G_i , for component i, is

$$G_i(q) = Q(1_i, q) - Q(0_i, q) \qquad (8)$$

Where i refer to component HA in Equation (2), and q_i corresponds to Φ_{HA}. The Birnbaum for component HA is then

$$G_i(q) = Q(1_i, q) - Q(0_i, q) = (\lambda_{HA} \cdot \Phi_{HB} + \lambda_{HB} \cdot 1) - (\lambda_{HA} \cdot \Phi_{HB} + \lambda_{HB} \cdot 0)$$

$$= \lambda_{HB} = 4.59E-7 \tag{9}$$

This is clearly a very different result than was calculated from the unavailability model and it does not represent the total impact of component HA on the unavailability of the heat exchange function, which is the true basis for the expected number of heat exchange failures. If one were to just read the importance measure output from the explicit event model, one might be tempted to conclude the result from Equation (9) is the correct Birnbaum result for component HA. It is clearly an incomplete result, and possibly a wrong result.

Next consider the initiating events. Let q_i correspond to λ_{HA}. The Birnbaum for component HA is now

$$G_i(q) = Q(1_i, q) - Q(0_i, q) = (1 \cdot \Phi_{HB} + \lambda_{HB} \cdot \Phi_{HA}) - (0 \cdot \Phi_{HB} + \lambda_{HB} \cdot \Phi_{HA})$$

$$= \Phi_{HB} = 1.10E-5 \tag{10}$$

This time the result happens to agree with the result from the unavailability method. This result does not appear complete either, since it is based on the sensitivity of heat exchange failure frequency with respect to only λ_{HA} without propagating the impact of λ_{HA} on Φ_{HA} .

To explore the possibility of capturing the complete effect of component HA on the frequency of heat exchange failure, consider the alternate definition of the Birnbaum importance, and apply it with respect to the failure rate for HA.

$$G_i(q) = \frac{\partial Q(q)}{\partial q} = \frac{\partial(\lambda_{HA} \cdot \Phi_{HB} + \lambda_{HB} \cdot \Phi_{HA})}{\partial \lambda_{HA}} = \Phi_{HB} + \lambda_{HB} \frac{\partial \Phi_{HA}}{\partial \lambda_{HA}} \tag{11}$$

$$G_i(q) = \Phi_{HB} + \lambda_{HB} \frac{\partial(1 - e^{-\lambda_{HA}\tau})}{\partial \lambda_{HA}} = \Phi_{HB} + \lambda_{HB} \cdot \tau \cdot e^{-\lambda_{HA}\tau}$$

$$= 2.18E-5 \tag{12}$$

The point of this exercise is that the unavailability method, Equation (9), Equation (10), and Equation (12) all provide interpretations of the Birnbaum importance measure with respect to the heat exchange function in Figure 1. Of these, only the unavailability method is consistent with the formal definition of the Birnbaum found in the reliability literature. Equations (9), (10), and

(12) provide variations on the formal definition. Equations (9) and (10) represent results currently reported by the industry quantification codes. So the important question that remains is: What is meant by the Birnbaum importance for components in industry PRAs and in SPAR models that have initiating event fault trees, and how do we calculate it? The treatment of this issue in this report is provided in Section 2.3.5.

The Event Tree

The initiating event fault tree provides an expected number of system failures per year. This information can be used in one of two ways in a SPAR model or industry PRA. Consider the event tree provided in Figure C-2. One option is to use the frequency provided as a point estimate for the frequency of the initiating event node labeled IE-LOCCW. When this option is used the node IEFT-LOCCW should be deleted. Another option is to include the initiating event fault tree cutsets in the set of core damage cutsets. This is accomplished by setting the value of IE-LOCCW to 1.0 and including node IEFT-LOCCW in the event tree as shown. In both options there are sequence flag sets that cause the component cooling water support model to evaluate to TRUE. Therefore there are no CCW events included in the resulting sequence cutsets unless they are introduced at node IEFT-LOCCW. If this second option is used it will result in an increase in the importance measure result for the CCW components. The CCW component importance will be higher because all cutsets contained in the LOCCW event tree core damage end state will now contain basic events related to the CCW system; when the first option is used, none of the end state cutsets will contain any event from the CCW support model. Instead, each cutset will contain only IE-LOCCW. This is the major difference between the two approaches. However, until such time as there is a consensus for the correct approach for calculating component importance, the value of the resulting importance measure refinement is moot.

Computational Issues

The software used in the development of PRA models may have some issues related to the computation of frequencies, as opposed to probabilities. When using the explicit event method these issues are of no concern so long as the initiating event fault tree is producing system failure frequencies that are small. At higher frequencies, they may become important. Exactly where the cut off is depends on the model. The known computational issues are centered on the use of the min cut upper bound approximation regularly used to combine cutset probabilities.

When cutsets are being combined during the computation of fault tree top event probability, or during the manipulation of cutsets for event importance calculation, and the cutsets represent probabilities, the main issue with the min cut is the independence of the terms being combined. The independence issue is always present and generally results in acceptable computational error.

When the cutsets represent frequencies instead of probabilities, and the individual cutset frequencies become large, say on the order of 1.0E-2, then another issue arises. The min cut constrains the cutset sum to be less than 1.0 by effectively subtracting the intersection of cutset frequencies. This is not appropriate for frequencies, and when the individual cutset frequencies become large enough, this issue becomes significant. The problem is more extreme with respect to the calculation of component importance. Consider the Birnbaum calculation. When events are set to 1.0 as in Equation (9), and this causes a cutset frequency value greater than 1.0, then the min cut fails completely, producing negative contributions in the cutset frequency sum. These issues are most significant when the multiplier method is used, but are still present when the explicit event method is used.

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Table C-2.
Dominant Cutsets from the Loss of Component Cooling Water System Fault Tree

Cut No.	% Total	% Cutset	Prob./ Frequency	Basic Event	Description	Event Prob.
1	19.89	19.89	1.754E-004	IE-CCW-HTX-CF-FCAB	CCF OF CCW HTXs A/B	1.754E-004
2	32.83	12.94	1.141E-004	IE-CCW-MDP-CF-FRBC	CCF OF CCW MDPs B AND C TO RUN	2.282E-004
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
3	45.77	12.94	1.141E-004	IE-CCW-MDP-CF-FRAC	CCF OF CCW MDPs A AND C TO RUN	2.282E-004
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
4	58.71	12.94	1.141E-004	IE-CCW-MDP-CF-FRAB	CCF OF CCW MDPs A AND BTO RUN	2.282E-004
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
5	70.77	12.06	1.063E-004	IE-CCW-MDP-CF-FRABC	CCF OF CCW MDPs A, B AND CTO RUN	2.127E-004
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
6	82.83	12.06	1.063E-004	IE-CCW-MDP-CF-FRABC	CCF OF CCW MDPs A, B AND CTO RUN	2.127E-004
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
7	84.81	1.98	1.750E-005	IE-CCW-TNK-FC-SURGE	FAILURE OF CCW SURGE TANK	1.750E-005
8	86.48	1.67	1.471E-005	IE-CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	1.472E-002
				CCW-MDP-TM-MDPC	CCW MDP-C UNAVAILABLE DUE TO T & M	6.000E-003
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-CSBY	CCW MDP-C IS IN STANDBY	3.330E-001
9	88.15	1.67	1.471E-005	IE-CCW-MDP-FR-MDPC	CCW MDP-CFAILS TO RUN	1.472E-002
				CCW-MDP-TM-MDPB	CCW MDP-B UNAVAILABLE DUE TO T & M	6.000E-003
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-BSBY	CCW MDP-B IS IN STANDBY	3.330E-001
10	89.82	1.67	1.471E-005	IE-CCW-MDP-FR-MDPC	CCW MDP-CFAILS TO RUN	1.472E-002
				CCW-MDP-TM-MDPA	CCW MDP-A UNAVAILABLE DUE TO T & M	6.000E-003
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-ASBY	CCW MDP-A IS IN STANDBY	3.330E-001
Total			8.82E-004			

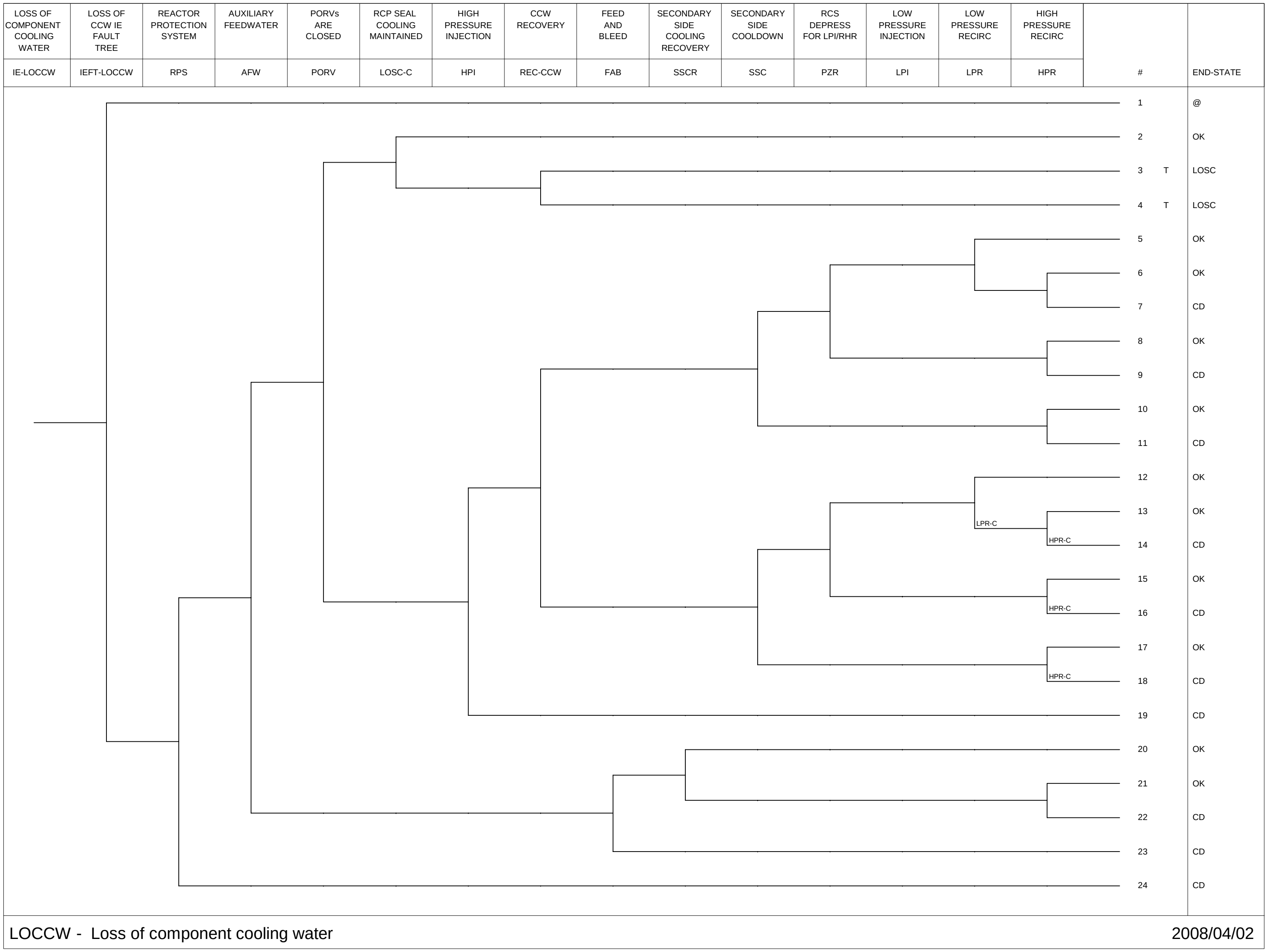


Figure C-2
Typical Loss of Component Cooling Water Event Tree

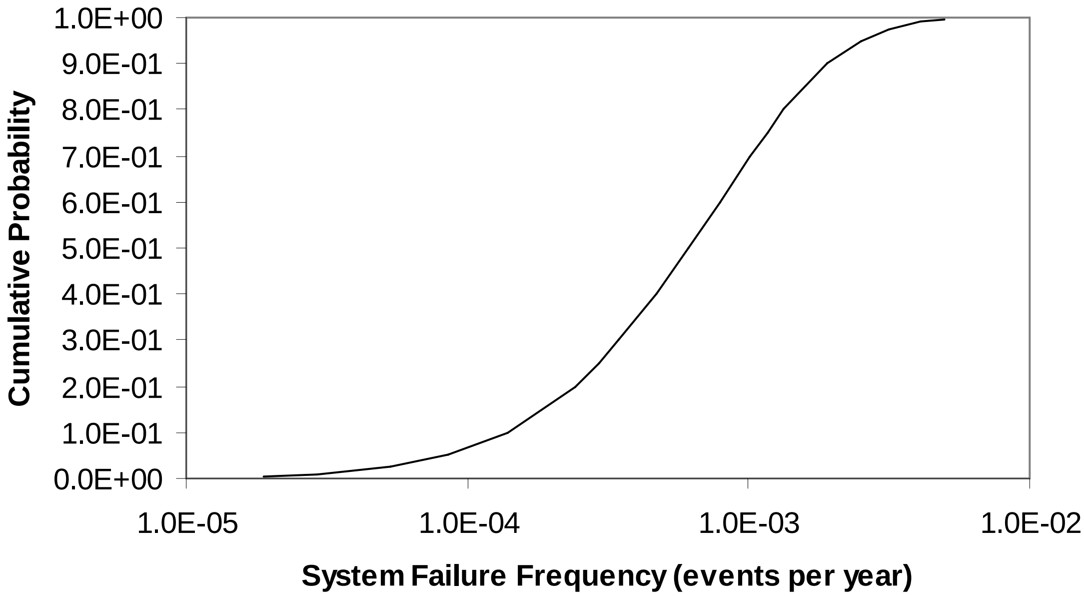


Figure C-3
System Failure Frequency Cumulative Distribution Function.

Mean = 8.7E-04, Percentiles: 5^{th} = 8.6E-05, Median = 6.2E-04, 95^{th} = 2.5E-03

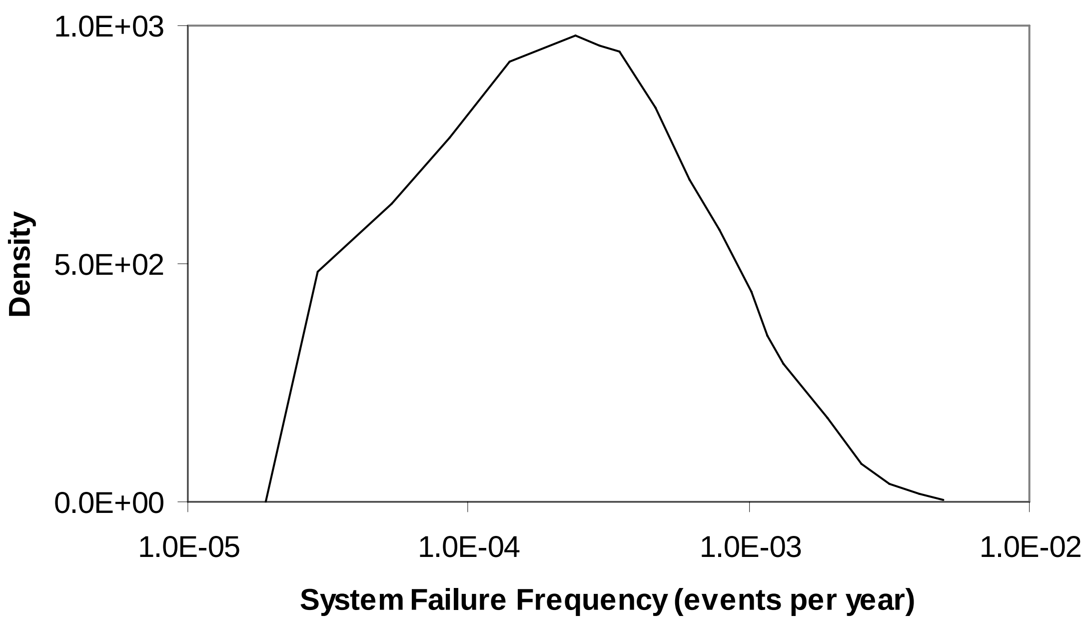
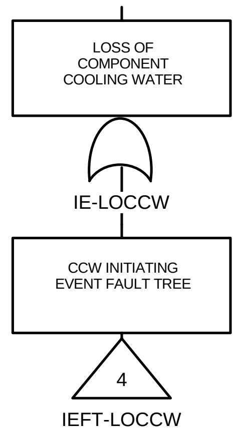


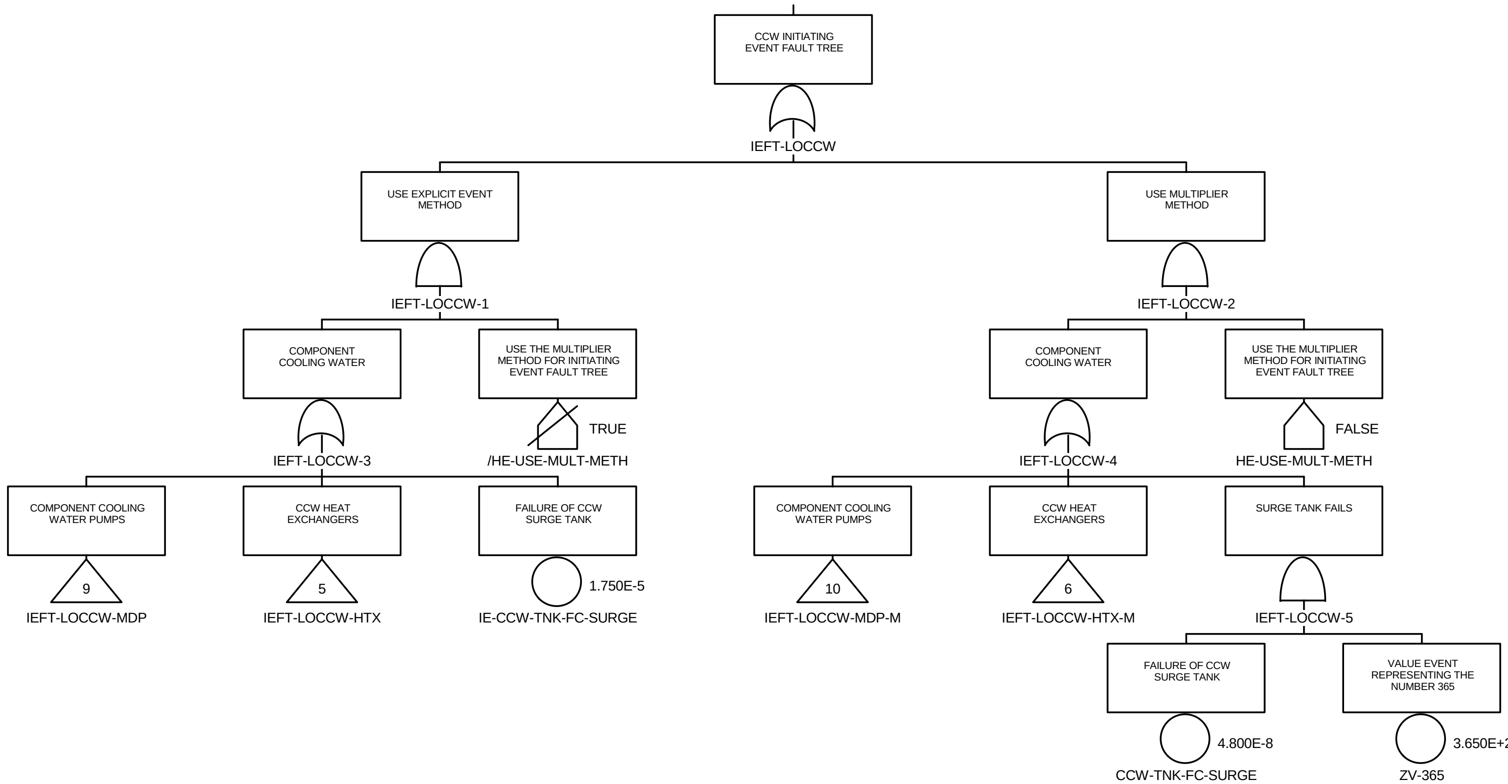
Figure C-4
System Failure Frequency Density Function.

Attachment A to Appendix C

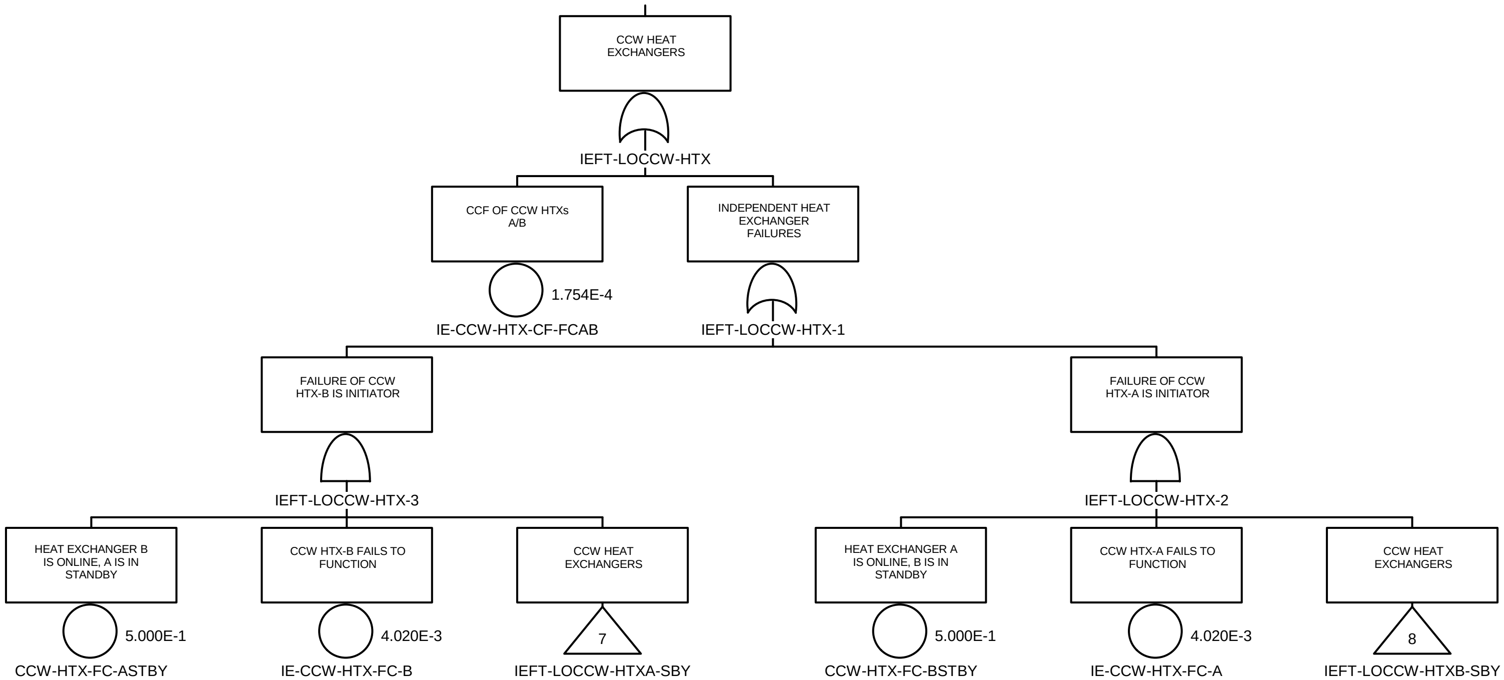
Fault Tree



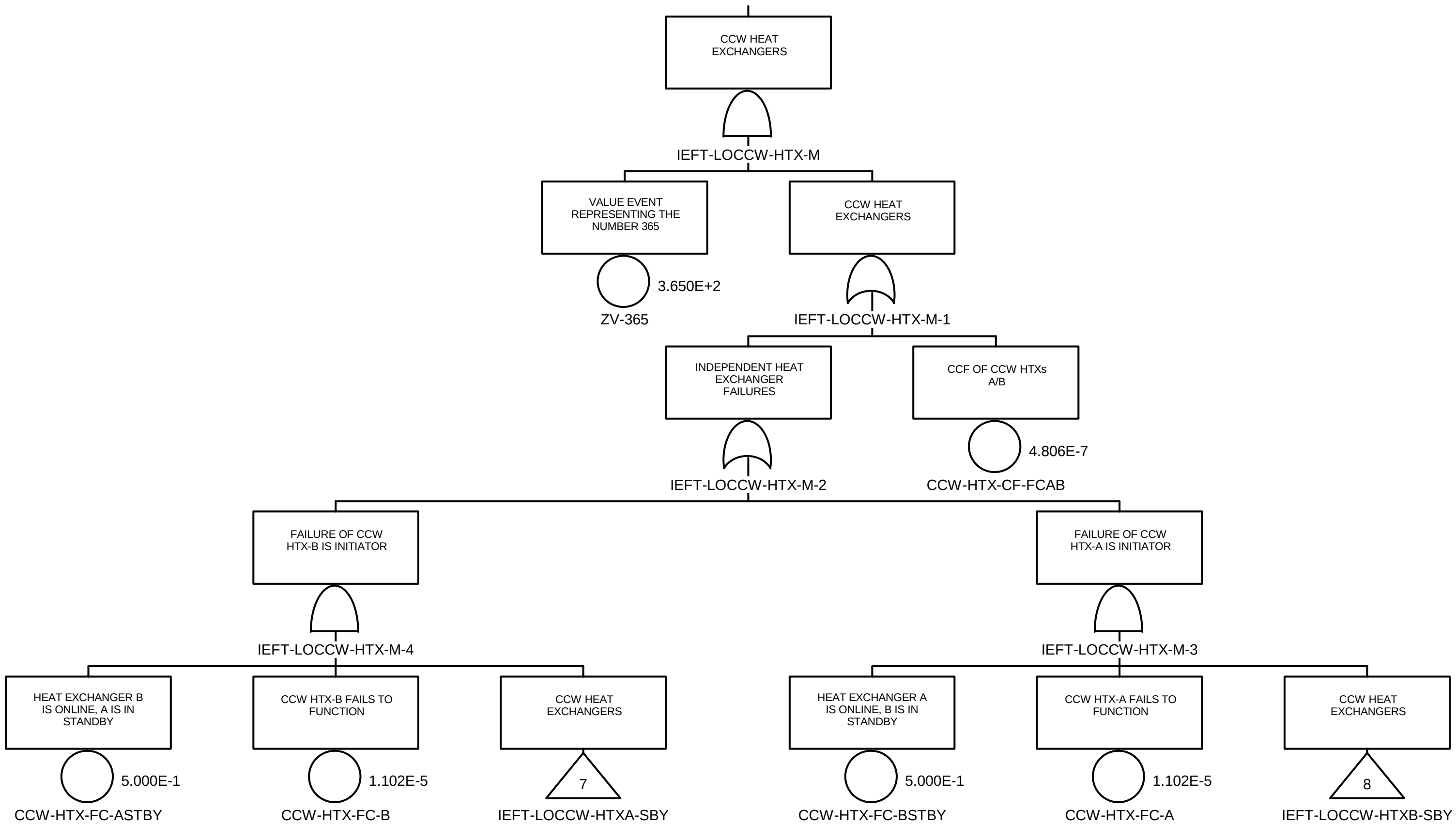
IE-LOCCW - LOSS OF COMPONENT COOLING WATER 2008/06/03 A- 3



IEFT-LOCCW - LOSS OF CCW IE FAULT TREE 2008/06/03 A- 4



IEFT-LOCCW-HTX - CCW HEAT EXCHANGERS 2008/06/03 A- 5



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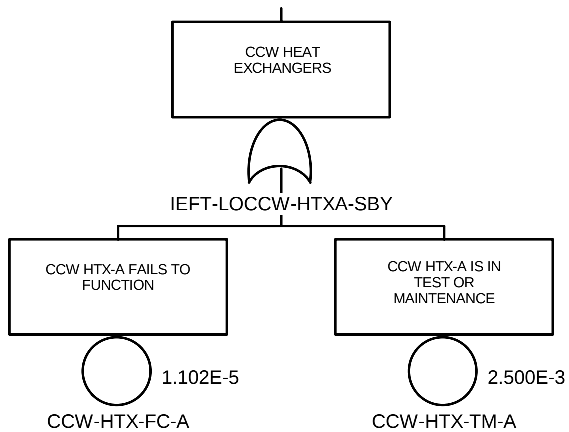

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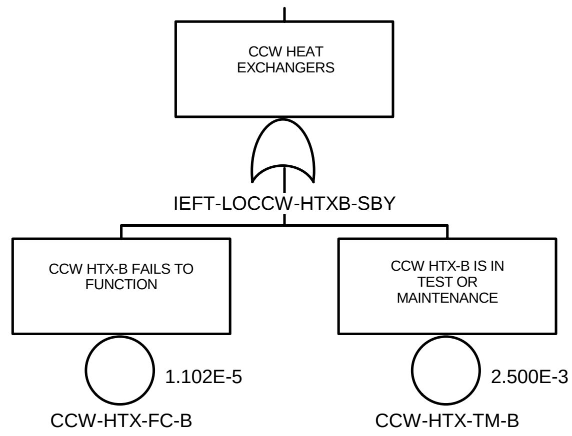

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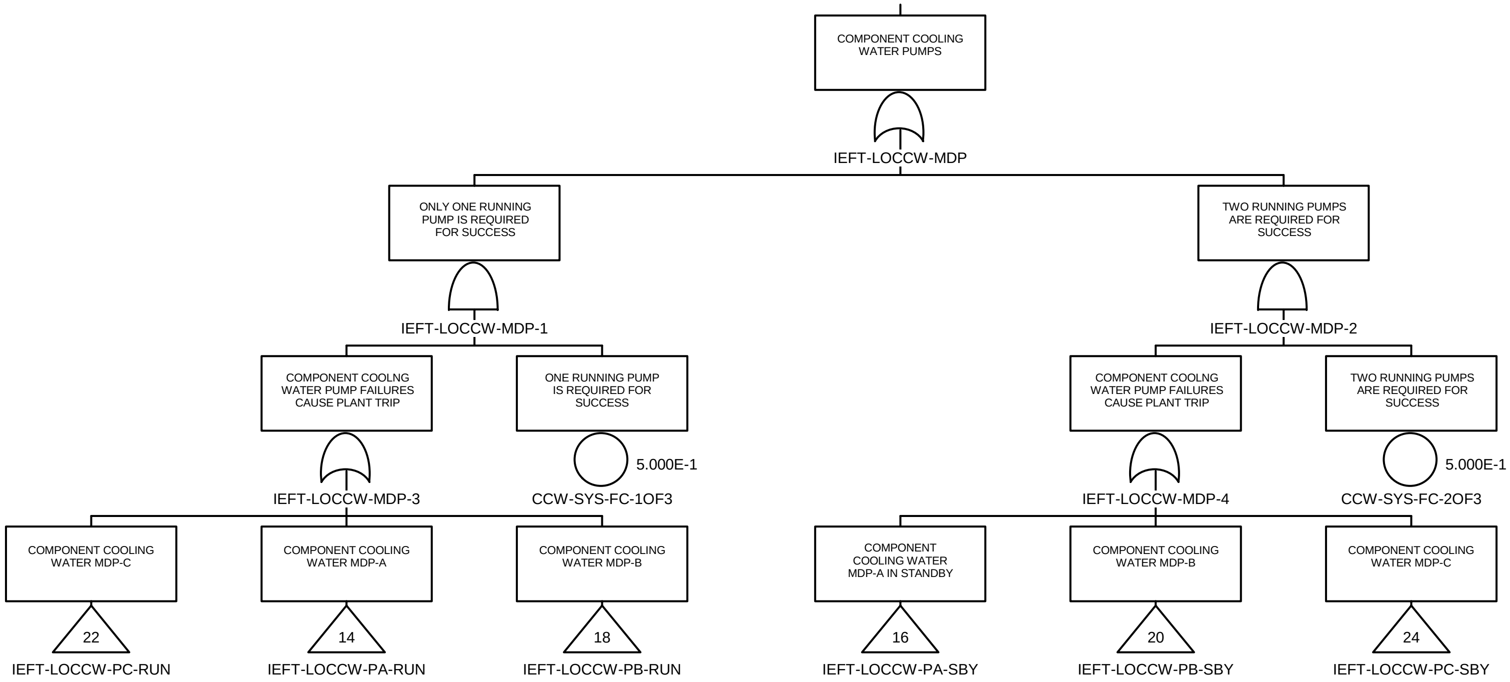

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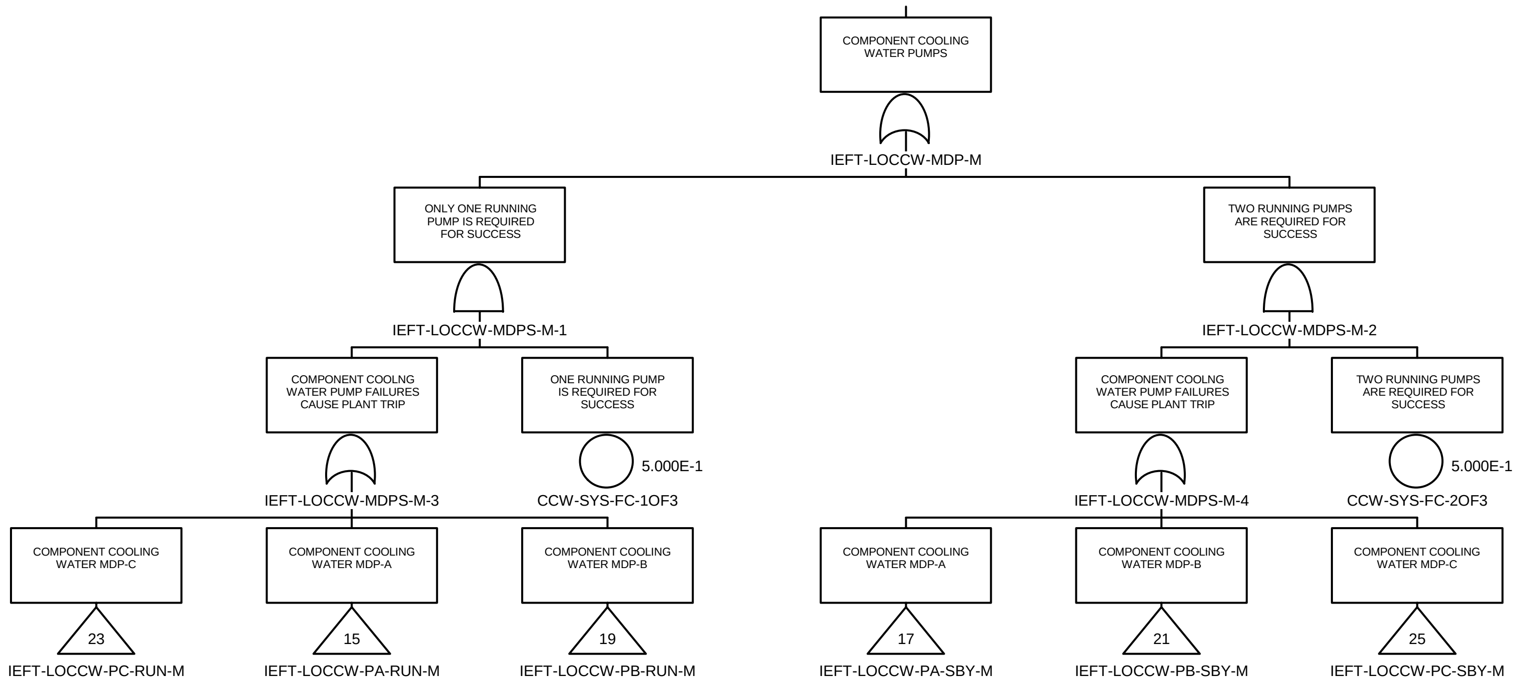

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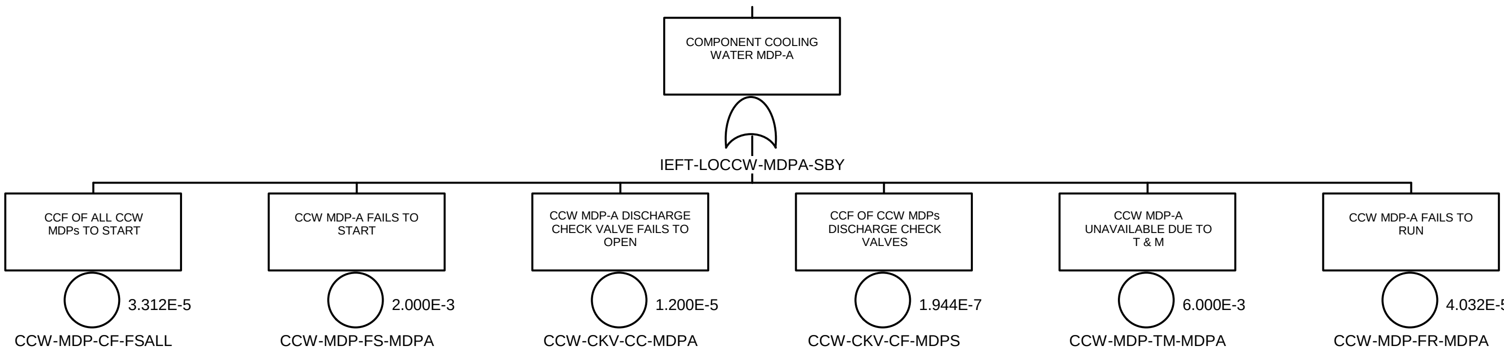

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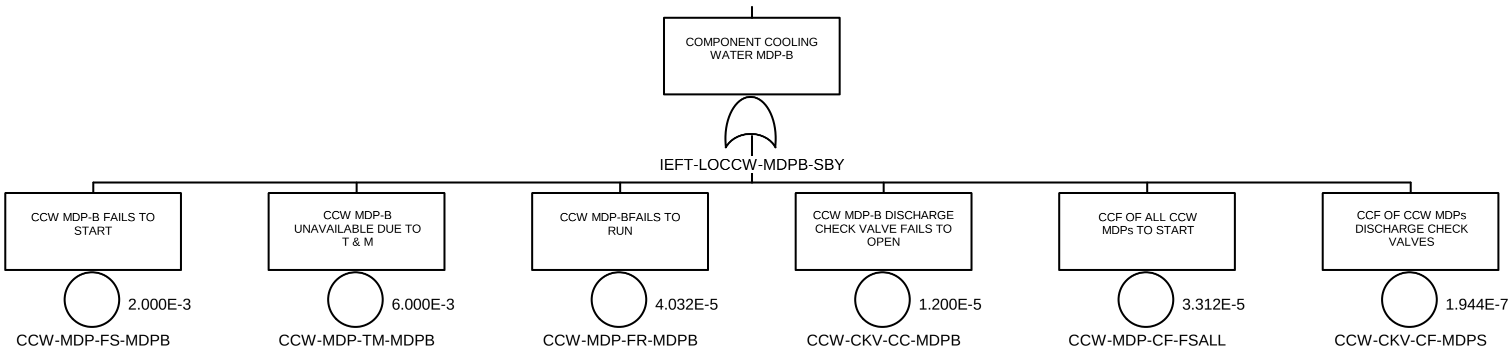

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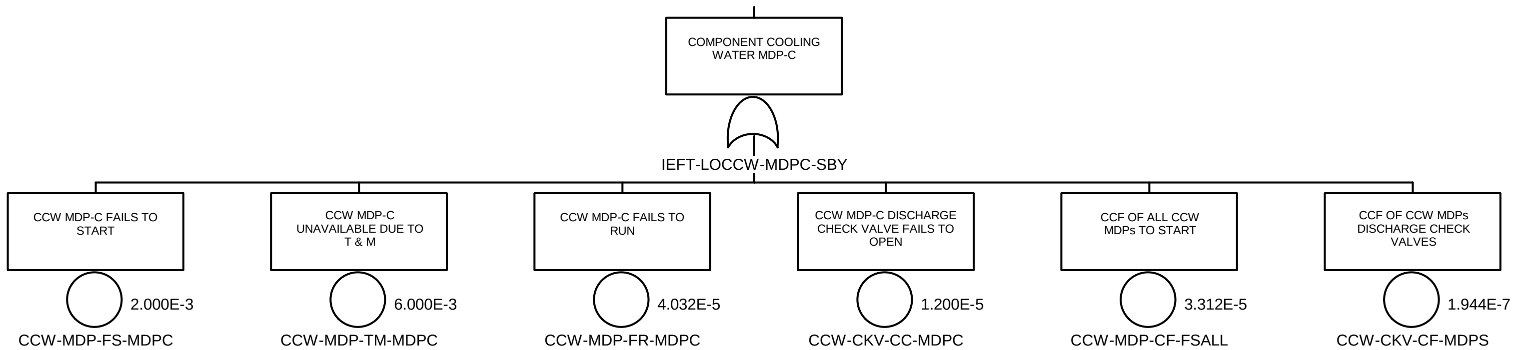

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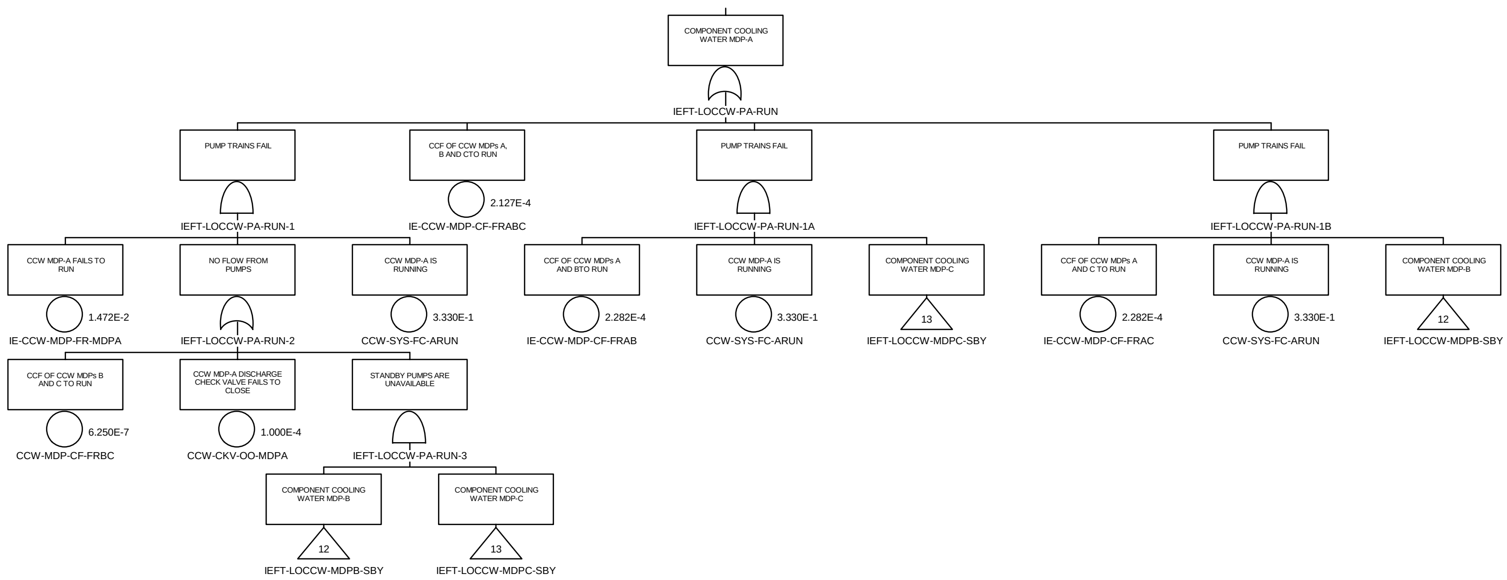
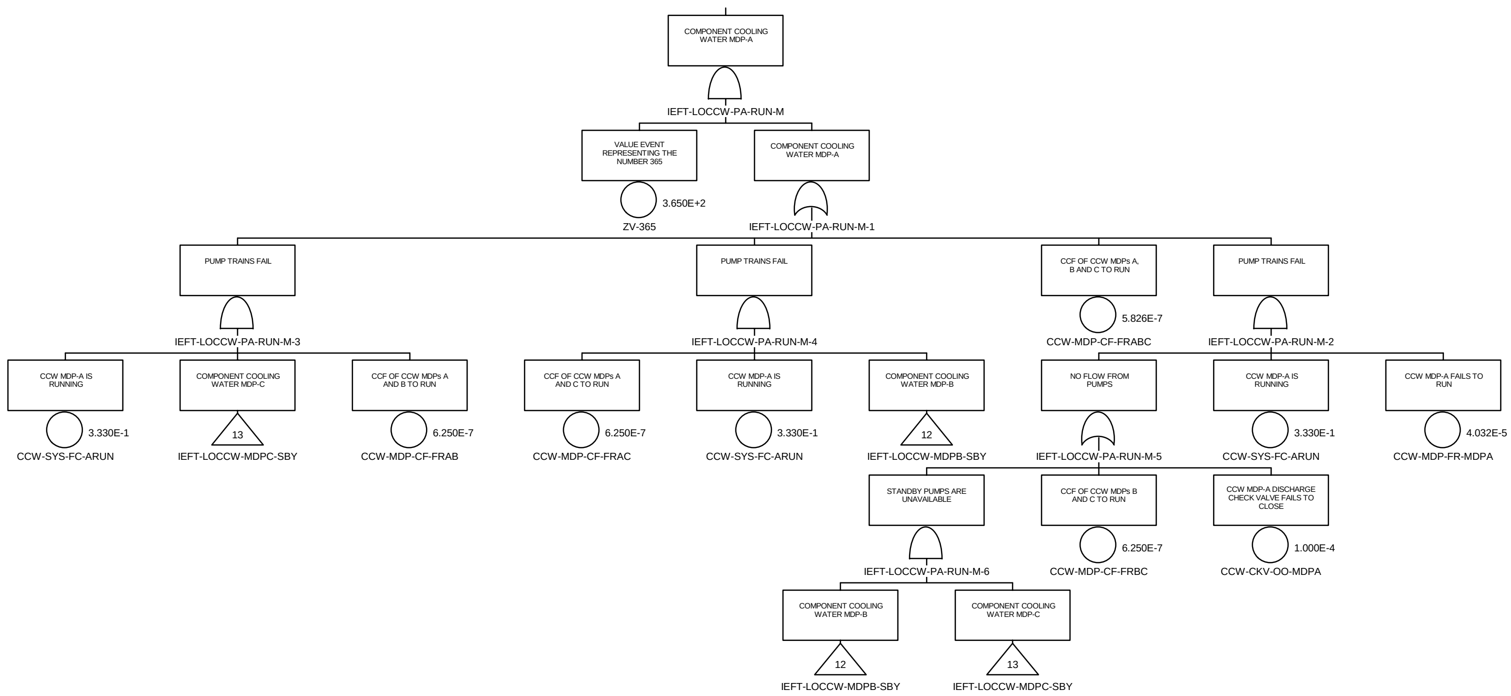


IEFT-LOCCW-PA-RUN - COMPONENT COOLING WATER MDP-A 2008/06/03 A- 14



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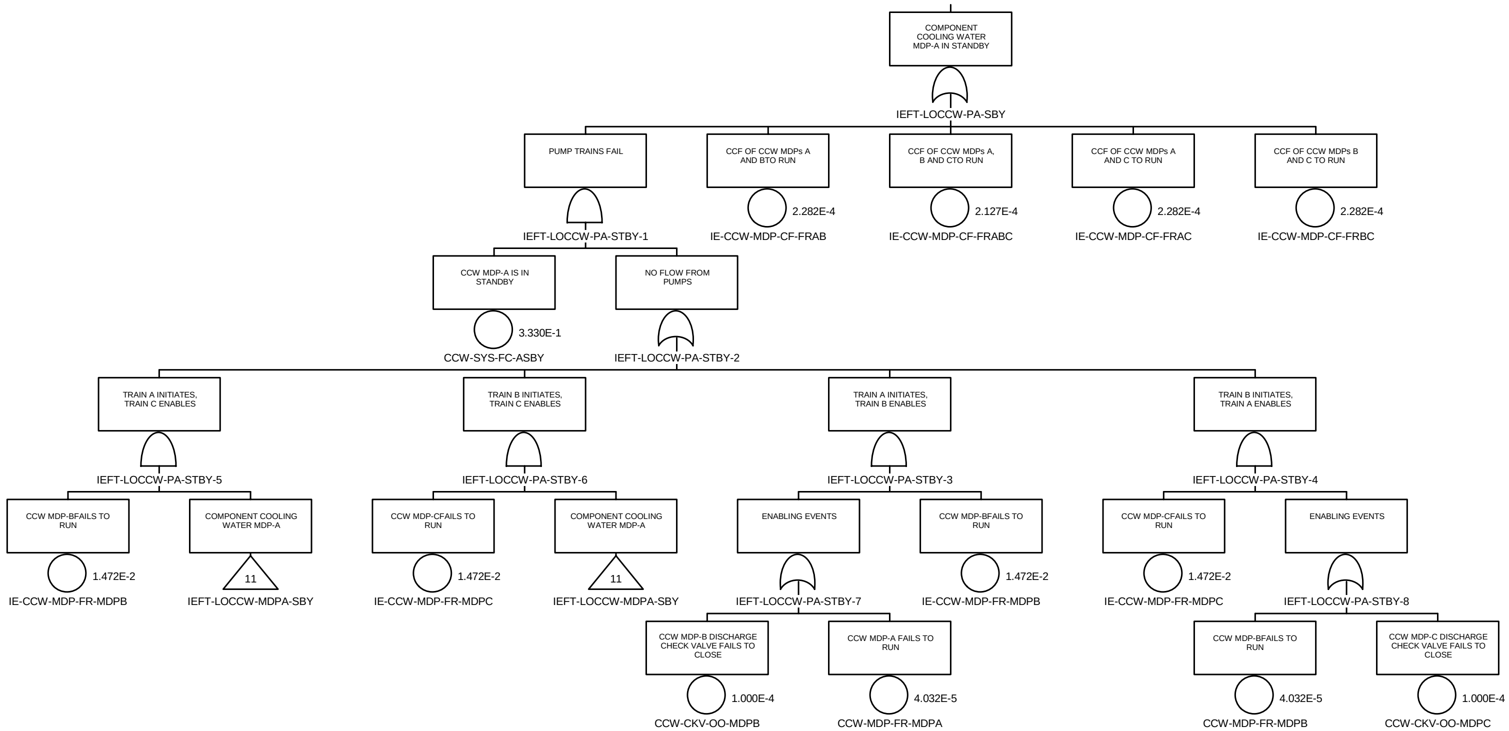

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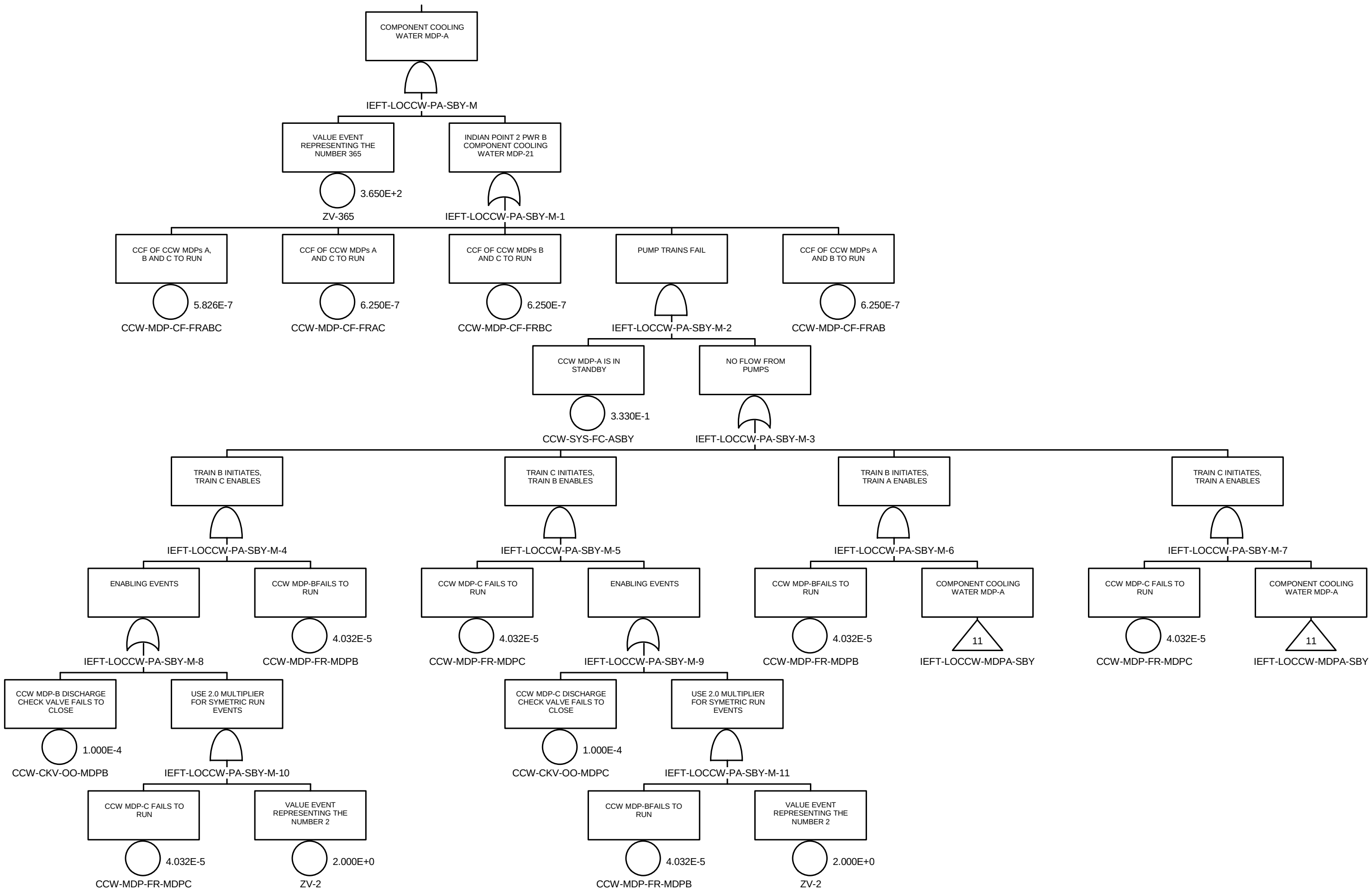

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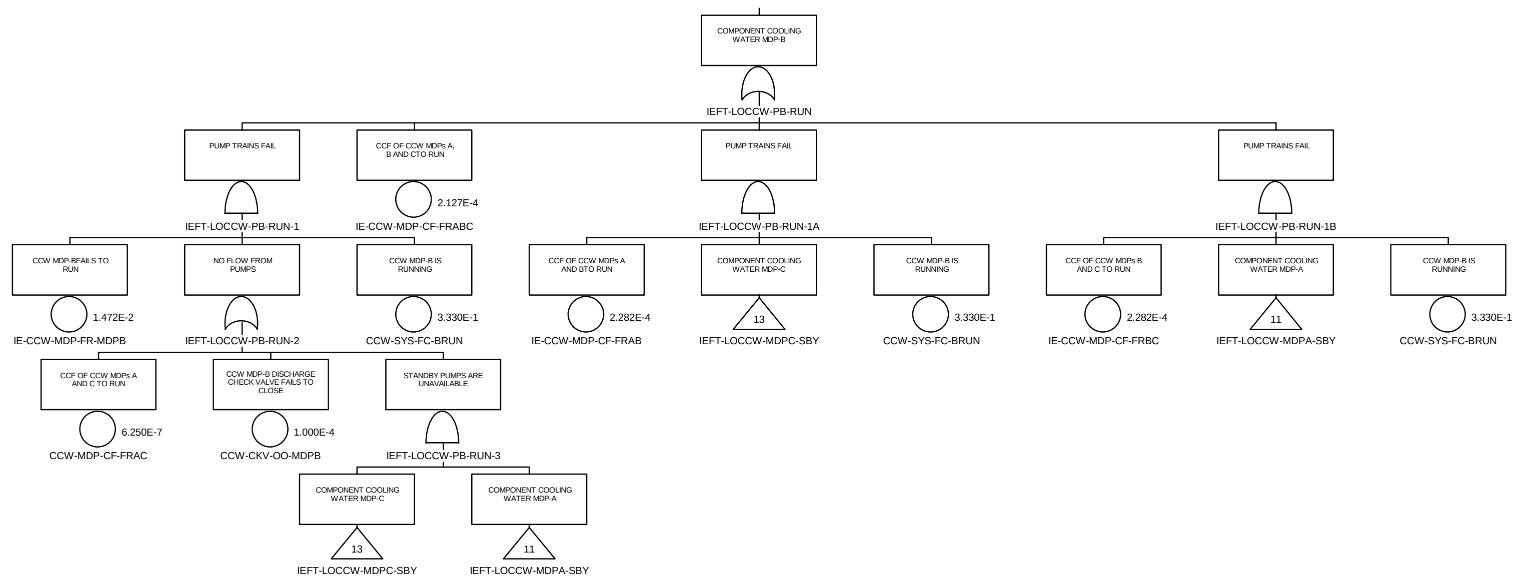

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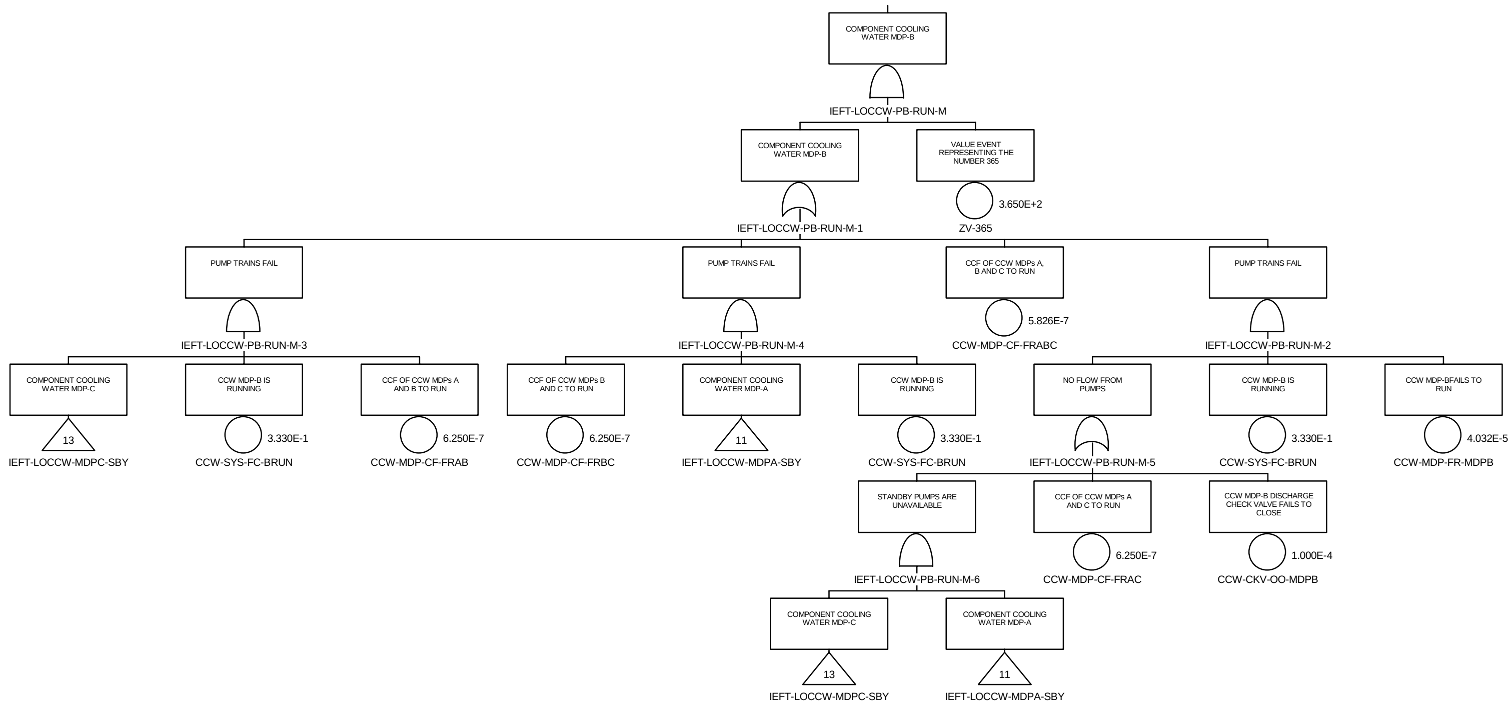

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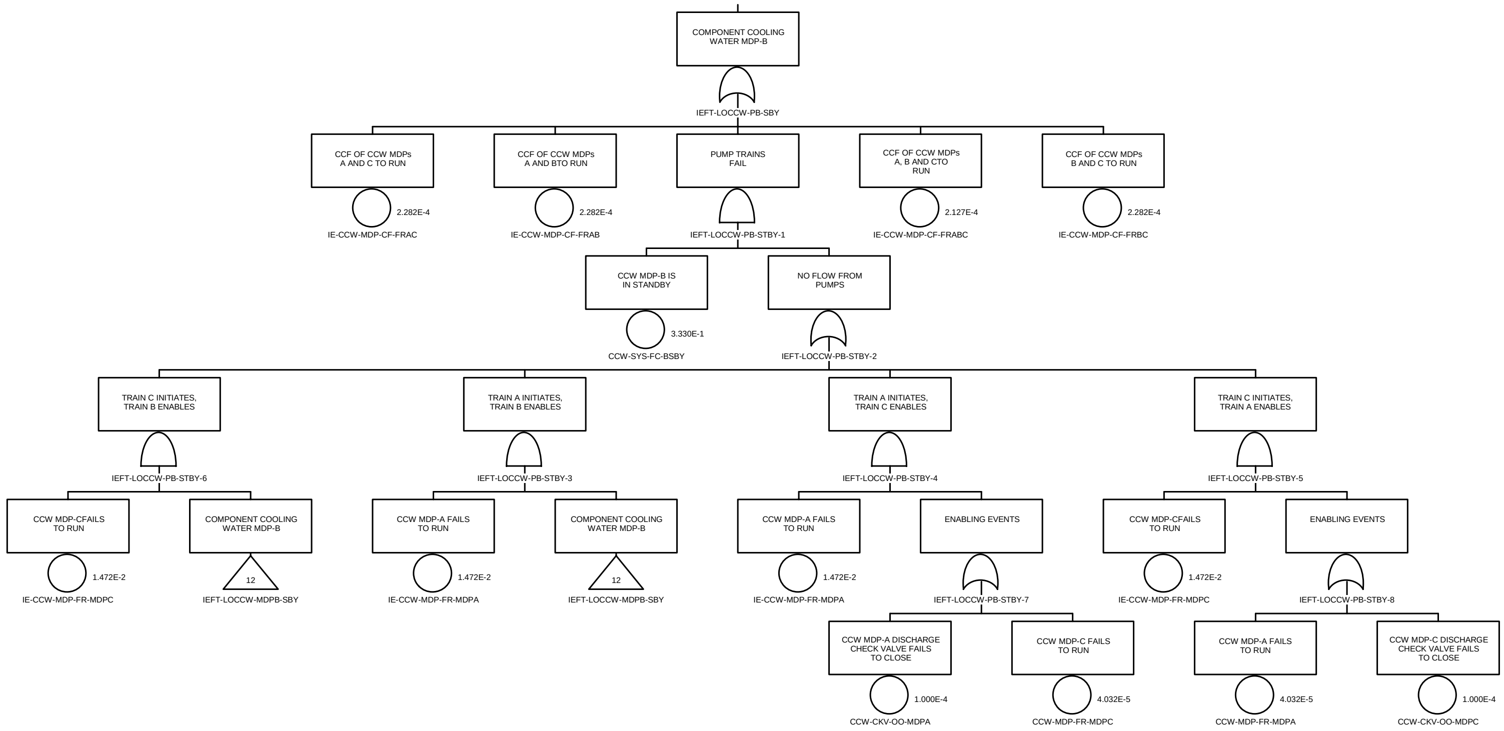

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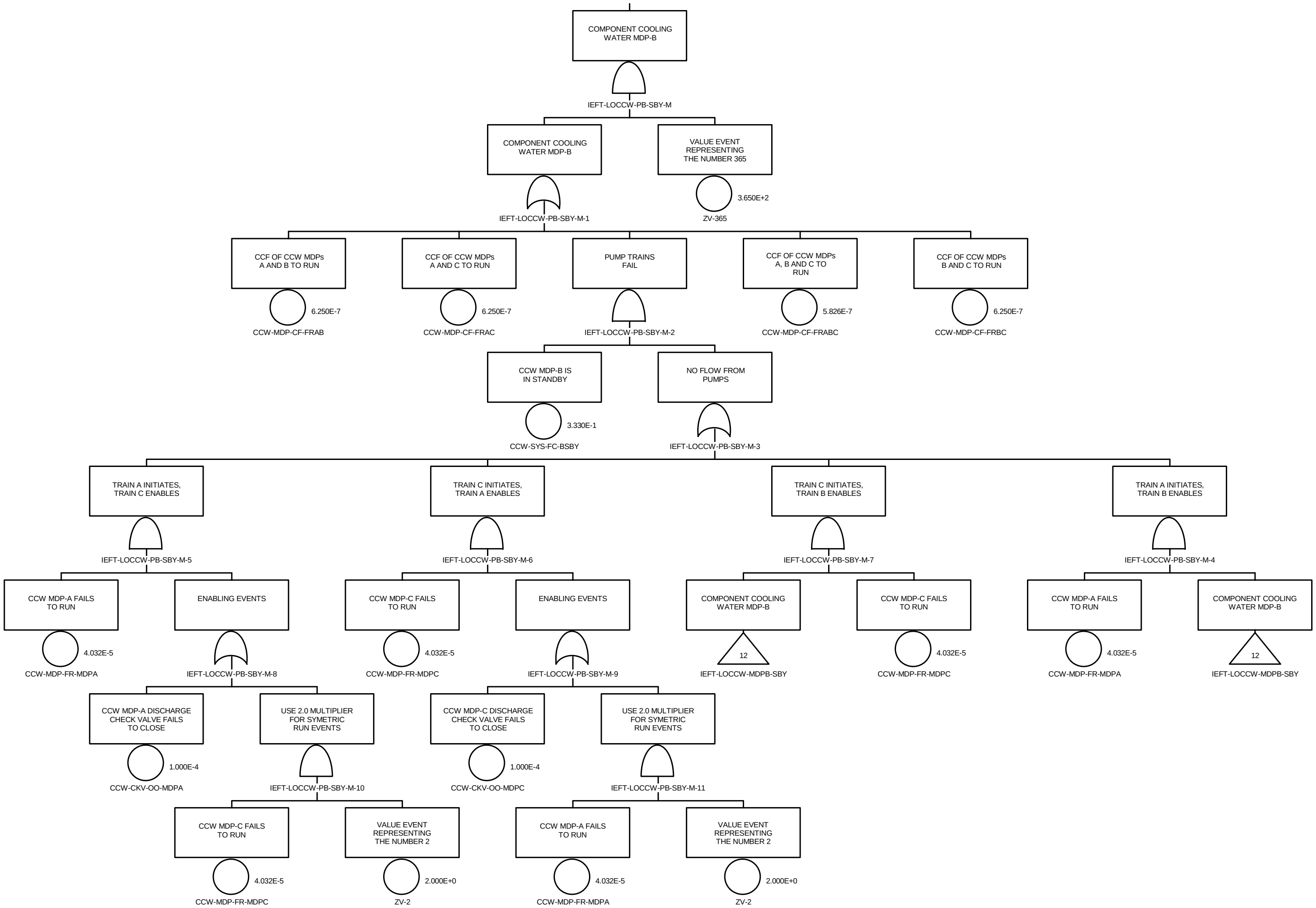

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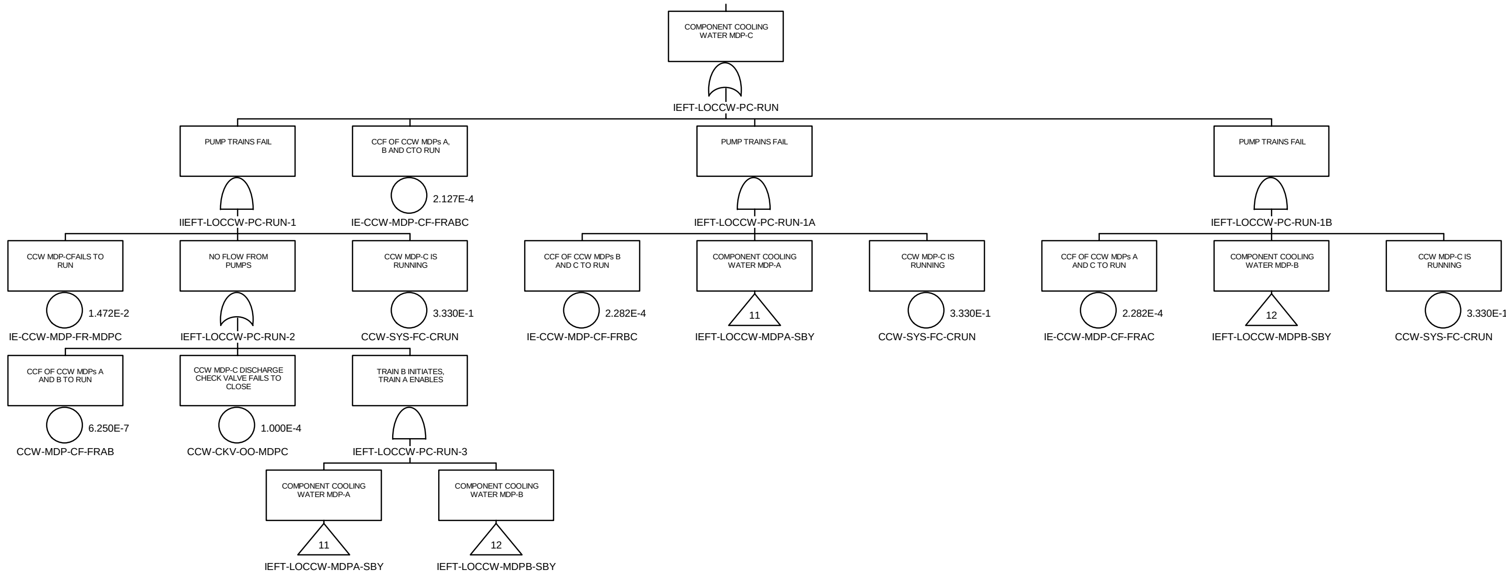

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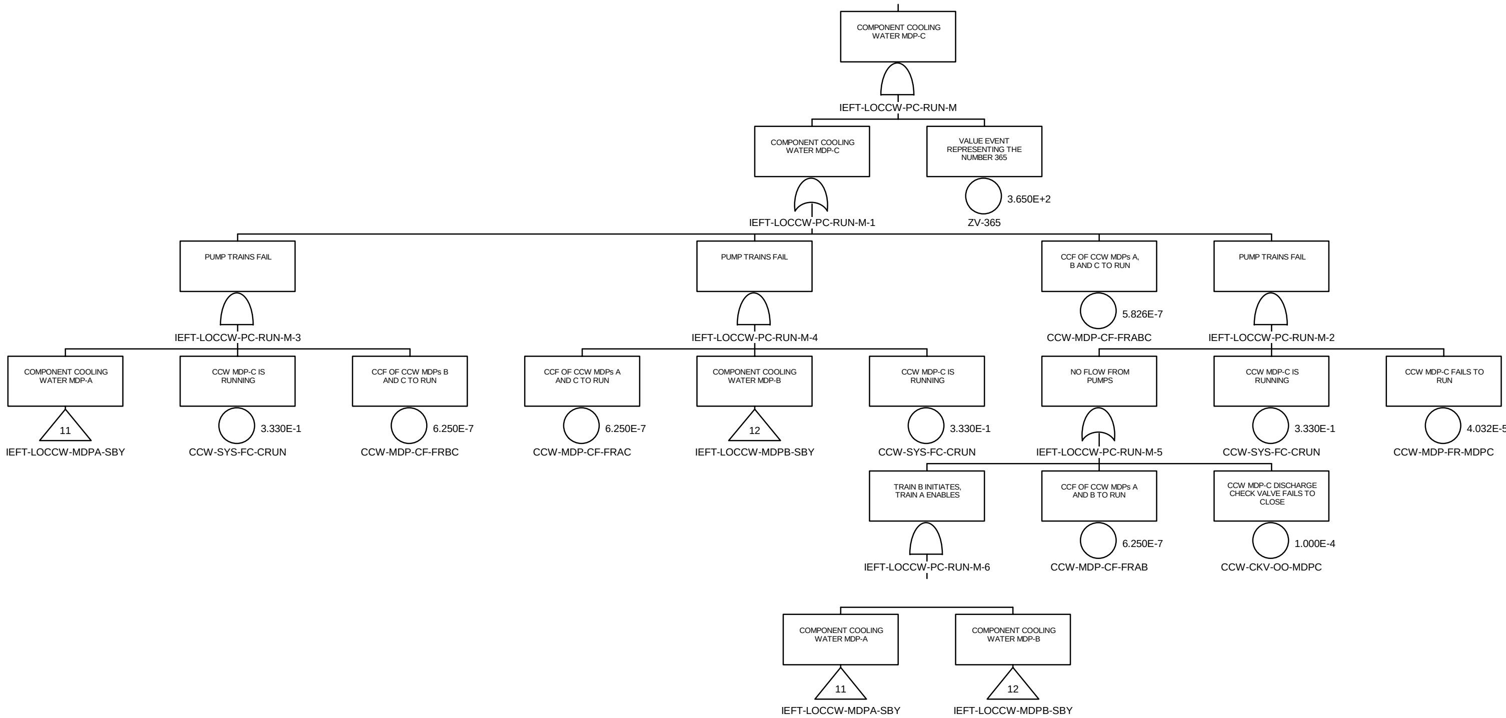

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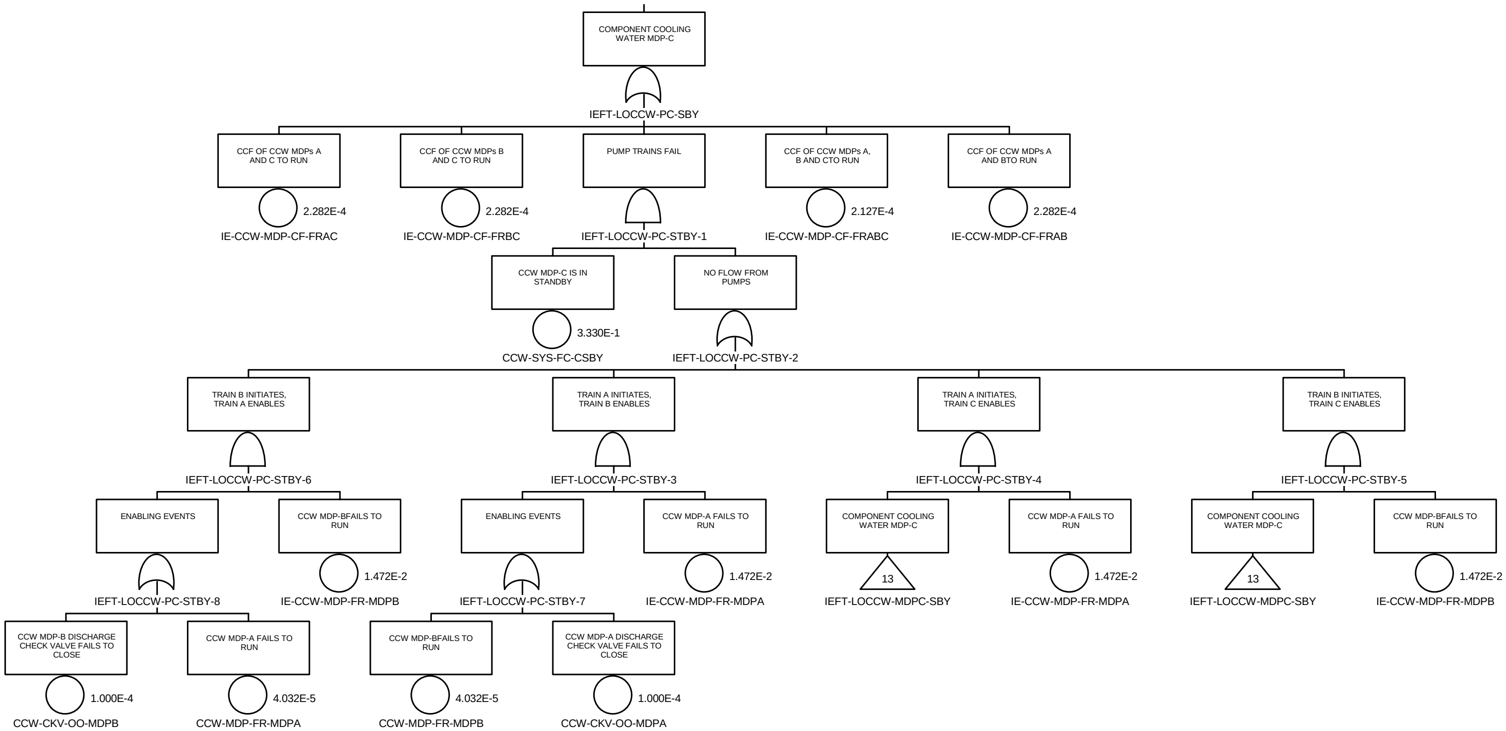

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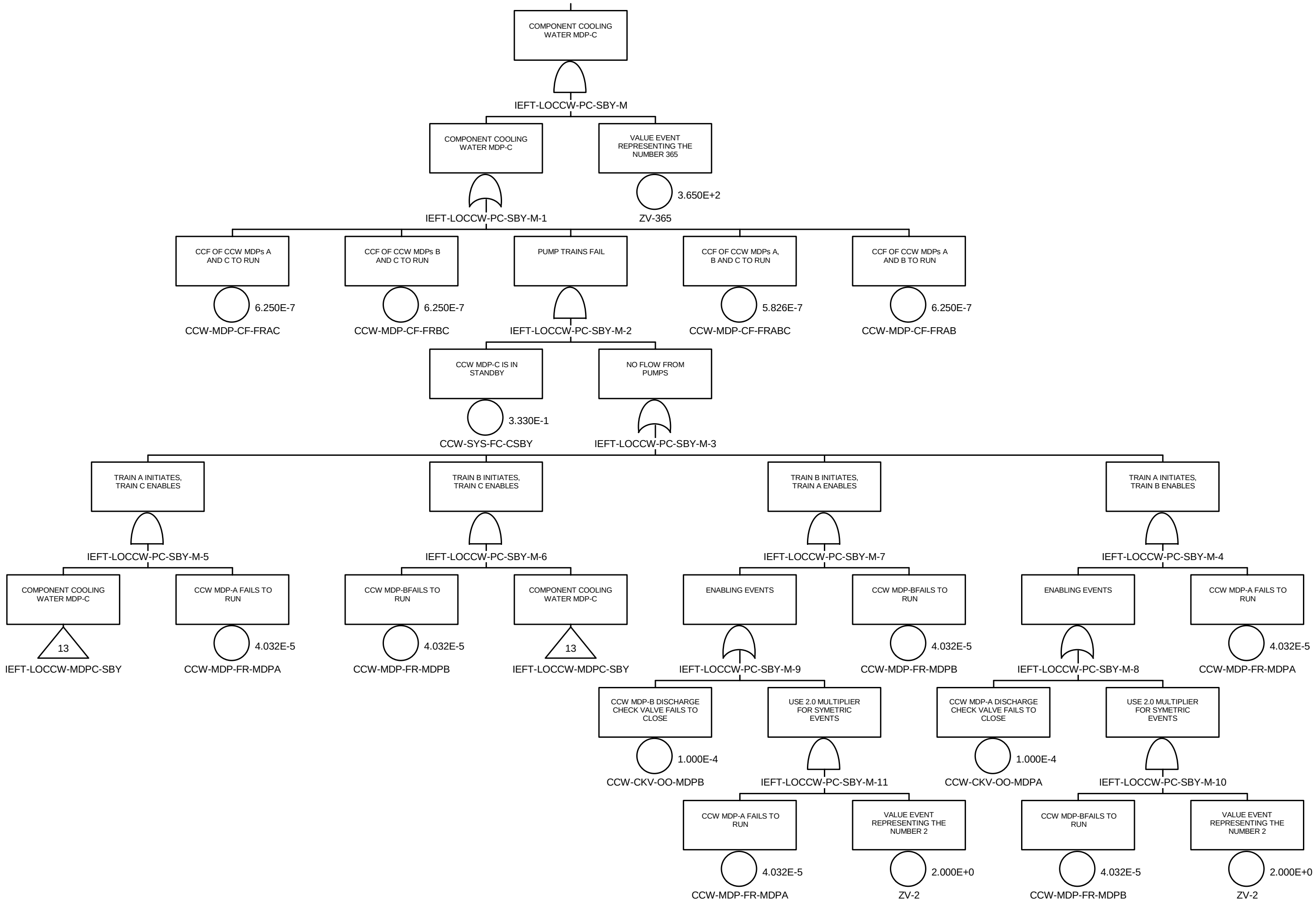


IEFT-LOCCW-PC-SBY-M - COMPONENT COOLING WATER MDP-C 2008/06/03 A- 25

Attachment B to Appendix C

Cutsets

Cut No.	% Total	% Cutset	Prob./ Frequency	Basic Event	Description	Event Prob.
1	19.89	19.89	1.754E-004	IE-CCW-HTX-CF-FCAB	CCF OF CCW HTXs A/B	1.754E-004
2	32.83	12.94	1.141E-004	CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				IE-CCW-MDP-CF-FRAC	CCF OF CCW MDPs A AND C TO RUN	2.282E-004
3	45.77	12.94	1.141E-004	CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				IE-CCW-MDP-CF-FRBC	CCF OF CCW MDPs B AND C TO RUN	2.282E-004
4	58.71	12.94	1.141E-004	CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				IE-CCW-MDP-CF-FRAB	CCF OF CCW MDPs A AND BTO RUN	2.282E-004
5	70.77	12.06	1.063E-004	CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				IE-CCW-MDP-CF-FRABC	CCF OF CCW MDPs A, B AND CTO RUN	2.127E-004
6	82.83	12.06	1.063E-004	CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				IE-CCW-MDP-CF-FRABC	CCF OF CCW MDPs A, B AND CTO RUN	2.127E-004
7	84.81	1.98	1.750E-005	IE-CCW-TNK-FC-SURGE	FAILURE OF CCW SURGE TANK	1.750E-005
8	86.48	1.67	1.471E-005	CCW-MDP-TM-MDPA	CCW MDP-A UNAVAILABLE DUE TO T & M	6.000E-003
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-ASBY	CCW MDP-A IS IN STANDBY	3.330E-001
				IE-CCW-MDP-FR-MDPC	CCW MDP-CFAILS TO RUN	1.472E-002
9	88.15	1.67	1.471E-005	CCW-MDP-TM-MDPA	CCW MDP-A UNAVAILABLE DUE TO T & M	6.000E-003
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-ASBY	CCW MDP-A IS IN STANDBY	3.330E-001
				IE-CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	1.472E-002
10	89.82	1.67	1.471E-005	CCW-MDP-TM-MDPB	CCW MDP-B UNAVAILABLE DUE TO T & M	6.000E-003
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-BSBY	CCW MDP-B IS IN STANDBY	3.330E-001
				IE-CCW-MDP-FR-MDPC	CCW MDP-CFAILS TO RUN	1.472E-002
11	91.49	1.67	1.471E-005	CCW-MDP-TM-MDPC	CCW MDP-C UNAVAILABLE DUE TO T & M	6.000E-003
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-CSBY	CCW MDP-C IS IN STANDBY	3.330E-001
				IE-CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	1.472E-002
12	93.16	1.67	1.471E-005	CCW-MDP-TM-MDPC	CCW MDP-C UNAVAILABLE DUE TO T & M	6.000E-003
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001

Cut No.	% Total	% Cutset	Prob./ Frequency	Basic Event	Description	Event Prob.
				CCW-SYS-FC-CSBY	CCW MDP-C IS IN STANDBY	3.330E-001
				IE-CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	1.472E-002
13	94.83	1.67	1.471E-005	CCW-MDP-TM-MDPB	CCW MDP-B UNAVAILABLE DUE TO T & M	6.000E-003
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-BSBY	CCW MDP-B IS IN STANDBY	3.330E-001
				IE-CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	1.472E-002
14	95.40	0.57	5.025E-006	CCW-HTX-FC-BSTBY	HEAT EXCHANGER A IS ONLINE, B IS IN STANDBY	5.000E-001
				CCW-HTX-TM-B	CCW HTX-B IS IN TEST OR MAINTENANCE	2.500E-003
				IE-CCW-HTX-FC-A	CCW HTX-A FAILS TO FUNCTION	4.020E-003
15	95.97	0.57	5.025E-006	CCW-HTX-FC-ASTBY	HEAT EXCHANGER B IS ONLINE, A IS IN STANDBY	5.000E-001
				CCW-HTX-TM-A	CCW HTX-A IS IN TEST OR MAINTENANCE	2.500E-003
				IE-CCW-HTX-FC-B	CCW HTX-B FAILS TO FUNCTION	4.020E-003
16	96.53	0.56	4.902E-006	CCW-MDP-FS-MDPA	CCW MDP-A FAILS TO START	2.000E-003
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-ASBY	CCW MDP-A IS IN STANDBY	3.330E-001
				IE-CCW-MDP-FR-MDPC	CCW MDP-CFAILS TO RUN	1.472E-002
17	97.09	0.56	4.902E-006	CCW-MDP-FS-MDPA	CCW MDP-A FAILS TO START	2.000E-003
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-ASBY	CCW MDP-A IS IN STANDBY	3.330E-001
				IE-CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	1.472E-002
18	97.65	0.56	4.902E-006	CCW-MDP-FS-MDPC	CCW MDP-C FAILS TO START	2.000E-003
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-CSBY	CCW MDP-C IS IN STANDBY	3.330E-001
				IE-CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	1.472E-002
19	98.21	0.56	4.902E-006	CCW-MDP-FS-MDPB	CCW MDP-B FAILS TO START	2.000E-003
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-BSBY	CCW MDP-B IS IN STANDBY	3.330E-001
				IE-CCW-MDP-FR-MDPC	CCW MDP-CFAILS TO RUN	1.472E-002
20	98.77	0.56	4.902E-006	CCW-MDP-FS-MDPB	CCW MDP-B FAILS TO START	2.000E-003
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001

Cut No.	% Total	% Cutset	Prob./ Frequency	Basic Event	Description	Event Prob.
				CCW-SYS-FC-BSBY	CCW MDP-B IS IN STANDBY	3.330E-001
				IE-CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	1.472E-002
21	99.33	0.56	4.902E-006	CCW-MDP-FS-MDPC	CCW MDP-C FAILS TO START	2.000E-003
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-CSBY	CCW MDP-C IS IN STANDBY	3.330E-001
				IE-CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	1.472E-002
22	99.36	0.03	2.451E-007	CCW-CKV-OO-MDPA	CCW MDP-A DISCHARGE CHECK VALVE FAILS TO CLOSE	1.000E-004
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-ARUN	CCW MDP-A IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	1.472E-002
23	99.39	0.03	2.451E-007	CCW-CKV-OO-MDPB	CCW MDP-B DISCHARGE CHECK VALVE FAILS TO CLOSE	1.000E-004
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-BRUN	CCW MDP-B IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	1.472E-002
24	99.42	0.03	2.451E-007	CCW-CKV-OO-MDPC	CCW MDP-C DISCHARGE CHECK VALVE FAILS TO CLOSE	1.000E-004
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-CRUN	CCW MDP-C IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPC	CCW MDP-CFAILS TO RUN	1.472E-002
25	99.45	0.03	2.451E-007	CCW-CKV-OO-MDPB	CCW MDP-B DISCHARGE CHECK VALVE FAILS TO CLOSE	1.000E-004
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-ASBY	CCW MDP-A IS IN STANDBY	3.330E-001
				IE-CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	1.472E-002
26	99.48	0.03	2.451E-007	CCW-CKV-OO-MDPC	CCW MDP-C DISCHARGE CHECK VALVE FAILS TO CLOSE	1.000E-004
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-ASBY	CCW MDP-A IS IN STANDBY	3.330E-001
				IE-CCW-MDP-FR-MDPC	CCW MDP-CFAILS TO RUN	1.472E-002
27	99.51	0.03	2.451E-007	CCW-CKV-OO-MDPA	CCW MDP-A DISCHARGE CHECK VALVE FAILS TO CLOSE	1.000E-004
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-BSBY	CCW MDP-B IS IN STANDBY	3.330E-001
				IE-CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	1.472E-002

Cut No.	% Total	% Cutset	Prob./ Frequency	Basic Event	Description	Event Prob.
28	99.54	0.03	2.451E-007	CCW-CKV-OO-MDPA	CCW MDP-A DISCHARGE CHECK VALVE FAILS TO CLOSE	1.000E-004
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-CSBY	CCW MDP-C IS IN STANDBY	3.330E-001
				IE-CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	1.472E-002
29	99.57	0.03	2.451E-007	CCW-CKV-OO-MDPC	CCW MDP-C DISCHARGE CHECK VALVE FAILS TO CLOSE	1.000E-004
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-BSBY	CCW MDP-B IS IN STANDBY	3.330E-001
				IE-CCW-MDP-FR-MDPC	CCW MDP-CFAILS TO RUN	1.472E-002
30	99.60	0.03	2.451E-007	CCW-CKV-OO-MDPB	CCW MDP-B DISCHARGE CHECK VALVE FAILS TO CLOSE	1.000E-004
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-CSBY	CCW MDP-C IS IN STANDBY	3.330E-001
				IE-CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	1.472E-002
31	99.63	0.03	2.280E-007	CCW-MDP-TM-MDPB	CCW MDP-B UNAVAILABLE DUE TO T & M	6.000E-003
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-ARUN	CCW MDP-A IS RUNNING	3.330E-001
				IE-CCW-MDP-CF-FRAC	CCF OF CCW MDPs A AND C TO RUN	2.282E-004
32	99.66	0.03	2.280E-007	CCW-MDP-TM-MDPB	CCW MDP-B UNAVAILABLE DUE TO T & M	6.000E-003
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-CRUN	CCW MDP-C IS RUNNING	3.330E-001
				IE-CCW-MDP-CF-FRAC	CCF OF CCW MDPs A AND C TO RUN	2.282E-004
33	99.69	0.03	2.280E-007	CCW-MDP-TM-MDPC	CCW MDP-C UNAVAILABLE DUE TO T & M	6.000E-003
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-ARUN	CCW MDP-A IS RUNNING	3.330E-001
				IE-CCW-MDP-CF-FRAB	CCF OF CCW MDPs A AND BTO RUN	2.282E-004
34	99.72	0.03	2.280E-007	CCW-MDP-TM-MDPC	CCW MDP-C UNAVAILABLE DUE TO T & M	6.000E-003
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-BRUN	CCW MDP-B IS RUNNING	3.330E-001
				IE-CCW-MDP-CF-FRAB	CCF OF CCW MDPs A AND BTO RUN	2.282E-004
35	99.75	0.03	2.280E-007	CCW-MDP-TM-MDPA	CCW MDP-A UNAVAILABLE DUE TO T & M	6.000E-003
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001

Cut No.	% Total	% Cutset	Prob./ Frequency	Basic Event	Description	Event Prob.
				CCW-SYS-FC-BRUN	CCW MDP-B IS RUNNING	3.330E-001
				IE-CCW-MDP-CF-FRBC	CCF OF CCW MDPs B AND C TO RUN	2.282E-004
36	99.78	0.03	2.280E-007	CCW-MDP-TM-MDPA	CCW MDP-A UNAVAILABLE DUE TO T & M	6.000E-003
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-CRUN	CCW MDP-C IS RUNNING	3.330E-001
				IE-CCW-MDP-CF-FRBC	CCF OF CCW MDPs B AND C TO RUN	2.282E-004
37	99.79	0.01	9.882E-008	CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	4.032E-005
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-ASBY	CCW MDP-A IS IN STANDBY	3.330E-001
				IE-CCW-MDP-FR-MDPC	CCW MDP-CFAILS TO RUN	1.472E-002
38	99.80	0.01	9.882E-008	CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	4.032E-005
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-ASBY	CCW MDP-A IS IN STANDBY	3.330E-001
				IE-CCW-MDP-FR-MDPC	CCW MDP-CFAILS TO RUN	1.472E-002
39	99.81	0.01	9.882E-008	CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	4.032E-005
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-ASBY	CCW MDP-A IS IN STANDBY	3.330E-001
				IE-CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	1.472E-002
40	99.82	0.01	9.882E-008	CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	4.032E-005
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-BSBY	CCW MDP-B IS IN STANDBY	3.330E-001
				IE-CCW-MDP-FR-MDPC	CCW MDP-CFAILS TO RUN	1.472E-002
41	99.83	0.01	9.882E-008	CCW-MDP-FR-MDPC	CCW MDP-C FAILS TO RUN	4.032E-005
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-CSBY	CCW MDP-C IS IN STANDBY	3.330E-001
				IE-CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	1.472E-002
42	99.84	0.01	9.882E-008	CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	4.032E-005
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-BSBY	CCW MDP-B IS IN STANDBY	3.330E-001
				IE-CCW-MDP-FR-MDPC	CCW MDP-CFAILS TO RUN	1.472E-002

Cut No.	% Total	% Cutset	Prob./ Frequency	Basic Event	Description	Event Prob.
43	99.85	0.01	9.882E-008	CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	4.032E-005
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-CSBY	CCW MDP-C IS IN STANDBY	3.330E-001
				IE-CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	1.472E-002
44	99.86	0.01	9.882E-008	CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	4.032E-005
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-BSBY	CCW MDP-B IS IN STANDBY	3.330E-001
				IE-CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	1.472E-002
45	99.87	0.01	9.882E-008	CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	4.032E-005
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-CSBY	CCW MDP-C IS IN STANDBY	3.330E-001
				IE-CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	1.472E-002
46	99.88	0.01	9.882E-008	CCW-MDP-FR-MDPC	CCW MDP-C FAILS TO RUN	4.032E-005
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-BSBY	CCW MDP-B IS IN STANDBY	3.330E-001
				IE-CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	1.472E-002
47	99.89	0.01	9.882E-008	CCW-MDP-FR-MDPC	CCW MDP-C FAILS TO RUN	4.032E-005
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-CSBY	CCW MDP-C IS IN STANDBY	3.330E-001
				IE-CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	1.472E-002
48	99.90	0.01	8.823E-008	CCW-MDP-TM-MDPA	CCW MDP-A UNAVAILABLE DUE TO T & M	6.000E-003
				CCW-MDP-TM-MDPC	CCW MDP-C UNAVAILABLE DUE TO T & M	6.000E-003
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-BRUN	CCW MDP-B IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	1.472E-002
49	99.91	0.01	8.823E-008	CCW-MDP-TM-MDPA	CCW MDP-A UNAVAILABLE DUE TO T & M	6.000E-003
				CCW-MDP-TM-MDPB	CCW MDP-B UNAVAILABLE DUE TO T & M	6.000E-003
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-CRUN	CCW MDP-C IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPC	CCW MDP-CFAILS TO RUN	1.472E-002

Cut No.	% Total	% Cutset	Prob./ Frequency	Basic Event	Description	Event Prob.
50	99.92	0.01	8.823E-008	CCW-MDP-TM-MDPB	CCW MDP-B UNAVAILABLE DUE TO T & M	6.000E-003
				CCW-MDP-TM-MDPC	CCW MDP-C UNAVAILABLE DUE TO T & M	6.000E-003
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-ARUN	CCW MDP-A IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	1.472E-002
51	99.93	0.01	8.117E-008	CCW-MDP-CF-FSALL	CCF OF ALL CCW MDPs TO START	3.312E-005
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-BRUN	CCW MDP-B IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	1.472E-002
52	99.94	0.01	8.117E-008	CCW-MDP-CF-FSALL	CCF OF ALL CCW MDPs TO START	3.312E-005
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-CRUN	CCW MDP-C IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPC	CCW MDP-CFAILS TO RUN	1.472E-002
53	99.95	0.01	8.117E-008	CCW-MDP-CF-FSALL	CCF OF ALL CCW MDPs TO START	3.312E-005
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-ARUN	CCW MDP-A IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	1.472E-002
54	99.96	0.01	8.117E-008	CCW-MDP-CF-FSALL	CCF OF ALL CCW MDPs TO START	3.312E-005
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-ASBY	CCW MDP-A IS IN STANDBY	3.330E-001
				IE-CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	1.472E-002
55	99.97	0.01	8.117E-008	CCW-MDP-CF-FSALL	CCF OF ALL CCW MDPs TO START	3.312E-005
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-ASBY	CCW MDP-A IS IN STANDBY	3.330E-001
				IE-CCW-MDP-FR-MDPC	CCW MDP-CFAILS TO RUN	1.472E-002
56	99.98	0.01	8.117E-008	CCW-MDP-CF-FSALL	CCF OF ALL CCW MDPs TO START	3.312E-005
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-CSBY	CCW MDP-C IS IN STANDBY	3.330E-001
				IE-CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	1.472E-002
57	99.99	0.01	8.117E-008	CCW-MDP-CF-FSALL	CCF OF ALL CCW MDPs TO START	3.312E-005

Cut No.	% Total	% Cutset	Prob./ Frequency	Basic Event	Description	Event Prob.
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-BSBY	CCW MDP-B IS IN STANDBY	3.330E-001
				IE-CCW-MDP-FR-MDPC	CCW MDP-CFAILS TO RUN	1.472E-002
58	100.00	0.01	8.117E-008	CCW-MDP-CF-FSALL	CCF OF ALL CCW MDPs TO START	3.312E-005
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-BSBY	CCW MDP-B IS IN STANDBY	3.330E-001
				IE-CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	1.472E-002
59	100.00	0.01	8.117E-008	CCW-MDP-CF-FSALL	CCF OF ALL CCW MDPs TO START	3.312E-005
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-CSBY	CCW MDP-C IS IN STANDBY	3.330E-001
				IE-CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	1.472E-002
60	100.00	0.01	7.598E-008	CCW-MDP-FS-MDPA	CCW MDP-A FAILS TO START	2.000E-003
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-BRUN	CCW MDP-B IS RUNNING	3.330E-001
				IE-CCW-MDP-CF-FRBC	CCF OF CCW MDPs B AND C TO RUN	2.282E-004
61	100.00	0.01	7.598E-008	CCW-MDP-FS-MDPA	CCW MDP-A FAILS TO START	2.000E-003
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-CRUN	CCW MDP-C IS RUNNING	3.330E-001
				IE-CCW-MDP-CF-FRBC	CCF OF CCW MDPs B AND C TO RUN	2.282E-004
62	100.00	0.01	7.598E-008	CCW-MDP-FS-MDPB	CCW MDP-B FAILS TO START	2.000E-003
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-ARUN	CCW MDP-A IS RUNNING	3.330E-001
				IE-CCW-MDP-CF-FRAC	CCF OF CCW MDPs A AND C TO RUN	2.282E-004
63	100.00	0.01	7.598E-008	CCW-MDP-FS-MDPB	CCW MDP-B FAILS TO START	2.000E-003
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-CRUN	CCW MDP-C IS RUNNING	3.330E-001
				IE-CCW-MDP-CF-FRAC	CCF OF CCW MDPs A AND C TO RUN	2.282E-004
64	100.00	0.01	7.598E-008	CCW-MDP-FS-MDPC	CCW MDP-C FAILS TO START	2.000E-003
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-ARUN	CCW MDP-A IS RUNNING	3.330E-001

Cut No.	% Total	% Cutset	Prob./ Frequency	Basic Event	Description	Event Prob.
				IE-CCW-MDP-CF-FRAB	CCF OF CCW MDPs A AND BTO RUN	2.282E-004
65	100.00	0.01	7.598E-008	CCW-MDP-FS-MDPC	CCW MDP-C FAILS TO START	2.000E-003
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-BRUN	CCW MDP-B IS RUNNING	3.330E-001
				IE-CCW-MDP-CF-FRAB	CCF OF CCW MDPs A AND BTO RUN	2.282E-004
66	100.00	0.00	2.941E-008	CCW-CKV-CC-MDPA	CCW MDP-A DISCHARGE CHECK VALVE FAILS TO OPEN	1.200E-005
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-ASBY	CCW MDP-A IS IN STANDBY	3.330E-001
				IE-CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	1.472E-002
67	100.00	0.00	2.941E-008	CCW-CKV-CC-MDPA	CCW MDP-A DISCHARGE CHECK VALVE FAILS TO OPEN	1.200E-005
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-ASBY	CCW MDP-A IS IN STANDBY	3.330E-001
				IE-CCW-MDP-FR-MDPC	CCW MDP-CFAILS TO RUN	1.472E-002
68	100.00	0.00	2.941E-008	CCW-CKV-CC-MDPB	CCW MDP-B DISCHARGE CHECK VALVE FAILS TO OPEN	1.200E-005
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-BSBY	CCW MDP-B IS IN STANDBY	3.330E-001
				IE-CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	1.472E-002
69	100.00	0.00	2.941E-008	CCW-CKV-CC-MDPC	CCW MDP-C DISCHARGE CHECK VALVE FAILS TO OPEN	1.200E-005
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-CSBY	CCW MDP-C IS IN STANDBY	3.330E-001
				IE-CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	1.472E-002
70	100.00	0.00	2.941E-008	CCW-CKV-CC-MDPC	CCW MDP-C DISCHARGE CHECK VALVE FAILS TO OPEN	1.200E-005
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-CSBY	CCW MDP-C IS IN STANDBY	3.330E-001
				IE-CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	1.472E-002
71	100.00	0.00	2.941E-008	CCW-CKV-CC-MDPB	CCW MDP-B DISCHARGE CHECK VALVE FAILS TO OPEN	1.200E-005
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-BSBY	CCW MDP-B IS IN STANDBY	3.330E-001
				IE-CCW-MDP-FR-MDPC	CCW MDP-CFAILS TO RUN	1.472E-002
72	100.00	0.00	2.941E-008	CCW-MDP-FS-MDPB	CCW MDP-B FAILS TO START	2.000E-003

Cut No.	% Total	% Cutset	Prob./ Frequency	Basic Event	Description	Event Prob.
				CCW-MDP-TM-MDPA	CCW MDP-A UNAVAILABLE DUE TO T & M	6.000E-003
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-CRUN	CCW MDP-C IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPC	CCW MDP-CFAILS TO RUN	1.472E-002
73	100.00	0.00	2.941E-008	CCW-MDP-FS-MDPC	CCW MDP-C FAILS TO START	2.000E-003
				CCW-MDP-TM-MDPA	CCW MDP-A UNAVAILABLE DUE TO T & M	6.000E-003
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-BRUN	CCW MDP-B IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	1.472E-002
74	100.00	0.00	2.941E-008	CCW-MDP-FS-MDPC	CCW MDP-C FAILS TO START	2.000E-003
				CCW-MDP-TM-MDPB	CCW MDP-B UNAVAILABLE DUE TO T & M	6.000E-003
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-ARUN	CCW MDP-A IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	1.472E-002
75	100.00	0.00	2.941E-008	CCW-MDP-FS-MDPB	CCW MDP-B FAILS TO START	2.000E-003
				CCW-MDP-TM-MDPC	CCW MDP-C UNAVAILABLE DUE TO T & M	6.000E-003
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-ARUN	CCW MDP-A IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	1.472E-002
76	100.00	0.00	2.941E-008	CCW-MDP-FS-MDPA	CCW MDP-A FAILS TO START	2.000E-003
				CCW-MDP-TM-MDPC	CCW MDP-C UNAVAILABLE DUE TO T & M	6.000E-003
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-BRUN	CCW MDP-B IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	1.472E-002
77	100.00	0.00	2.941E-008	CCW-MDP-FS-MDPA	CCW MDP-A FAILS TO START	2.000E-003
				CCW-MDP-TM-MDPB	CCW MDP-B UNAVAILABLE DUE TO T & M	6.000E-003
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-CRUN	CCW MDP-C IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPC	CCW MDP-CFAILS TO RUN	1.472E-002
78	100.00	0.00	2.214E-008	CCW-HTX-FC-A	CCW HTX-A FAILS TO FUNCTION	1.102E-005

Cut No.	% Total	% Cutset	Prob./ Frequency	Basic Event	Description	Event Prob.
				CCW-HTX-FC-ASTBY	HEAT EXCHANGER B IS ONLINE, A IS IN STANDBY	5.000E-001
				IE-CCW-HTX-FC-B	CCW HTX-B FAILS TO FUNCTION	4.020E-003
79	100.00	0.00	2.214E-008	CCW-HTX-FC-B	CCW HTX-B FAILS TO FUNCTION	1.102E-005
				CCW-HTX-FC-BSTBY	HEAT EXCHANGER A IS ONLINE, B IS IN STANDBY	5.000E-001
				IE-CCW-HTX-FC-A	CCW HTX-A FAILS TO FUNCTION	4.020E-003
80	100.00	0.00	9.804E-009	CCW-MDP-FS-MDPB	CCW MDP-B FAILS TO START	2.000E-003
				CCW-MDP-FS-MDPC	CCW MDP-C FAILS TO START	2.000E-003
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-ARUN	CCW MDP-A IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	1.472E-002
81	100.00	0.00	9.804E-009	CCW-MDP-FS-MDPA	CCW MDP-A FAILS TO START	2.000E-003
				CCW-MDP-FS-MDPB	CCW MDP-B FAILS TO START	2.000E-003
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-CRUN	CCW MDP-C IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPC	CCW MDP-CFAILS TO RUN	1.472E-002
82	100.00	0.00	9.804E-009	CCW-MDP-FS-MDPA	CCW MDP-A FAILS TO START	2.000E-003
				CCW-MDP-FS-MDPC	CCW MDP-C FAILS TO START	2.000E-003
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-BRUN	CCW MDP-B IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	1.472E-002
83	100.00	0.00	1.532E-009	CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	4.032E-005
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-ARUN	CCW MDP-A IS RUNNING	3.330E-001
				IE-CCW-MDP-CF-FRAC	CCF OF CCW MDPs A AND C TO RUN	2.282E-004
84	100.00	0.00	1.532E-009	CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	4.032E-005
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-CRUN	CCW MDP-C IS RUNNING	3.330E-001
				IE-CCW-MDP-CF-FRAC	CCF OF CCW MDPs A AND C TO RUN	2.282E-004
85	100.00	0.00	1.532E-009	CCW-MDP-FR-MDPC	CCW MDP-C FAILS TO RUN	4.032E-005
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001

Cut No.	% Total	% Cutset	Prob./ Frequency	Basic Event	Description	Event Prob.
				CCW-SYS-FC-ARUN	CCW MDP-A IS RUNNING	3.330E-001
				IE-CCW-MDP-CF-FRAB	CCF OF CCW MDPs A AND BTO RUN	2.282E-004
86	100.00	0.00	1.532E-009	CCW-MDP-FR-MDPC	CCW MDP-C FAILS TO RUN	4.032E-005
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-BRUN	CCW MDP-B IS RUNNING	3.330E-001
				IE-CCW-MDP-CF-FRAB	CCF OF CCW MDPs A AND BTO RUN	2.282E-004
87	100.00	0.00	1.532E-009	CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	4.032E-005
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-BRUN	CCW MDP-B IS RUNNING	3.330E-001
				IE-CCW-MDP-CF-FRBC	CCF OF CCW MDPs B AND C TO RUN	2.282E-004
88	100.00	0.00	1.532E-009	CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	4.032E-005
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-CRUN	CCW MDP-C IS RUNNING	3.330E-001
				IE-CCW-MDP-CF-FRBC	CCF OF CCW MDPs B AND C TO RUN	2.282E-004
89	100.00	0.00	1.532E-009	CCW-MDP-CF-FRBC	CCF OF CCW MDPs B AND C TO RUN	6.250E-007
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-ARUN	CCW MDP-A IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	1.472E-002
90	100.00	0.00	1.532E-009	CCW-MDP-CF-FRAC	CCF OF CCW MDPs A AND C TO RUN	6.250E-007
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-BRUN	CCW MDP-B IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	1.472E-002
91	100.00	0.00	1.532E-009	CCW-MDP-CF-FRAB	CCF OF CCW MDPs A AND B TO RUN	6.250E-007
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-CRUN	CCW MDP-C IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPC	CCW MDP-CFAILS TO RUN	1.472E-002
92	100.00	0.00	1.258E-009	CCW-MDP-CF-FSALL	CCF OF ALL CCW MDPs TO START	3.312E-005
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-ARUN	CCW MDP-A IS RUNNING	3.330E-001
				IE-CCW-MDP-CF-FRAB	CCF OF CCW MDPs A AND BTO RUN	2.282E-004

Cut No.	% Total	% Cutset	Prob./ Frequency	Basic Event	Description	Event Prob.
93	100.00	0.00	1.258E-009	CCW-MDP-CF-FSALL	CCF OF ALL CCW MDPs TO START	3.312E-005
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-BRUN	CCW MDP-B IS RUNNING	3.330E-001
				IE-CCW-MDP-CF-FRAB	CCF OF CCW MDPs A AND BTO RUN	2.282E-004
94	100.00	0.00	1.258E-009	CCW-MDP-CF-FSALL	CCF OF ALL CCW MDPs TO START	3.312E-005
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-ARUN	CCW MDP-A IS RUNNING	3.330E-001
				IE-CCW-MDP-CF-FRAC	CCF OF CCW MDPs A AND C TO RUN	2.282E-004
95	100.00	0.00	1.258E-009	CCW-MDP-CF-FSALL	CCF OF ALL CCW MDPs TO START	3.312E-005
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-CRUN	CCW MDP-C IS RUNNING	3.330E-001
				IE-CCW-MDP-CF-FRAC	CCF OF CCW MDPs A AND C TO RUN	2.282E-004
96	100.00	0.00	1.258E-009	CCW-MDP-CF-FSALL	CCF OF ALL CCW MDPs TO START	3.312E-005
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-BRUN	CCW MDP-B IS RUNNING	3.330E-001
				IE-CCW-MDP-CF-FRBC	CCF OF CCW MDPs B AND C TO RUN	2.282E-004
97	100.00	0.00	1.258E-009	CCW-MDP-CF-FSALL	CCF OF ALL CCW MDPs TO START	3.312E-005
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-CRUN	CCW MDP-C IS RUNNING	3.330E-001
				IE-CCW-MDP-CF-FRBC	CCF OF CCW MDPs B AND C TO RUN	2.282E-004
98	100.00	0.00	5.929E-010	CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	4.032E-005
				CCW-MDP-TM-MDPA	CCW MDP-A UNAVAILABLE DUE TO T & M	6.000E-003
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-CRUN	CCW MDP-C IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPC	CCW MDP-CFAILS TO RUN	1.472E-002
99	100.00	0.00	5.929E-010	CCW-MDP-FR-MDPC	CCW MDP-C FAILS TO RUN	4.032E-005
				CCW-MDP-TM-MDPA	CCW MDP-A UNAVAILABLE DUE TO T & M	6.000E-003
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-BRUN	CCW MDP-B IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	1.472E-002

Cut No.	% Total	% Cutset	Prob./ Frequency	Basic Event	Description	Event Prob.
100	100.00	0.00	5.929E-010	CCW-MDP-FR-MDPC	CCW MDP-C FAILS TO RUN	4.032E-005
				CCW-MDP-TM-MDPB	CCW MDP-B UNAVAILABLE DUE TO T & M	6.000E-003
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-ARUN	CCW MDP-A IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	1.472E-002
101	100.00	0.00	5.929E-010	CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	4.032E-005
				CCW-MDP-TM-MDPC	CCW MDP-C UNAVAILABLE DUE TO T & M	6.000E-003
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-ARUN	CCW MDP-A IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	1.472E-002
102	100.00	0.00	5.929E-010	CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	4.032E-005
				CCW-MDP-TM-MDPC	CCW MDP-C UNAVAILABLE DUE TO T & M	6.000E-003
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-BRUN	CCW MDP-B IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	1.472E-002
103	100.00	0.00	5.929E-010	CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	4.032E-005
				CCW-MDP-TM-MDPB	CCW MDP-B UNAVAILABLE DUE TO T & M	6.000E-003
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-CRUN	CCW MDP-C IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPC	CCW MDP-CFAILS TO RUN	1.472E-002
104	100.00	0.00	4.765E-010	CCW-CKV-CF-MDPS	CCF OF CCW MDPs DISCHARGE CHECK VALVES	1.944E-007
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-CRUN	CCW MDP-C IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPC	CCW MDP-CFAILS TO RUN	1.472E-002
105	100.00	0.00	4.765E-010	CCW-CKV-CF-MDPS	CCF OF CCW MDPs DISCHARGE CHECK VALVES	1.944E-007
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-BRUN	CCW MDP-B IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	1.472E-002
106	100.00	0.00	4.765E-010	CCW-CKV-CF-MDPS	CCF OF CCW MDPs DISCHARGE CHECK VALVES	1.944E-007
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001

Cut No.	% Total	% Cutset	Prob./ Frequency	Basic Event	Description	Event Prob.
				CCW-SYS-FC-ARUN	CCW MDP-A IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	1.472E-002
107	100.00	0.00	4.765E-010	CCW-CKV-CF-MDPS	CCF OF CCW MDPs DISCHARGE CHECK VALVES	1.944E-007
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-ASBY	CCW MDP-A IS IN STANDBY	3.330E-001
				IE-CCW-MDP-FR-MDPC	CCW MDP-CFAILS TO RUN	1.472E-002
108	100.00	0.00	4.765E-010	CCW-CKV-CF-MDPS	CCF OF CCW MDPs DISCHARGE CHECK VALVES	1.944E-007
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-ASBY	CCW MDP-A IS IN STANDBY	3.330E-001
				IE-CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	1.472E-002
109	100.00	0.00	4.765E-010	CCW-CKV-CF-MDPS	CCF OF CCW MDPs DISCHARGE CHECK VALVES	1.944E-007
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-BSBY	CCW MDP-B IS IN STANDBY	3.330E-001
				IE-CCW-MDP-FR-MDPC	CCW MDP-CFAILS TO RUN	1.472E-002
110	100.00	0.00	4.765E-010	CCW-CKV-CF-MDPS	CCF OF CCW MDPs DISCHARGE CHECK VALVES	1.944E-007
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-CSBY	CCW MDP-C IS IN STANDBY	3.330E-001
				IE-CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	1.472E-002
111	100.00	0.00	4.765E-010	CCW-CKV-CF-MDPS	CCF OF CCW MDPs DISCHARGE CHECK VALVES	1.944E-007
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-BSBY	CCW MDP-B IS IN STANDBY	3.330E-001
				IE-CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	1.472E-002
112	100.00	0.00	4.765E-010	CCW-CKV-CF-MDPS	CCF OF CCW MDPs DISCHARGE CHECK VALVES	1.944E-007
				CCW-SYS-FC-2OF3	TWO RUNNING PUMPS ARE REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-CSBY	CCW MDP-C IS IN STANDBY	3.330E-001
				IE-CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	1.472E-002
113	100.00	0.00	4.559E-010	CCW-CKV-CC-MDPC	CCW MDP-C DISCHARGE CHECK VALVE FAILS TO OPEN	1.200E-005
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-ARUN	CCW MDP-A IS RUNNING	3.330E-001
				IE-CCW-MDP-CF-FRAB	CCF OF CCW MDPs A AND BTO RUN	2.282E-004

Cut No.	% Total	% Cutset	Prob./ Frequency	Basic Event	Description	Event Prob.
114	100.00	0.00	4.559E-010	CCW-CKV-CC-MDPC	CCW MDP-C DISCHARGE CHECK VALVE FAILS TO OPEN	1.200E-005
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-BRUN	CCW MDP-B IS RUNNING	3.330E-001
				IE-CCW-MDP-CF-FRAB	CCF OF CCW MDPs A AND BTO RUN	2.282E-004
115	100.00	0.00	4.559E-010	CCW-CKV-CC-MDPA	CCW MDP-A DISCHARGE CHECK VALVE FAILS TO OPEN	1.200E-005
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-BRUN	CCW MDP-B IS RUNNING	3.330E-001
				IE-CCW-MDP-CF-FRBC	CCF OF CCW MDPs B AND C TO RUN	2.282E-004
116	100.00	0.00	4.559E-010	CCW-CKV-CC-MDPA	CCW MDP-A DISCHARGE CHECK VALVE FAILS TO OPEN	1.200E-005
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-CRUN	CCW MDP-C IS RUNNING	3.330E-001
				IE-CCW-MDP-CF-FRBC	CCF OF CCW MDPs B AND C TO RUN	2.282E-004
117	100.00	0.00	4.559E-010	CCW-CKV-CC-MDPB	CCW MDP-B DISCHARGE CHECK VALVE FAILS TO OPEN	1.200E-005
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-ARUN	CCW MDP-A IS RUNNING	3.330E-001
				IE-CCW-MDP-CF-FRAC	CCF OF CCW MDPs A AND C TO RUN	2.282E-004
118	100.00	0.00	4.559E-010	CCW-CKV-CC-MDPB	CCW MDP-B DISCHARGE CHECK VALVE FAILS TO OPEN	1.200E-005
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-CRUN	CCW MDP-C IS RUNNING	3.330E-001
				IE-CCW-MDP-CF-FRAC	CCF OF CCW MDPs A AND C TO RUN	2.282E-004
119	100.00	0.00	1.976E-010	CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	4.032E-005
				CCW-MDP-FS-MDPC	CCW MDP-C FAILS TO START	2.000E-003
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-ARUN	CCW MDP-A IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	1.472E-002
120	100.00	0.00	1.976E-010	CCW-MDP-FR-MDPC	CCW MDP-C FAILS TO RUN	4.032E-005
				CCW-MDP-FS-MDPB	CCW MDP-B FAILS TO START	2.000E-003
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-ARUN	CCW MDP-A IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	1.472E-002

Cut No.	% Total	% Cutset	Prob./ Frequency	Basic Event	Description	Event Prob.
121	100.00	0.00	1.976E-010	CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	4.032E-005
				CCW-MDP-FS-MDPB	CCW MDP-B FAILS TO START	2.000E-003
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-CRUN	CCW MDP-C IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPC	CCW MDP-CFAILS TO RUN	1.472E-002
122	100.00	0.00	1.976E-010	CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	4.032E-005
				CCW-MDP-FS-MDPC	CCW MDP-C FAILS TO START	2.000E-003
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-BRUN	CCW MDP-B IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	1.472E-002
123	100.00	0.00	1.976E-010	CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	4.032E-005
				CCW-MDP-FS-MDPA	CCW MDP-A FAILS TO START	2.000E-003
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-CRUN	CCW MDP-C IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPC	CCW MDP-CFAILS TO RUN	1.472E-002
124	100.00	0.00	1.976E-010	CCW-MDP-FR-MDPC	CCW MDP-C FAILS TO RUN	4.032E-005
				CCW-MDP-FS-MDPA	CCW MDP-A FAILS TO START	2.000E-003
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-BRUN	CCW MDP-B IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	1.472E-002
125	100.00	0.00	1.765E-010	CCW-CKV-CC-MDPB	CCW MDP-B DISCHARGE CHECK VALVE FAILS TO OPEN	1.200E-005
				CCW-MDP-TM-MDPA	CCW MDP-A UNAVAILABLE DUE TO T & M	6.000E-003
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-CRUN	CCW MDP-C IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPC	CCW MDP-CFAILS TO RUN	1.472E-002
126	100.00	0.00	1.765E-010	CCW-CKV-CC-MDPC	CCW MDP-C DISCHARGE CHECK VALVE FAILS TO OPEN	1.200E-005
				CCW-MDP-TM-MDPA	CCW MDP-A UNAVAILABLE DUE TO T & M	6.000E-003
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-BRUN	CCW MDP-B IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	1.472E-002

Cut No.	% Total	% Cutset	Prob./ Frequency	Basic Event	Description	Event Prob.
127	100.00	0.00	1.765E-010	CCW-CKV-CC-MDPC	CCW MDP-C DISCHARGE CHECK VALVE FAILS TO OPEN	1.200E-005
				CCW-MDP-TM-MDPB	CCW MDP-B UNAVAILABLE DUE TO T & M	6.000E-003
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-ARUN	CCW MDP-A IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	1.472E-002
128	100.00	0.00	1.765E-010	CCW-CKV-CC-MDPB	CCW MDP-B DISCHARGE CHECK VALVE FAILS TO OPEN	1.200E-005
				CCW-MDP-TM-MDPC	CCW MDP-C UNAVAILABLE DUE TO T & M	6.000E-003
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-ARUN	CCW MDP-A IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	1.472E-002
129	100.00	0.00	1.765E-010	CCW-CKV-CC-MDPA	CCW MDP-A DISCHARGE CHECK VALVE FAILS TO OPEN	1.200E-005
				CCW-MDP-TM-MDPC	CCW MDP-C UNAVAILABLE DUE TO T & M	6.000E-003
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-BRUN	CCW MDP-B IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	1.472E-002
130	100.00	0.00	1.765E-010	CCW-CKV-CC-MDPA	CCW MDP-A DISCHARGE CHECK VALVE FAILS TO OPEN	1.200E-005
				CCW-MDP-TM-MDPB	CCW MDP-B UNAVAILABLE DUE TO T & M	6.000E-003
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-CRUN	CCW MDP-C IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPC	CCW MDP-CFAILS TO RUN	1.472E-002
131	100.00	0.00	5.882E-011	CCW-CKV-CC-MDPB	CCW MDP-B DISCHARGE CHECK VALVE FAILS TO OPEN	1.200E-005
				CCW-MDP-FS-MDPC	CCW MDP-C FAILS TO START	2.000E-003
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-ARUN	CCW MDP-A IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	1.472E-002
132	100.00	0.00	5.882E-011	CCW-CKV-CC-MDPC	CCW MDP-C DISCHARGE CHECK VALVE FAILS TO OPEN	1.200E-005
				CCW-MDP-FS-MDPB	CCW MDP-B FAILS TO START	2.000E-003
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-ARUN	CCW MDP-A IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	1.472E-002

Cut No.	% Total	% Cutset	Prob./ Frequency	Basic Event	Description	Event Prob.
133	100.00	0.00	5.882E-011	CCW-CKV-CC-MDPB	CCW MDP-B DISCHARGE CHECK VALVE FAILS TO OPEN	1.200E-005
				CCW-MDP-FS-MDPA	CCW MDP-A FAILS TO START	2.000E-003
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-CRUN	CCW MDP-C IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPC	CCW MDP-CFAILS TO RUN	1.472E-002
134	100.00	0.00	5.882E-011	CCW-CKV-CC-MDPC	CCW MDP-C DISCHARGE CHECK VALVE FAILS TO OPEN	1.200E-005
				CCW-MDP-FS-MDPA	CCW MDP-A FAILS TO START	2.000E-003
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-BRUN	CCW MDP-B IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	1.472E-002
135	100.00	0.00	5.882E-011	CCW-CKV-CC-MDPA	CCW MDP-A DISCHARGE CHECK VALVE FAILS TO OPEN	1.200E-005
				CCW-MDP-FS-MDPB	CCW MDP-B FAILS TO START	2.000E-003
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-CRUN	CCW MDP-C IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPC	CCW MDP-CFAILS TO RUN	1.472E-002
136	100.00	0.00	5.882E-011	CCW-CKV-CC-MDPA	CCW MDP-A DISCHARGE CHECK VALVE FAILS TO OPEN	1.200E-005
				CCW-MDP-FS-MDPC	CCW MDP-C FAILS TO START	2.000E-003
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-BRUN	CCW MDP-B IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	1.472E-002
137	100.00	0.00	7.386E-012	CCW-CKV-CF-MDPS	CCF OF CCW MDPs DISCHARGE CHECK VALVES	1.944E-007
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-ARUN	CCW MDP-A IS RUNNING	3.330E-001
				IE-CCW-MDP-CF-FRAB	CCF OF CCW MDPs A AND BTO RUN	2.282E-004
138	100.00	0.00	7.386E-012	CCW-CKV-CF-MDPS	CCF OF CCW MDPs DISCHARGE CHECK VALVES	1.944E-007
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-BRUN	CCW MDP-B IS RUNNING	3.330E-001
				IE-CCW-MDP-CF-FRAB	CCF OF CCW MDPs A AND BTO RUN	2.282E-004
139	100.00	0.00	7.386E-012	CCW-CKV-CF-MDPS	CCF OF CCW MDPs DISCHARGE CHECK VALVES	1.944E-007
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001

Cut No.	% Total	% Cutset	Prob./ Frequency	Basic Event	Description	Event Prob.
				CCW-SYS-FC-BRUN	CCW MDP-B IS RUNNING	3.330E-001
				IE-CCW-MDP-CF-FRBC	CCF OF CCW MDPs B AND C TO RUN	2.282E-004
140	100.00	0.00	7.386E-012	CCW-CKV-CF-MDPS	CCF OF CCW MDPs DISCHARGE CHECK VALVES	1.944E-007
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-CRUN	CCW MDP-C IS RUNNING	3.330E-001
				IE-CCW-MDP-CF-FRBC	CCF OF CCW MDPs B AND C TO RUN	2.282E-004
141	100.00	0.00	7.386E-012	CCW-CKV-CF-MDPS	CCF OF CCW MDPs DISCHARGE CHECK VALVES	1.944E-007
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-ARUN	CCW MDP-A IS RUNNING	3.330E-001
				IE-CCW-MDP-CF-FRAC	CCF OF CCW MDPs A AND C TO RUN	2.282E-004
142	100.00	0.00	7.386E-012	CCW-CKV-CF-MDPS	CCF OF CCW MDPs DISCHARGE CHECK VALVES	1.944E-007
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-CRUN	CCW MDP-C IS RUNNING	3.330E-001
				IE-CCW-MDP-CF-FRAC	CCF OF CCW MDPs A AND C TO RUN	2.282E-004
143	100.00	0.00	3.984E-012	CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	4.032E-005
				CCW-MDP-FR-MDPC	CCW MDP-C FAILS TO RUN	4.032E-005
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-ARUN	CCW MDP-A IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	1.472E-002
144	100.00	0.00	3.984E-012	CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	4.032E-005
				CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	4.032E-005
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-CRUN	CCW MDP-C IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPC	CCW MDP-CFAILS TO RUN	1.472E-002
145	100.00	0.00	3.984E-012	CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	4.032E-005
				CCW-MDP-FR-MDPC	CCW MDP-C FAILS TO RUN	4.032E-005
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-BRUN	CCW MDP-B IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	1.472E-002
146	100.00	0.00	1.186E-012	CCW-CKV-CC-MDPC	CCW MDP-C DISCHARGE CHECK VALVE FAILS TO OPEN	1.200E-005

Cut No.	% Total	% Cutset	Prob./ Frequency	Basic Event	Description	Event Prob.
				CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	4.032E-005
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-ARUN	CCW MDP-A IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	1.472E-002
147	100.00	0.00	1.186E-012	CCW-CKV-CC-MDPB	CCW MDP-B DISCHARGE CHECK VALVE FAILS TO OPEN	1.200E-005
				CCW-MDP-FR-MDPC	CCW MDP-C FAILS TO RUN	4.032E-005
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-ARUN	CCW MDP-A IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	1.472E-002
148	100.00	0.00	1.186E-012	CCW-CKV-CC-MDPB	CCW MDP-B DISCHARGE CHECK VALVE FAILS TO OPEN	1.200E-005
				CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	4.032E-005
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-CRUN	CCW MDP-C IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPC	CCW MDP-CFAILS TO RUN	1.472E-002
149	100.00	0.00	1.186E-012	CCW-CKV-CC-MDPC	CCW MDP-C DISCHARGE CHECK VALVE FAILS TO OPEN	1.200E-005
				CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	4.032E-005
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-BRUN	CCW MDP-B IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	1.472E-002
150	100.00	0.00	1.186E-012	CCW-CKV-CC-MDPA	CCW MDP-A DISCHARGE CHECK VALVE FAILS TO OPEN	1.200E-005
				CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	4.032E-005
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-CRUN	CCW MDP-C IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPC	CCW MDP-CFAILS TO RUN	1.472E-002
151	100.00	0.00	1.186E-012	CCW-CKV-CC-MDPA	CCW MDP-A DISCHARGE CHECK VALVE FAILS TO OPEN	1.200E-005
				CCW-MDP-FR-MDPC	CCW MDP-C FAILS TO RUN	4.032E-005
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-BRUN	CCW MDP-B IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	1.472E-002
152	100.00	0.00	3.529E-013	CCW-CKV-CC-MDPB	CCW MDP-B DISCHARGE CHECK VALVE FAILS TO OPEN	1.200E-005

Cut No.	% Total	% Cutset	Prob./ Frequency	Basic Event	Description	Event Prob.
				CCW-CKV-CC-MDPC	CCW MDP-C DISCHARGE CHECK VALVE FAILS TO OPEN	1.200E-005
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-ARUN	CCW MDP-A IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPA	CCW MDP-A FAILS TO RUN	1.472E-002
153	100.00	0.00	3.529E-013	CCW-CKV-CC-MDPA	CCW MDP-A DISCHARGE CHECK VALVE FAILS TO OPEN	1.200E-005
				CCW-CKV-CC-MDPB	CCW MDP-B DISCHARGE CHECK VALVE FAILS TO OPEN	1.200E-005
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-CRUN	CCW MDP-C IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPC	CCW MDP-CFAILS TO RUN	1.472E-002
154	100.00	0.00	3.529E-013	CCW-CKV-CC-MDPA	CCW MDP-A DISCHARGE CHECK VALVE FAILS TO OPEN	1.200E-005
				CCW-CKV-CC-MDPC	CCW MDP-C DISCHARGE CHECK VALVE FAILS TO OPEN	1.200E-005
				CCW-SYS-FC-1OF3	ONE RUNNING PUMP IS REQUIRED FOR SUCCESS	5.000E-001
				CCW-SYS-FC-BRUN	CCW MDP-B IS RUNNING	3.330E-001
				IE-CCW-MDP-FR-MDPB	CCW MDP-BFAILS TO RUN	1.472E-002

Attachment C to Appendix C

Example Unavailability Calculation

File: 1-of-2FTR.xmcd

Description: This document demonstrates a procedure for calculating the expected number of system failures in a system characterized by two normally operating trains, A and B. System success requires 1-of-2 trains to operate. The system failure cut set is {A, B}.

Author: John A. Schroeder

References: 1. J.D. Andrews and T.R. Moss, Reliability and Risk Assessment, ISBN 0-7918-0183-7
2. Kumamoto...

Some failure and repair data. Time in hours; rates in units of per hour

$T_m := 8760$ Mission time $\tau := 24$ Mean time to repair

$\lambda_A := 4.59 \times 10^{-7}$ $\nu_A := \frac{1}{\tau}$ Component failure repair rates

$\lambda_B := 4.59 \times 10^{-7}$ $\nu_B := \frac{1}{\tau}$

Component unavailabilities, SAPHIRE type 5 calculation type

$$q_A(t) := \frac{\lambda_A}{\lambda_A + \nu_A} \cdot \left[1 - e^{-(\lambda_A + \nu_A)t}\right] \qquad q_A(T_m) = 1.10 \times 10^{-5}$$

$$q_B(t) := \frac{\lambda_B}{\lambda_B + \nu_B} \cdot \left[1 - e^{-(\lambda_B + \nu_B)t}\right] \qquad q_B(T_m) = 1.10 \times 10^{-5}$$

Component unconditional failure intensities

$$w_A(t) := \lambda_A \cdot (1 - q_A(t)) \qquad w_A(T_m) = 4.59 \times 10^{-7}$$

$$w_B(t) := \lambda_B \cdot (1 - q_B(t)) \qquad w_B(T_m) = 4.59 \times 10^{-7}$$

Criticality functions (this is exactly the Birnbaum Importance for each component)

$G_A(t) := q_B(t)$ $\qquad$ $G_A(T_m) = 1.10 \times 10^{-5}$

$G_B(t) := q_A(t)$ $\qquad$ $G_B(T_m) = 1.10 \times 10^{-5}$

The system failure intensity is calculated from separate component contributions as

$w_{sA}(t) := w_A(t) \cdot G_A(t)$

$w_{sB}(t) := w_B(t) \cdot G_B(t)$

$w_s(t) := w_{sA}(t) + w_{sB}(t)$ $\qquad$ $w_s(T_m) = 1.01 \times 10^{-11}$

The expected number of system failures over some mission T_m is then

$$W_s(t_1, t_2) := \int_{t_1}^{t_2} w_s(u)\, du$$

$W_s(0, T_m) = 8.83 \times 10^{-8}$

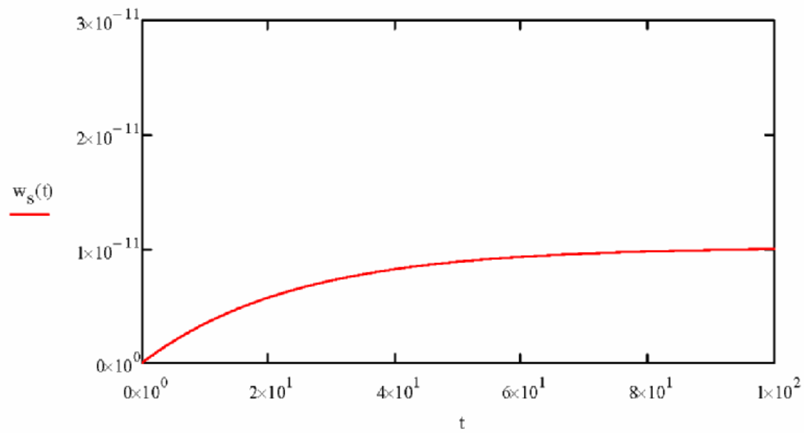


Figure 1. Asymptotic behavior of the system unconditional failure intensity.

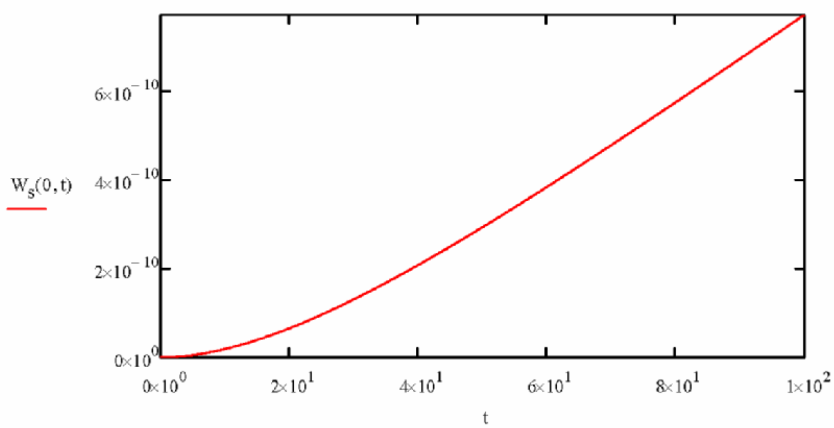


Figure 2. Asymptotic behavior of the expected number of system failures

D
SSIE MODELING USING POINT ESTIMATE FAULT TREE

D.1 Loss of TECW Initiating Event Fault Tree Using the Point Estimate Fault Tree Method and the Impact of Utilizing Updated INL Data

This appendix includes another example of an explicit event method fault tree development, but is based on a simple two train system with two pumps and two heat exchangers. Additionally, the treatment shown here also provides an example of what could be done to develop the logic necessary for determining the frequency value for utilization as a point estimate in the model. If it is desired to integrate this fault tree into model, the additional steps required to ensure that all dependencies are captured are also identified.

For the sample TECW (or TBCCW) system, the pump and heat exchanger paths are separate (i.e. The “A” Pump is not dedicated to the “A” heat exchanger). The pumps and heat exchangers are normally rotated and therefore are each assumed to be running/operating 50% of the time. The success criteria for the system are the same from an initiating event perspective and from a mitigation perspective with flow required through one pump and one heat exchanger.

In the first part of this example, the construction and evaluation of the SSIE fault tree is discussed. In the second part, the impact of using the INL modified data presented in Section 3 (Table 3-3) is discussed.

<u>Part 1: SSIE Fault Tree Construction and Evaluation</u>

The SSIE fault tree was modified from the mitigation version in the following steps:

- The fault tree was modified to include 8760 events for all supporting events out to the point where it reached another initiating event that is included in the model. That is, the 480V dependencies for the pumps were explicitly treated here, but the logic expansion for new 8760 events stopped at the 4 kV buses that feed the 480V system, since loss of a 4 kV bus is separately identified as a special initiator for the site.

- Similarly, the service water dependency for flow to the heat exchangers is not included, since loss of service water is also included as a separate support system initiating event in the model for the site. The resulting Loss of TECW fault tree is presented at Figure D-1.

- Common cause failures based on independent failures using a 24-hour mission time were replaced with common cause failures based on the new independent failures using 8760-hour mission times.

- The 8760 events added above should only impact the running/operating train. As indicated above, each train of TECW is assumed to be running/operating 50% of the time. Therefore, logic was added in which each train is modeled as the running/operating train and the other train is in standby. The 8760-hour version of the logic is used for the running/operating train and the 24-hour version of the logic is used for the standby train. The "A" 8760-hour logic is "AND"ed with the "B" 24-hour logic and the basic event that indicates "A" is the running pump. The opposite combination is modeled similarly. The two combinations are "OR"ed together to ensure that either combination fails the system.

If a full explicit event method treatment is desired, to ensure that the use of this SSIE fault tree appropriately captures dependencies, the following steps would also need to be taken:

- For all new 8760 events, also add these same 8760 events to the corresponding 24-hour versions of the fault tree "AND"ed with the initiator flag (%TCFACTOR). Note that %TCFACTOR is tagged as an initiating event and the quantifier was set to automatically remove all dual initiator cutsets. This ensures that second order dependencies of TECW (e.g. MCC or breakers) that could be referenced from other systems would be carried through in the quantification for the second order contributors to the initiating event frequency.

- Also add the SSIE fault tree top gate (%TECW) as an input to the TECW mitigation fault tree to ensure that all of the dependencies from the initiating event are carried through during quantification.

- Note that %TCFACTOR is 1.0 in this example but could be set to 0.95 (or so) to represent the availability factor. This would ensure that the initiating event frequency is retained as frequency per calendar year in the base model as required by the PRA Standard.

Table D-2 presents the resulting top fifty cutsets. The Loss of TECW initiating event frequency in this example was found to be 3.33E-3/yr.

Part 2: SSIE Fault Tree Evaluation with Modified INL Data

INL Data has been updated for use in a closed-loop cooling water system, in this example, TECW. Table D-1 below presents for each modified component failure mode the original data value and its revised data values for the Loss of TECW initiating event fault tree. These changes are based on utilizing the independent failure rates and alpha-factors shown in Table 3-3 of this report in lieu of the previous values used in the example.

Table D-1
Impact of Revised INL Data on TECW Initiating Event Basic Events

Basic Event / Type Code	Description	Original Value	Revised Value	Comment
TPM---HR----	TECW Pump fails to run	4.40E-6/hr	2.58E-6/hr	Changes 24 hr mission time events from 1.06E-4 to 6.19E-5, and changes 8760 hour mission time events from 3.78E-2 to 2.23E-2.
TPM03XCRIIEY	CCF of TECW A and B Pumps to Run (Initiating Event)	1.45E-3	1.83E-4	Based on α_{P22} of 0.008 and new independent failure rate of 2.58E-6/hr for 8760 hours
ZPMRTXCRIIEY	Inter-system CCF for TECW and RECW pumps (Initiating Event)	1.18E-3	6.78E-5	Based on α_{P33} of 0.003 (assumed applicable for α_{P44} inter-system group of 4) and new independent failure rate of 2.58E-6/hr for 8760 hours
THX---HW----	TECW Heat Exchanger fails to operate	1.00E-6/hr	3.68E-7/hr	Changes 24-hour mission time events from 2.40E-5 to 8.83E-6, and changes 8760 hour mission time events from 8.72E-3 to 3.22E-3.
THX23XCWIIEY	CCF of TECW A and B Heat Exchangers to Operate (Initiating Event)	N/A (Not included)	6.83E-5	Based on α_{H22} of 0.0212 and new independent failure rate of 3.68E-7/hr for 8760 hours

Table D-3 presents the resulting top fifty cutsets. The impact of implementing these data changes reduces the Loss of TECW initiating event frequency from 3.33E-3/yr to 7.94E-4/yr. This represents a reduction of more than a factor of four in the support system initiating event frequency.

Table D-2
Loss of TECW Initiating Event Cutsets

Cutsets with Descriptions Report							
		%TECW = 3.33E-03					
#	Cutset Prob	Event Prob	Rate	U	Exposure	Event	Description
1	1.45E-03	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		1.45E-03			0.00145	TPM03XCRIIEY	COMMON CAUSE FAILURE OF TECW PUMPS FAIL TO RUN
2	1.18E-03	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		1.18E-03			0.00118	ZPMRTXCRIIEY	COMMON CAUSE FAILURE OF RECW / TECW PUMPS TO RUN
3	1.89E-04	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		3.79E-02	4.40E-06	H	8760	TPM03AHRIIEY	TECW PUMP 1AP103 FAILS TO CONTINUE TO RUN
		1.00E-02			0.01	TPM03BTM	TECW PUMP B UNAVAILABLE DUE TO TEST/MAINT
		5.00E-01			0.5	TPMAFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1AP103
4	1.89E-04	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		1.00E-02			0.01	TPM03ATM	TECW PUMP A UNAVAILABLE DUE TO TEST/MAINT
		3.79E-02	4.40E-06	H	8760	TPM03BHRIIEY	TECW PUMP 1BP103 FAILS TO CONTINUE TO RUN
		5.00E-01			0.5	TPMBFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1BP2103
5	4.36E-05	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		1.00E-02			0.01	THUTHXDXI	OPERATOR FAILS TO ALIGN STANDBY TECW HX
		8.72E-03	1.00E-06	H	8760	THX23AHWIIEY	HEAT EXCHANGER A 1AE123 RUPTURES/FAILS
		5.00E-01			0.5	THXAFACTOR	FRACTION OF RUN TIME FOR TECW HX A
6	4.36E-05	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		1.00E-02			0.01	THUTHXDXI	OPERATOR FAILS TO ALIGN STANDBY TECW HX
		8.72E-03	1.00E-06	H	8760	THX23BHWIIEY	HEAT EXCHANGER B 1BE123 RUPTURES/FAILS
		5.00E-01			0.5	THXBFACTOR	FRACTION OF RUN TIME FOR TECW HX B
7	2.94E-05	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		5.88E-03	6.73E-07	H	8760	EXM201HWIIEY	D114 4KV-480V TRANSFORMER 10X201 FAILS
		1.00E-02			0.01	TPM03BTM	TECW PUMP B UNAVAILABLE DUE TO TEST/MAINT
		5.00E-01			0.5	TPMAFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1AP103
8	2.94E-05	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)

Table D-2
Loss of TECW Initiating Event Cutsets

		5.88E-03	6.73E-07	H	8760	EXM202HWIIEY	D124 4KV-480V TRANSFORMER 10X202 FAILS
		1.00E-02			0.01	TPM03ATM	TECW PUMP A UNAVAILABLE DUE TO TEST/MAINT
		5.00E-01			0.5	TPMBFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1BP2103
9	2.19E-05	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		4.37E-03	5.00E-07	H	8760	ELB1GDHOIIEY	D114-G-D LOAD CNTR BREAKER 52-20124 (NC) FAILS OPEN
		1.00E-02			0.01	TPM03BTM	TECW PUMP B UNAVAILABLE DUE TO TEST/MAINT
		5.00E-01			0.5	TPMAFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1AP103
10	2.19E-05	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		4.37E-03	5.00E-07	H	8760	ELB2GDHOIIEY	D124-G-D LOAD CNTR BREAKER 52-20224 (NC) FAILS OPEN
		1.00E-02			0.01	TPM03ATM	TECW PUMP A UNAVAILABLE DUE TO TEST/MAINT
		5.00E-01			0.5	TPMBFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1BP2103
11	1.92E-05	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		3.85E-03	4.40E-07	H	8760	ECB505HOIIEY	D114 BUS XFRMR BREAKER 152-11505 (NC) FAILS OPEN
		1.00E-02			0.01	TPM03BTM	TECW PUMP B UNAVAILABLE DUE TO TEST/MAINT
		5.00E-01			0.5	TPMAFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1AP103
12	1.92E-05	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		3.85E-03	4.40E-07	H	8760	ECB605HOIIEY	D124 BUS XFRMR BREAKER 152-11605 (NC) FAILS OPEN
		1.00E-02			0.01	TPM03ATM	TECW PUMP A UNAVAILABLE DUE TO TEST/MAINT
		5.00E-01			0.5	TPMBFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1BP2103
13	8.75E-06	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		1.75E-03	2.00E-07	H	8760	EBS114HWIIEY	480V D114 BUS OR SWITCHGEAR FAILS TO OPERATE
		1.00E-02			0.01	TPM03BTM	TECW PUMP B UNAVAILABLE DUE TO TEST/MAINT
		5.00E-01			0.5	TPMAFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1AP103
14	8.75E-06	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		1.75E-03	2.00E-07	H	8760	EBS124HWIIEY	480V D124 BUS OR SWITCHGEAR FAILS TO OPERATE
		1.00E-02			0.01	TPM03ATM	TECW PUMP A UNAVAILABLE DUE TO TEST/MAINT
		5.00E-01			0.5	TPMBFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1BP2103
15	8.75E-06	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		1.75E-03	2.00E-07	H	8760	EMC1GDHWIIEY	480V MCC D114-G-D FAILS TO OPERATE
		1.00E-02			0.01	TPM03BTM	TECW PUMP B UNAVAILABLE DUE TO TEST/MAINT

Table D-2
Loss of TECW Initiating Event Cutsets

		5.00E-01			0.5	TPMAFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1AP103
16	8.75E-06	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		1.75E-03	2.00E-07	H	8760	EMC2GDHWIIEY	480V MCC D124-G-D FAILS TO OPERATE
		1.00E-02			0.01	TPM03ATM	TECW PUMP A UNAVAILABLE DUE TO TEST/MAINT
		5.00E-01			0.5	TPMBFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1BP2103
17	6.40E-06	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		3.38E-04	3.38E-04	N	1	TPM03ADSI	TECW PUMP 1AP103 FAILS TO START
		3.79E-02	4.40E-06	H	8760	TPM03BHRIIEY	TECW PUMP 1BP103 FAILS TO CONTINUE TO RUN
		5.00E-01			0.5	TPMBFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1BP2103
18	6.40E-06	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		3.79E-02	4.40E-06	H	8760	TPM03AHRIIEY	TECW PUMP 1AP103 FAILS TO CONTINUE TO RUN
		3.38E-04	3.38E-04	N	1	TPM03BDSI	TECW PUMP 1BP103 FAILS TO START
		5.00E-01			0.5	TPMAFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1AP103
19	2.18E-06	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		8.72E-03	1.00E-06	H	8760	THX23AHWIIEY	HEAT EXCHANGER A 1AE123 RUPTURES/FAILS
		5.00E-01			0.5	THXAFACTOR	FRACTION OF RUN TIME FOR TECW HX A
		5.00E-04	5.00E-04	N	1	TXV16ADNI	HX VALVE 14-1016A (WHEN OPEN) FAILS OPEN
20	2.18E-06	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		8.72E-03	1.00E-06	H	8760	THX23AHWIIEY	HEAT EXCHANGER A 1AE123 RUPTURES/FAILS
		5.00E-01			0.5	THXAFACTOR	FRACTION OF RUN TIME FOR TECW HX A
		5.00E-04	5.00E-04	N	1	TXV16BDPI	HX VALVE 14-1016B (WHEN CLOSED) FAILS TO OPEN
21	2.18E-06	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		8.72E-03	1.00E-06	H	8760	THX23BHWIIEY	HEAT EXCHANGER B 1BE123 RUPTURES/FAILS
		5.00E-01			0.5	THXBFACTOR	FRACTION OF RUN TIME FOR TECW HX B
		5.00E-04	5.00E-04	N	1	TXV16ADPI	HX VALVE 14-1016A (WHEN CLOSED) FAILS TO OPEN
22	2.18E-06	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		8.72E-03	1.00E-06	H	8760	THX23BHWIIEY	HEAT EXCHANGER B 1BE123 RUPTURES/FAILS
		5.00E-01			0.5	THXBFACTOR	FRACTION OF RUN TIME FOR TECW HX B
		5.00E-04	5.00E-04	N	1	TXV16BDNI	HX VALVE 14-1016B (WHEN OPEN) FAILS OPEN
23	2.01E-06	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)

Table D-2
Loss of TECW Initiating Event Cutsets

		1.06E-04	4.40E-06	H	24	TPM03AHRI	TECW PUMP 1AP103 FAILS TO CONTINUE TO RUN
		3.79E-02	4.40E-06	H	8760	TPM03BHRIIEY	TECW PUMP 1BP103 FAILS TO CONTINUE TO RUN
		5.00E-01			0.5	TPMBFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1BP2103
24	2.01E-06	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		3.79E-02	4.40E-06	H	8760	TPM03AHRIIEY	TECW PUMP 1AP103 FAILS TO CONTINUE TO RUN
		1.06E-04	4.40E-06	H	24	TPM03BHRI	TECW PUMP 1BP103 FAILS TO CONTINUE TO RUN
		5.00E-01			0.5	TPMAFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1AP103
25	1.44E-06	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		8.72E-03	1.00E-06	H	8760	THX23AHWIIEY	HEAT EXCHANGER A 1AE123 RUPTURES/FAILS
		5.00E-01			0.5	THXAFACTOR	FRACTION OF RUN TIME FOR TECW HX A
		3.30E-04			0.00033	ZHUXWTDXI	JOINT HEP FOR WHUESW AND THUTHXDXI
26	1.44E-06	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		8.72E-03	1.00E-06	H	8760	THX23BHWIIEY	HEAT EXCHANGER B 1BE123 RUPTURES/FAILS
		5.00E-01			0.5	THXBFACTOR	FRACTION OF RUN TIME FOR TECW HX B
		3.30E-04			0.00033	ZHUXWTDXI	JOINT HEP FOR WHUESW AND THUTHXDXI
27	1.31E-06	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		1.00E-02			0.01	THUTHXDXI	OPERATOR FAILS TO ALIGN STANDBY TECW HX
		5.00E-01			0.5	THXAFACTOR	FRACTION OF RUN TIME FOR TECW HX A
		2.63E-04	3.00E-08	H	8760	TXV14AHQIIEY	HX VALVE 14-1014A (WHEN OPEN) FAILS CLOSED
28	1.31E-06	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		1.00E-02			0.01	THUTHXDXI	OPERATOR FAILS TO ALIGN STANDBY TECW HX
		5.00E-01			0.5	THXAFACTOR	FRACTION OF RUN TIME FOR TECW HX A
		2.63E-04	3.00E-08	H	8760	TXV16AHQIIEY	HX VALVE 14-1016A (WHEN OPEN) FAILS CLOSED
29	1.31E-06	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		1.00E-02			0.01	THUTHXDXI	OPERATOR FAILS TO ALIGN STANDBY TECW HX
		5.00E-01			0.5	THXAFACTOR	FRACTION OF RUN TIME FOR TECW HX A
		2.63E-04	3.00E-08	H	8760	WXV03AHQIIEY	HX VALVE 10-1003A (NORMALLY OPEN) FAILS CLOSED
30	1.31E-06	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		1.00E-02			0.01	THUTHXDXI	OPERATOR FAILS TO ALIGN STANDBY TECW HX
		5.00E-01			0.5	THXAFACTOR	FRACTION OF RUN TIME FOR TECW HX A

Table D-2
Loss of TECW Initiating Event Cutsets

		2.63E-04	3.00E-08	H	8760	WXVT2AHQIIEY	HX VALVE 10-1032A (NORMALLY OPEN) FAILS CLOSED
31	1.31E-06	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		1.00E-02			0.01	THUTHXDXI	OPERATOR FAILS TO ALIGN STANDBY TECW HX
		5.00E-01			0.5	THXAFACTOR	FRACTION OF RUN TIME FOR TECW HX A
		2.63E-04	3.00E-08	H	8760	WXVT3AHQIIEY	HX VALVE 10-1033A (NORMALLY OPEN) FAILS CLOSED
32	1.31E-06	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		1.00E-02			0.01	THUTHXDXI	OPERATOR FAILS TO ALIGN STANDBY TECW HX
		5.00E-01			0.5	THXBFACTOR	FRACTION OF RUN TIME FOR TECW HX B
		2.63E-04	3.00E-08	H	8760	TXV14BHQIIEY	HX VALVE 14-1014B (WHEN OPEN) FAILS CLOSED
33	1.31E-06	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		1.00E-02			0.01	THUTHXDXI	OPERATOR FAILS TO ALIGN STANDBY TECW HX
		5.00E-01			0.5	THXBFACTOR	FRACTION OF RUN TIME FOR TECW HX B
		2.63E-04	3.00E-08	H	8760	TXV16BHQIIEY	HX VALVE 14-1016B (WHEN OPEN) FAILS CLOSED
34	1.31E-06	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		1.00E-02			0.01	THUTHXDXI	OPERATOR FAILS TO ALIGN STANDBY TECW HX
		5.00E-01			0.5	THXBFACTOR	FRACTION OF RUN TIME FOR TECW HX B
		2.63E-04	3.00E-08	H	8760	WXV03BHQIIEY	HX VALVE 10-1003B (NORMALLY OPEN) FAILS CLOSED
35	1.31E-06	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		1.00E-02			0.01	THUTHXDXI	OPERATOR FAILS TO ALIGN STANDBY TECW HX
		5.00E-01			0.5	THXBFACTOR	FRACTION OF RUN TIME FOR TECW HX B
		2.63E-04	3.00E-08	H	8760	WXVT2BHQIIEY	HX VALVE 10-1032B (NORMALLY OPEN) FAILS CLOSED
36	1.31E-06	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		1.00E-02			0.01	THUTHXDXI	OPERATOR FAILS TO ALIGN STANDBY TECW HX
		5.00E-01			0.5	THXBFACTOR	FRACTION OF RUN TIME FOR TECW HX B
		2.63E-04	3.00E-08	H	8760	WXVT3BHQIIEY	HX VALVE 10-1033B (NORMALLY OPEN) FAILS CLOSED
37	1.31E-06	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		1.00E-02			0.01	TPM03ATM	TECW PUMP A UNAVAILABLE DUE TO TEST/MAINT
		5.00E-01			0.5	TPMBFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1BP2103
		2.63E-04	3.00E-08	H	8760	TXV01BHQIIEY	MANUAL VALVE (NO) 14-1001B FAILS CLOSED
38	1.31E-06	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)

Table D-2
Loss of TECW Initiating Event Cutsets

		1.00E-02			0.01	TPM03ATM	TECW PUMP A UNAVAILABLE DUE TO TEST/MAINT
		5.00E-01			0.5	TPMBFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1BP2103
		2.63E-04	3.00E-08	H	8760	TXV05BHQIIEY	MANUAL VALVE (NO) 14-1005B FAILS CLOSED
39	1.31E-06	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		1.00E-02			0.01	TPM03BTM	TECW PUMP B UNAVAILABLE DUE TO TEST/MAINT
		5.00E-01			0.5	TPMAFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1AP103
		2.63E-04	3.00E-08	H	8760	TXV01AHQIIEY	MANUAL VALVE (NO) 14-1001A FAILS CLOSED
40	1.31E-06	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		1.00E-02			0.01	TPM03BTM	TECW PUMP B UNAVAILABLE DUE TO TEST/MAINT
		5.00E-01			0.5	TPMAFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1AP103
		2.63E-04	3.00E-08	H	8760	TXV05AHQIIEY	MANUAL VALVE (NO) 14-1005A FAILS CLOSED
41	9.93E-07	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		5.88E-03	6.73E-07	H	8760	EXM201HWIIEY	D114 4KV-480V TRANSFORMER 10X201 FAILS
		3.38E-04	3.38E-04	N	1	TPM03BDSI	TECW PUMP 1BP103 FAILS TO START
		5.00E-01			0.5	TPMAFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1AP103
42	9.93E-07	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		5.88E-03	6.73E-07	H	8760	EXM202HWIIEY	D124 4KV-480V TRANSFORMER 10X202 FAILS
		3.38E-04	3.38E-04	N	1	TPM03ADSI	TECW PUMP 1AP103 FAILS TO START
		5.00E-01			0.5	TPMBFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1BP2103
43	7.39E-07	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		4.37E-03	5.00E-07	H	8760	ELB1GDHOIIEY	D114-G-D LOAD CNTR BREAKER 52-20124 (NC) FAILS OPEN
		3.38E-04	3.38E-04	N	1	TPM03BDSI	TECW PUMP 1BP103 FAILS TO START
		5.00E-01			0.5	TPMAFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1AP103
44	7.39E-07	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		4.37E-03	5.00E-07	H	8760	ELB2GDHOIIEY	D124-G-D LOAD CNTR BREAKER 52-20224 (NC) FAILS OPEN
		3.38E-04	3.38E-04	N	1	TPM03ADSI	TECW PUMP 1AP103 FAILS TO START
		5.00E-01			0.5	TPMBFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1BP2103
45	6.50E-07	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		3.85E-03	4.40E-07	H	8760	ECB505HOIIEY	D114 BUS XFRMR BREAKER 152-11505 (NC) FAILS OPEN
		3.38E-04	3.38E-04	N	1	TPM03BDSI	TECW PUMP 1BP103 FAILS TO START

Table D-2
Loss of TECW Initiating Event Cutsets

		5.00E-01			0.5	TPMAFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1AP103
46	6.50E-07	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		3.85E-03	4.40E-07	H	8760	ECB605HOIIEY	D124 BUS XFRMR BREAKER 152-11605 (NC) FAILS OPEN
		3.38E-04	3.38E-04	N	1	TPM03ADSI	TECW PUMP 1AP103 FAILS TO START
		5.00E-01			0.5	TPMBFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1BP2103
47	3.90E-07	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		3.79E-02	4.40E-06	H	8760	TPM03AHRIIEY	TECW PUMP 1AP103 FAILS TO CONTINUE TO RUN
		2.06E-05			2.06E-05	TPM03XCSI	COMMON CAUSE FAILURE OF TECW PUMPS FAIL TO START
		5.00E-01			0.5	TPMAFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1AP103
48	3.90E-07	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		3.79E-02	4.40E-06	H	8760	TPM03BHRIIEY	TECW PUMP 1BP103 FAILS TO CONTINUE TO RUN
		2.06E-05			2.06E-05	TPM03XCSI	COMMON CAUSE FAILURE OF TECW PUMPS FAIL TO START
		5.00E-01			0.5	TPMBFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1BP2103
49	3.11E-07	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		5.88E-03	6.73E-07	H	8760	EXM201HWIIEY	D114 4KV-480V TRANSFORMER 10X201 FAILS
		1.06E-04	4.40E-06	H	24	TPM03BHRI	TECW PUMP 1BP103 FAILS TO CONTINUE TO RUN
		5.00E-01			0.5	TPMAFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1AP103
50	3.11E-07	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		5.88E-03	6.73E-07	H	8760	EXM202HWIIEY	D124 4KV-480V TRANSFORMER 10X202 FAILS
		1.06E-04	4.40E-06	H	24	TPM03AHRI	TECW PUMP 1AP103 FAILS TO CONTINUE TO RUN
		5.00E-01			0.5	TPMBFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1BP2103

Table D-3
Loss of TECW Initiating Event Cutsets with Updated INL Data

Cutsets with Descriptions Report							
%TECW = 7.94E-04							
#	Cutset Prob	Event Prob	Rate	U	Exposure	Event	Description
1	1.83E-04	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		1.83E-04			0.000183	TPM03XCRIIEY	COMMON CAUSE FAILURE OF TECW PUMPS FAIL TO RUN
2	1.12E-04	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		2.23E-02	2.58E-06	H	8760	TPM03AHRIIEY	TECW PUMP 1AP103 FAILS TO CONTINUE TO RUN
		1.00E-02			0.01	TPM03BTM	TECW PUMP B UNAVAILABLE DUE TO TEST/MAINT
		5.00E-01			0.5	TPMAFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1AP103
3	1.12E-04	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		1.00E-02			0.01	TPM03ATM	TECW PUMP A UNAVAILABLE DUE TO TEST/MAINT
		2.23E-02	2.58E-06	H	8760	TPM03BHRIIEY	TECW PUMP 1BP103 FAILS TO CONTINUE TO RUN
		5.00E-01			0.5	TPMBFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1BP2103
4	6.83E-05	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		6.83E-05				THX23XCWIIEY	COMMON CAUSE FAILURE OF TECW HEAT EXCHANGERS
5	6.78E-05	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		6.78E-05			6.78E-05	ZPMRTXCRIIEY	COMMON CAUSE FAILURE OF RECW / TECW PUMPS TO RUN
6	2.94E-05	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		5.88E-03	6.73E-07	H	8760	EXM201HWIIEY	D114 4KV-480V TRANSFORMER 10X201 FAILS
		1.00E-02			0.01	TPM03BTM	TECW PUMP B UNAVAILABLE DUE TO TEST/MAINT
		5.00E-01			0.5	TPMAFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1AP103
7	2.94E-05	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		5.88E-03	6.73E-07	H	8760	EXM202HWIIEY	D124 4KV-480V TRANSFORMER 10X202 FAILS
		1.00E-02			0.01	TPM03ATM	TECW PUMP A UNAVAILABLE DUE TO TEST/MAINT
		5.00E-01			0.5	TPMBFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1BP2103
8	2.19E-05	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		4.37E-03	5.00E-07	H	8760	ELB1GDHOIIEY	D114-G-D LOAD CNTR BREAKER 52-20124 (NC) FAILS OPEN
		1.00E-02			0.01	TPM03BTM	TECW PUMP B UNAVAILABLE DUE TO TEST/MAINT
		5.00E-01			0.5	TPMAFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1AP103

Table D-3
Loss of TECW Initiating Event Cutsets with Updated INL Data

9	2.19E-05	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		4.37E-03	5.00E-07	H	8760	ELB2GDHOIIEY	D124-G-D LOAD CNTR BREAKER 52-20224 (NC) FAILS OPEN
		1.00E-02			0.01	TPM03ATM	TECW PUMP A UNAVAILABLE DUE TO TEST/MAINT
		5.00E-01			0.5	TPMBFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1BP2103
10	1.92E-05	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		3.85E-03	4.40E-07	H	8760	ECB505HOIIEY	D114 BUS XFRMR BREAKER 152-11505 (NC) FAILS OPEN
		1.00E-02			0.01	TPM03BTM	TECW PUMP B UNAVAILABLE DUE TO TEST/MAINT
		5.00E-01			0.5	TPMAFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1AP103
11	1.92E-05	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		3.85E-03	4.40E-07	H	8760	ECB605HOIIEY	D124 BUS XFRMR BREAKER 152-11605 (NC) FAILS OPEN
		1.00E-02			0.01	TPM03ATM	TECW PUMP A UNAVAILABLE DUE TO TEST/MAINT
		5.00E-01			0.5	TPMBFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1BP2103
12	1.61E-05	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		1.00E-02			0.01	THUTHXDXI	OPERATOR FAILS TO ALIGN STANDBY TECW HX
		3.22E-03	3.68E-07	H	8760	THX23AHWIIEY	HEAT EXCHANGER A 1AE123 RUPTURES/FAILS
		5.00E-01			0.5	THXAFACTOR	FRACTION OF RUN TIME FOR TECW HX A
13	1.61E-05	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		1.00E-02			0.01	THUTHXDXI	OPERATOR FAILS TO ALIGN STANDBY TECW HX
		3.22E-03	3.68E-07	H	8760	THX23BHWIIEY	HEAT EXCHANGER B 1BE123 RUPTURES/FAILS
		5.00E-01			0.5	THXBFACTOR	FRACTION OF RUN TIME FOR TECW HX B
14	8.75E-06	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		1.75E-03	2.00E-07	H	8760	EBS114HWIIEY	480V D114 BUS OR SWITCHGEAR FAILS TO OPERATE
		1.00E-02			0.01	TPM03BTM	TECW PUMP B UNAVAILABLE DUE TO TEST/MAINT
		5.00E-01			0.5	TPMAFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1AP103
15	8.75E-06	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		1.75E-03	2.00E-07	H	8760	EBS124HWIIEY	480V D124 BUS OR SWITCHGEAR FAILS TO OPERATE
		1.00E-02			0.01	TPM03ATM	TECW PUMP A UNAVAILABLE DUE TO TEST/MAINT
		5.00E-01			0.5	TPMBFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1BP2103
16	8.75E-06	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		1.75E-03	2.00E-07	H	8760	EMC1GDHWIIEY	480V MCC D114-G-D FAILS TO OPERATE
		1.00E-02			0.01	TPM03BTM	TECW PUMP B UNAVAILABLE DUE TO TEST/MAINT

Table D-3
Loss of TECW Initiating Event Cutsets with Updated INL Data

		5.00E-01			0.5	TPMAFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1AP103
17	8.75E-06	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		1.75E-03	2.00E-07	H	8760	EMC2GDHWIIEY	480V MCC D124-G-D FAILS TO OPERATE
		1.00E-02			0.01	TPM03ATM	TECW PUMP A UNAVAILABLE DUE TO TEST/MAINT
		5.00E-01			0.5	TPMBFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1BP2103
18	3.78E-06	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		3.38E-04	3.38E-04	N	1	TPM03ADSI	TECW PUMP 1AP103 FAILS TO START
		2.23E-02	2.58E-06	H	8760	TPM03BHRIIEY	TECW PUMP 1BP103 FAILS TO CONTINUE TO RUN
		5.00E-01			0.5	TPMBFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1BP2103
19	3.78E-06	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		2.23E-02	2.58E-06	H	8760	TPM03AHRIIEY	TECW PUMP 1AP103 FAILS TO CONTINUE TO RUN
		3.38E-04	3.38E-04	N	1	TPM03BDSI	TECW PUMP 1BP103 FAILS TO START
		5.00E-01			0.5	TPMAFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1AP103
20	1.31E-06	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		1.00E-02			0.01	THUTHXDXI	OPERATOR FAILS TO ALIGN STANDBY TECW HX
		5.00E-01			0.5	THXAFACTOR	FRACTION OF RUN TIME FOR TECW HX A
		2.63E-04	3.00E-08	H	8760	TXV14AHQIIEY	HX VALVE 14-1014A (WHEN OPEN) FAILS CLOSED
21	1.31E-06	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		1.00E-02			0.01	THUTHXDXI	OPERATOR FAILS TO ALIGN STANDBY TECW HX
		5.00E-01			0.5	THXAFACTOR	FRACTION OF RUN TIME FOR TECW HX A
		2.63E-04	3.00E-08	H	8760	TXV16AHQIIEY	HX VALVE 14-1016A (WHEN OPEN) FAILS CLOSED
22	1.31E-06	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		1.00E-02			0.01	THUTHXDXI	OPERATOR FAILS TO ALIGN STANDBY TECW HX
		5.00E-01			0.5	THXAFACTOR	FRACTION OF RUN TIME FOR TECW HX A
		2.63E-04	3.00E-08	H	8760	WXV03AHQIIEY	HX VALVE 10-1003A (NORMALLY OPEN) FAILS CLOSED
23	1.31E-06	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		1.00E-02			0.01	THUTHXDXI	OPERATOR FAILS TO ALIGN STANDBY TECW HX
		5.00E-01			0.5	THXAFACTOR	FRACTION OF RUN TIME FOR TECW HX A
		2.63E-04	3.00E-08	H	8760	WXVT2AHQIIEY	HX VALVE 10-1032A (NORMALLY OPEN) FAILS CLOSED
24	1.31E-06	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		1.00E-02			0.01	THUTHXDXI	OPERATOR FAILS TO ALIGN STANDBY TECW HX

Table D-3
Loss of TECW Initiating Event Cutsets with Updated INL Data

		5.00E-01			0.5	THXAFACTOR	FRACTION OF RUN TIME FOR TECW HX A
		2.63E-04	3.00E-08	H	8760	WXVT3AHQIIEY	HX VALVE 10-1033A (NORMALLY OPEN) FAILS CLOSED
25	1.31E-06	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		1.00E-02			0.01	THUTHXDXI	OPERATOR FAILS TO ALIGN STANDBY TECW HX
		5.00E-01			0.5	THXBFACTOR	FRACTION OF RUN TIME FOR TECW HX B
		2.63E-04	3.00E-08	H	8760	TXV14BHQIIEY	HX VALVE 14-1014B (WHEN OPEN) FAILS CLOSED
26	1.31E-06	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		1.00E-02			0.01	THUTHXDXI	OPERATOR FAILS TO ALIGN STANDBY TECW HX
		5.00E-01			0.5	THXBFACTOR	FRACTION OF RUN TIME FOR TECW HX B
		2.63E-04	3.00E-08	H	8760	TXV16BHQIIEY	HX VALVE 14-1016B (WHEN OPEN) FAILS CLOSED
27	1.31E-06	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		1.00E-02			0.01	THUTHXDXI	OPERATOR FAILS TO ALIGN STANDBY TECW HX
		5.00E-01			0.5	THXBFACTOR	FRACTION OF RUN TIME FOR TECW HX B
		2.63E-04	3.00E-08	H	8760	WXV03BHQIIEY	HX VALVE 10-1003B (NORMALLY OPEN) FAILS CLOSED
28	1.31E-06	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		1.00E-02			0.01	THUTHXDXI	OPERATOR FAILS TO ALIGN STANDBY TECW HX
		5.00E-01			0.5	THXBFACTOR	FRACTION OF RUN TIME FOR TECW HX B
		2.63E-04	3.00E-08	H	8760	WXVT2BHQIIEY	HX VALVE 10-1032B (NORMALLY OPEN) FAILS CLOSED
29	1.31E-06	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		1.00E-02			0.01	THUTHXDXI	OPERATOR FAILS TO ALIGN STANDBY TECW HX
		5.00E-01			0.5	THXBFACTOR	FRACTION OF RUN TIME FOR TECW HX B
		2.63E-04	3.00E-08	H	8760	WXVT3BHQIIEY	HX VALVE 10-1033B (NORMALLY OPEN) FAILS CLOSED
30	1.31E-06	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		1.00E-02			0.01	TPM03ATM	TECW PUMP A UNAVAILABLE DUE TO TEST/MAINT
		5.00E-01			0.5	TPMBFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1BP2103
		2.63E-04	3.00E-08	H	8760	TXV01BHQIIEY	MANUAL VALVE (NO) 14-1001B FAILS CLOSED
31	1.31E-06	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		1.00E-02			0.01	TPM03ATM	TECW PUMP A UNAVAILABLE DUE TO TEST/MAINT
		5.00E-01			0.5	TPMBFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1BP2103
		2.63E-04	3.00E-08	H	8760	TXV05BHQIIEY	MANUAL VALVE (NO) 14-1005B FAILS CLOSED
32	1.31E-06	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)

Table D-3
Loss of TECW Initiating Event Cutsets with Updated INL Data

		1.00E-02			0.01	TPM03BTM	TECW PUMP B UNAVAILABLE DUE TO TEST/MAINT
		5.00E-01			0.5	TPMAFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1AP103
		2.63E-04	3.00E-08	H	8760	TXV01AHQIIEY	MANUAL VALVE (NO) 14-1001A FAILS CLOSED
33	1.31E-06	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		1.00E-02			0.01	TPM03BTM	TECW PUMP B UNAVAILABLE DUE TO TEST/MAINT
		5.00E-01			0.5	TPMAFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1AP103
		2.63E-04	3.00E-08	H	8760	TXV05AHQIIEY	MANUAL VALVE (NO) 14-1005A FAILS CLOSED
34	9.93E-07	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		5.88E-03	6.73E-07	H	8760	EXM201HWIIEY	D114 4KV-480V TRANSFORMER 10X201 FAILS
		3.38E-04	3.38E-04	N	1	TPM03BDSI	TECW PUMP 1BP103 FAILS TO START
		5.00E-01			0.5	TPMAFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1AP103
35	9.93E-07	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		5.88E-03	6.73E-07	H	8760	EXM202HWIIEY	D124 4KV-480V TRANSFORMER 10X202 FAILS
		3.38E-04	3.38E-04	N	1	TPM03ADSI	TECW PUMP 1AP103 FAILS TO START
		5.00E-01			0.5	TPMBFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1BP2103
36	8.04E-07	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		3.22E-03	3.68E-07	H	8760	THX23AHWIIEY	HEAT EXCHANGER A 1AE123 RUPTURES/FAILS
		5.00E-01			0.5	THXAFACTOR	FRACTION OF RUN TIME FOR TECW HX A
		5.00E-04	5.00E-04	N	1	TXV16ADNI	HX VALVE 14-1016A (WHEN OPEN) FAILS OPEN
37	8.04E-07	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		3.22E-03	3.68E-07	H	8760	THX23AHWIIEY	HEAT EXCHANGER A 1AE123 RUPTURES/FAILS
		5.00E-01			0.5	THXAFACTOR	FRACTION OF RUN TIME FOR TECW HX A
		5.00E-04	5.00E-04	N	1	TXV16BDPI	HX VALVE 14-1016B (WHEN CLOSED) FAILS TO OPEN
38	8.04E-07	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		3.22E-03	3.68E-07	H	8760	THX23BHWIIEY	HEAT EXCHANGER B 1BE123 RUPTURES/FAILS
		5.00E-01			0.5	THXBFACTOR	FRACTION OF RUN TIME FOR TECW HX B
		5.00E-04	5.00E-04	N	1	TXV16ADPI	HX VALVE 14-1016A (WHEN CLOSED) FAILS TO OPEN
39	8.04E-07	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		3.22E-03	3.68E-07	H	8760	THX23BHWIIEY	HEAT EXCHANGER B 1BE123 RUPTURES/FAILS
		5.00E-01			0.5	THXBFACTOR	FRACTION OF RUN TIME FOR TECW HX B
		5.00E-04	5.00E-04	N	1	TXV16BDNI	HX VALVE 14-1016B (WHEN OPEN) FAILS OPEN

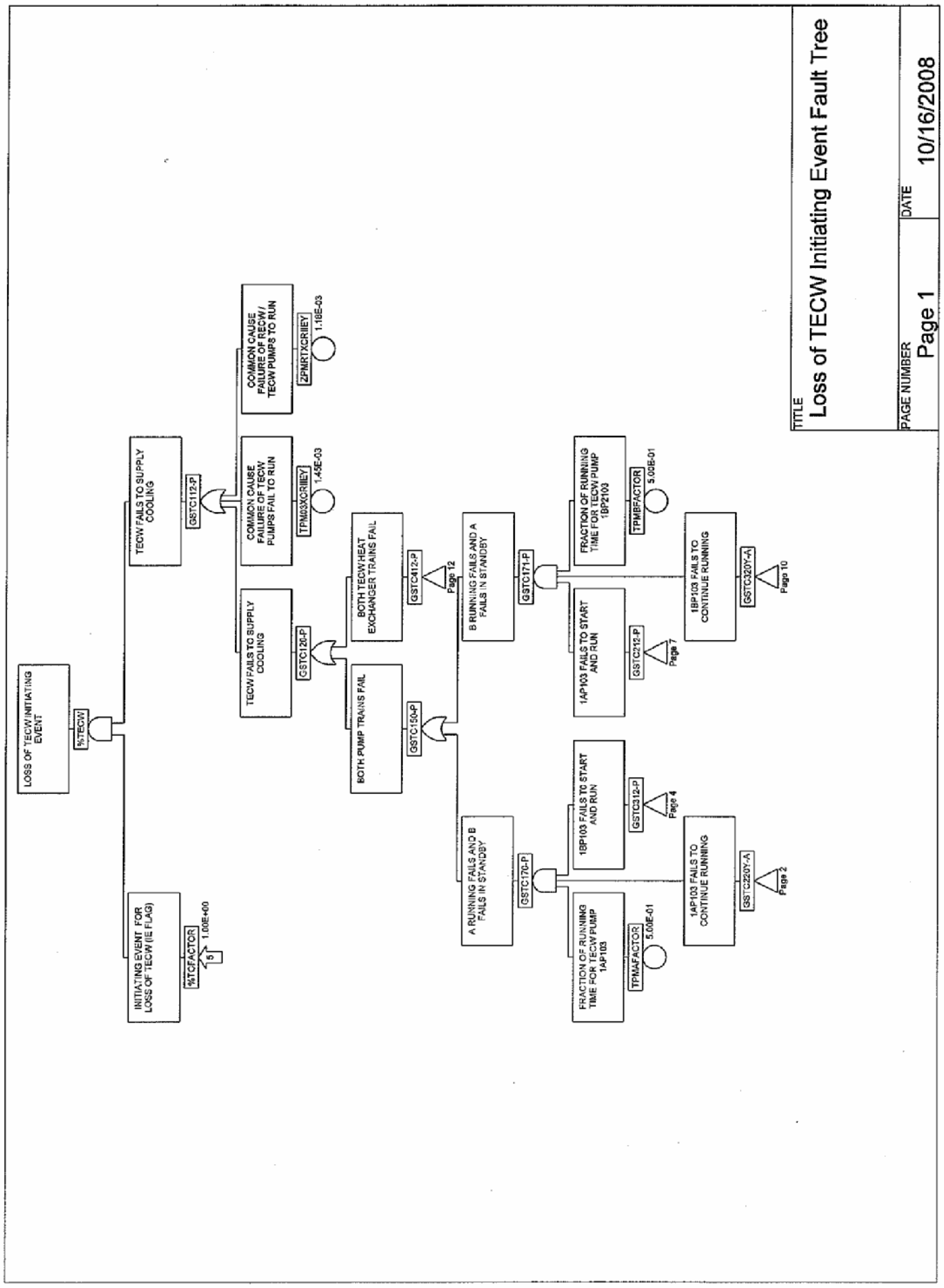
Table D-3
Loss of TECW Initiating Event Cutsets with Updated INL Data

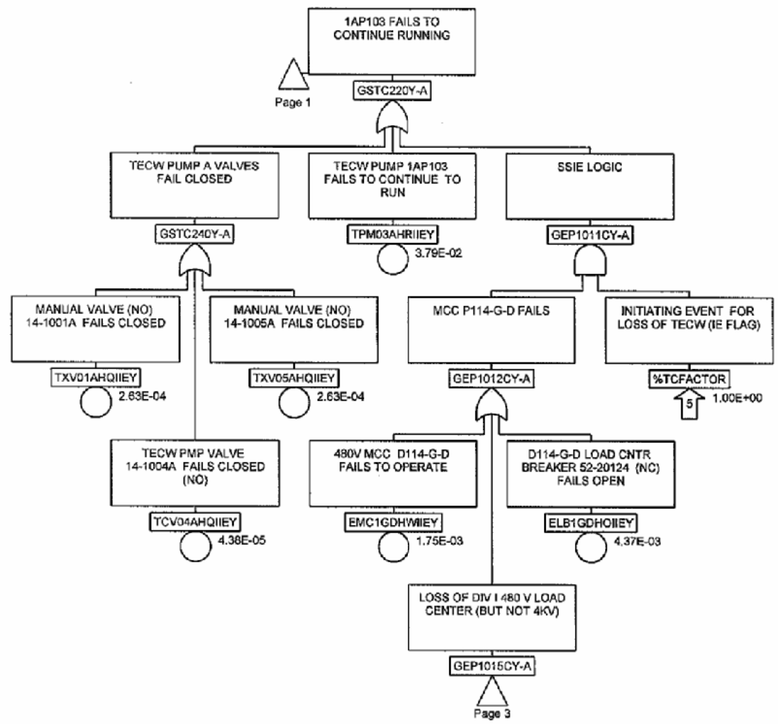
40	7.39E-07	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		4.37E-03	5.00E-07	H	8760	ELB1GDHOIIEY	D114-G-D LOAD CNTR BREAKER 52-20124 (NC) FAILS OPEN
		3.38E-04	3.38E-04	N	1	TPM03BDSI	TECW PUMP 1BP103 FAILS TO START
		5.00E-01			0.5	TPMAFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1AP103
41	7.39E-07	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		4.37E-03	5.00E-07	H	8760	ELB2GDHOIIEY	D124-G-D LOAD CNTR BREAKER 52-20224 (NC) FAILS OPEN
		3.38E-04	3.38E-04	N	1	TPM03ADSI	TECW PUMP 1AP103 FAILS TO START
		5.00E-01			0.5	TPMBFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1BP2103
42	6.92E-07	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		6.19E-05	2.58E-06	H	24	TPM03AHRI	TECW PUMP 1AP103 FAILS TO CONTINUE TO RUN
		2.23E-02	2.58E-06	H	8760	TPM03BHRIIEY	TECW PUMP 1BP103 FAILS TO CONTINUE TO RUN
		5.00E-01			0.5	TPMBFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1BP2103
43	6.92E-07	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		2.23E-02	2.58E-06	H	8760	TPM03AHRIIEY	TECW PUMP 1AP103 FAILS TO CONTINUE TO RUN
		6.19E-05	2.58E-06	H	24	TPM03BHRI	TECW PUMP 1BP103 FAILS TO CONTINUE TO RUN
		5.00E-01			0.5	TPMAFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1AP103
44	6.50E-07	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		3.85E-03	4.40E-07	H	8760	ECB505HOIIEY	D114 BUS XFRMR BREAKER 152-11505 (NC) FAILS OPEN
		3.38E-04	3.38E-04	N	1	TPM03BDSI	TECW PUMP 1BP103 FAILS TO START
		5.00E-01			0.5	TPMAFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1AP103
45	6.50E-07	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		3.85E-03	4.40E-07	H	8760	ECB605HOIIEY	D124 BUS XFRMR BREAKER 152-11605 (NC) FAILS OPEN
		3.38E-04	3.38E-04	N	1	TPM03ADSI	TECW PUMP 1AP103 FAILS TO START
		5.00E-01			0.5	TPMBFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1BP2103
46	5.31E-07	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		3.22E-03	3.68E-07	H	8760	THX23AHWIIEY	HEAT EXCHANGER A 1AE123 RUPTURES/FAILS
		5.00E-01			0.5	THXAFACTOR	FRACTION OF RUN TIME FOR TECW HX A
		3.30E-04			0.00033	ZHUXWTDXI	JOINT HEP FOR WHUESW AND THUTHXDXI
47	5.31E-07	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		3.22E-03	3.68E-07	H	8760	THX23BHWIIEY	HEAT EXCHANGER B 1BE123 RUPTURES/FAILS
		5.00E-01			0.5	THXBFACTOR	FRACTION OF RUN TIME FOR TECW HX B

Table D-3
Loss of TECW Initiating Event Cutsets with Updated INL Data

		3.30E-04			0.00033	ZHUXWTDXI	JOINT HEP FOR WHUESW AND THUTHXDXI
48	2.96E-07	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		1.75E-03	2.00E-07	H	8760	EBS114HWIIEY	480V D114 BUS OR SWITCHGEAR FAILS TO OPERATE
		3.38E-04	3.38E-04	N	1	TPM03BDSI	TECW PUMP 1BP103 FAILS TO START
		5.00E-01			0.5	TPMAFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1AP103
49	2.96E-07	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		1.75E-03	2.00E-07	H	8760	EBS124HWIIEY	480V D124 BUS OR SWITCHGEAR FAILS TO OPERATE
		3.38E-04	3.38E-04	N	1	TPM03ADSI	TECW PUMP 1AP103 FAILS TO START
		5.00E-01			0.5	TPMBFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1BP2103
50	2.96E-07	1.00E+00			1	%TCFACTOR	INITIATING EVENT FOR LOSS OF TECW (IE FLAG)
		1.75E-03	2.00E-07	H	8760	EMC1GDHWIIEY	480V MCC D114-G-D FAILS TO OPERATE
		3.38E-04	3.38E-04	N	1	TPM03BDSI	TECW PUMP 1BP103 FAILS TO START
		5.00E-01			0.5	TPMAFACTOR	FRACTION OF RUNNING TIME FOR TECW PUMP 1AP103

Figure D-1: Loss of TECW Initiating Event Fault Tree





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Loss of TECW Initiating Event Fault Tree	
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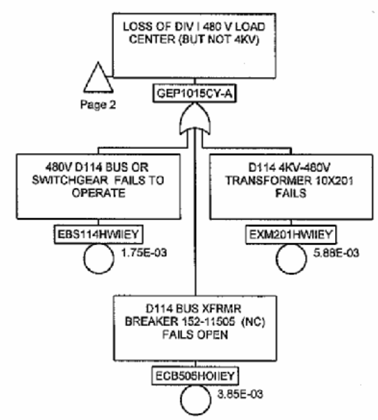
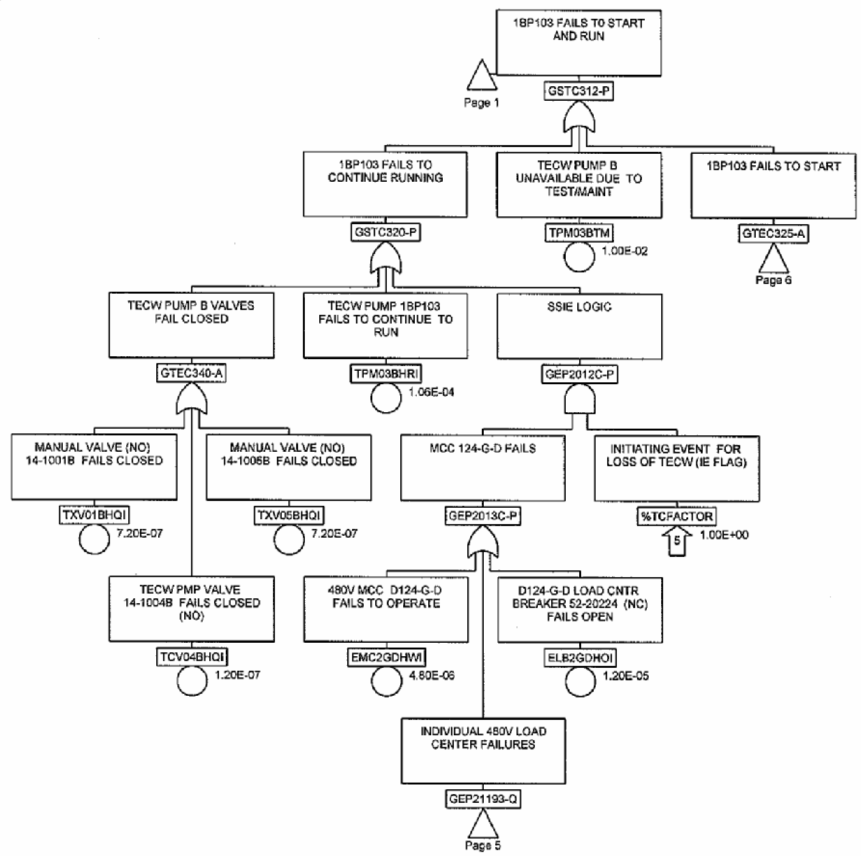


TITLE Loss of TECW Initiating Event Fault Tree	
PAGE NUMBER Page 3	DATE 10/16/2008



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Loss of TECW Initiating Event Fault Tree

PAGE NUMBER	DATE
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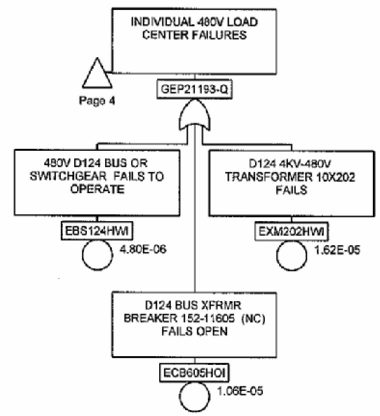

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Loss of TECW Initiating Event Fault Tree

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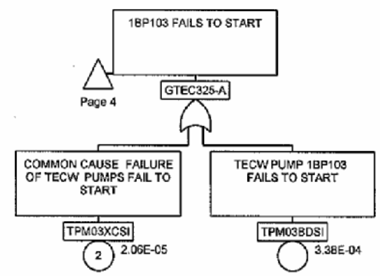

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Loss of TECW Initiating Event Fault Tree

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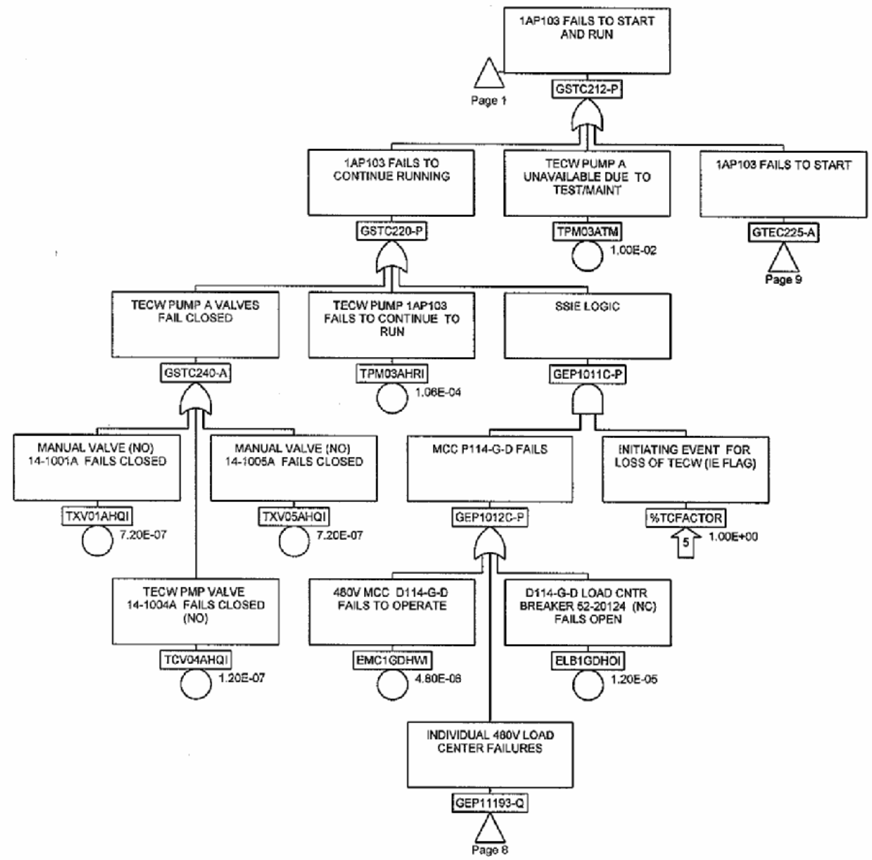

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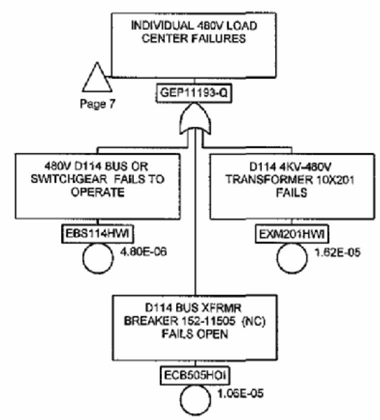

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Loss of TECW Initiating Event Fault Tree

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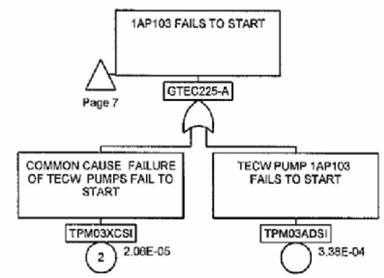

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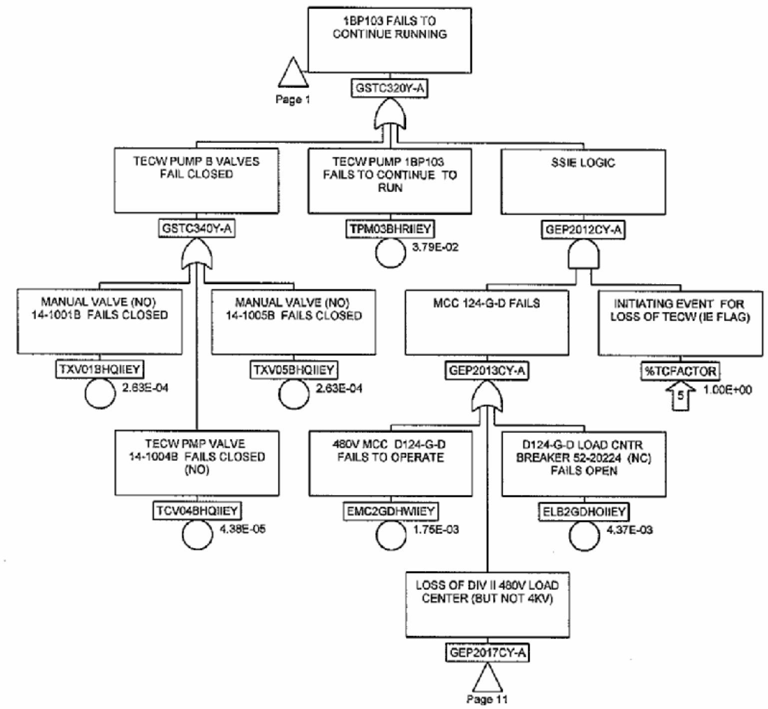

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PAGE NUMBER	DATE
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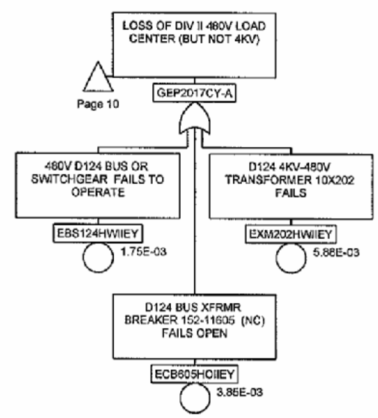

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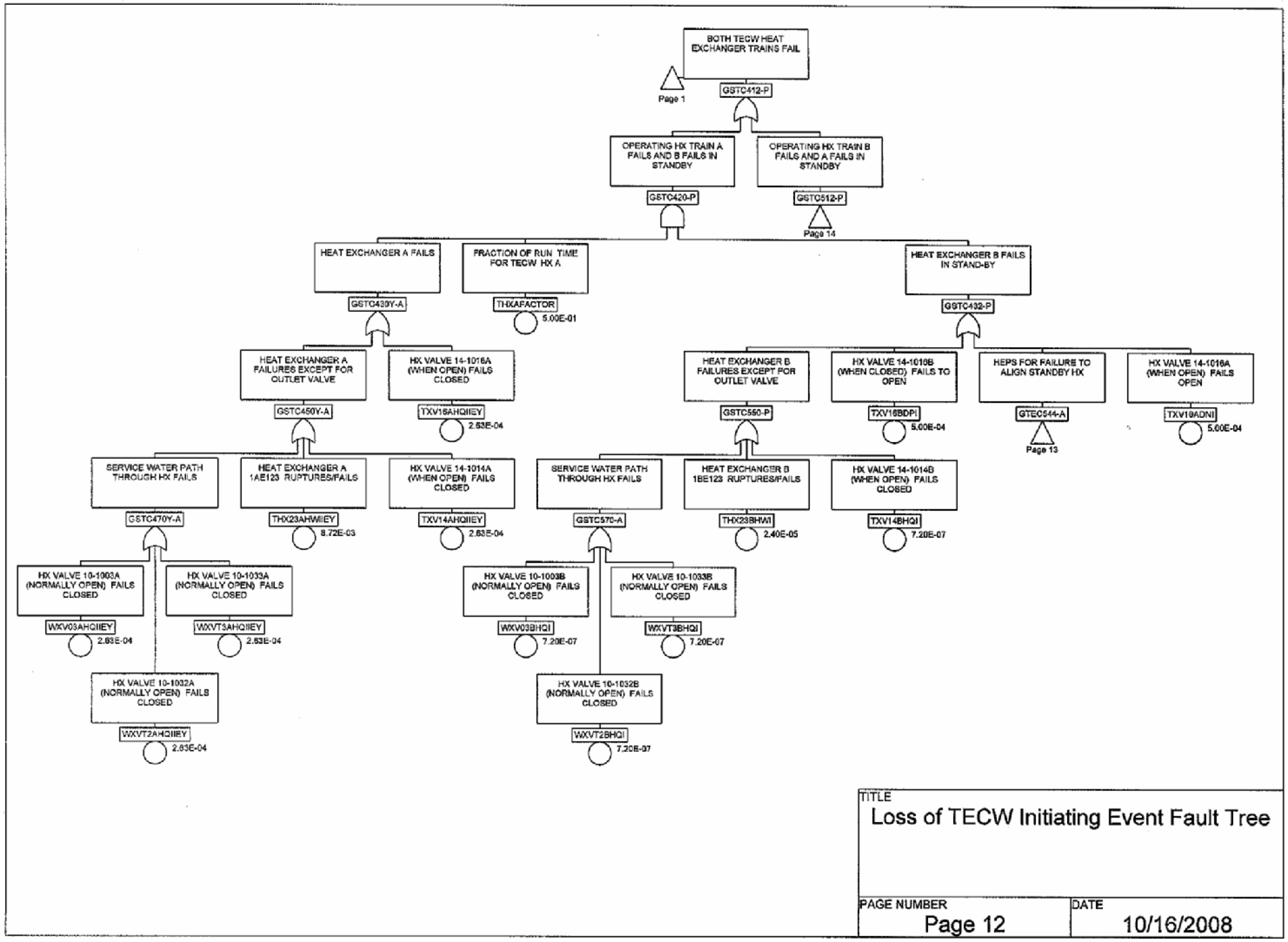
BOTH TECW HEAT EXCHANGER TRAINS FAIL
GSTC412-P
Page 1
OPERATING HX TRAIN A FAILS AND B FAILS IN STANDBY
GSTC420-P
OPERATING HX TRAIN B FAILS AND A FAILS IN STANDBY
GSTC512-P
Page 14
HEAT EXCHANGER A FAILS
GSTC430Y-A
FRACTION OF RUN TIME FOR TECW HX A
THXAFACTOR
5.00E-01
HEAT EXCHANGER B FAILS IN STAND-BY
GSTC432-P
HEAT EXCHANGER A FAILURES EXCEPT FOR OUTLET VALVE
GSTC450Y-A
HX VALVE 14-1016A (WHEN OPEN) FAILS CLOSED
TXV16AHQIIEY
2.63E-04
HEAT EXCHANGER B FAILURES EXCEPT FOR OUTLET VALVE
GSTC550-P
HX VALVE 14-1016B (WHEN CLOSED) FAILS TO OPEN
TXV16BDPI
5.00E-04
HEPS FOR FAILURE TO ALIGN STANDBY HX
GTEC544-A
Page 13
HX VALVE 14-1016A (WHEN OPEN) FAILS OPEN
TXV16ADNI
5.00E-04
SERVICE WATER PATH THROUGH HX FAILS
GSTC470Y-A
HEAT EXCHANGER A 1AE123 RUPTURES/FAILS
THX23AHWIIEY
8.72E-03
HX VALVE 14-1014A (WHEN OPEN) FAILS CLOSED
TXV14AHQIIEY
2.63E-04
SERVICE WATER PATH THROUGH HX FAILS
GSTC570-A
HEAT EXCHANGER B 1BE123 RUPTURES/FAILS
THX23BHWI
2.40E-05
HX VALVE 14-1014B (WHEN OPEN) FAILS CLOSED
TXV14BHQI
7.20E-07
HX VALVE 10-1003A (NORMALLY OPEN) FAILS CLOSED
WXV03AHQIIEY
2.63E-04
HX VALVE 10-1033A (NORMALLY OPEN) FAILS CLOSED
WXVT3AHQIIEY
2.63E-04
HX VALVE 10-1032A (NORMALLY OPEN) FAILS CLOSED
WXVT2AHQIIEY
2.63E-04
HX VALVE 10-1003B (NORMALLY OPEN) FAILS CLOSED
WXV03BHQI
7.20E-07
HX VALVE 10-1033B (NORMALLY OPEN) FAILS CLOSED
WXVT3BHQI
7.20E-07
HX VALVE 10-1032B (NORMALLY OPEN) FAILS CLOSED
WXVT2BHQI
7.20E-07
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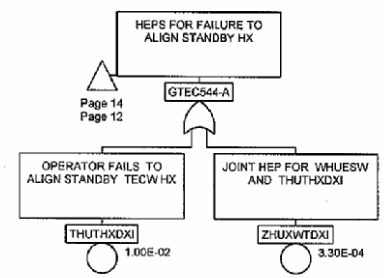

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Loss of TECW Initiating Event Fault Tree

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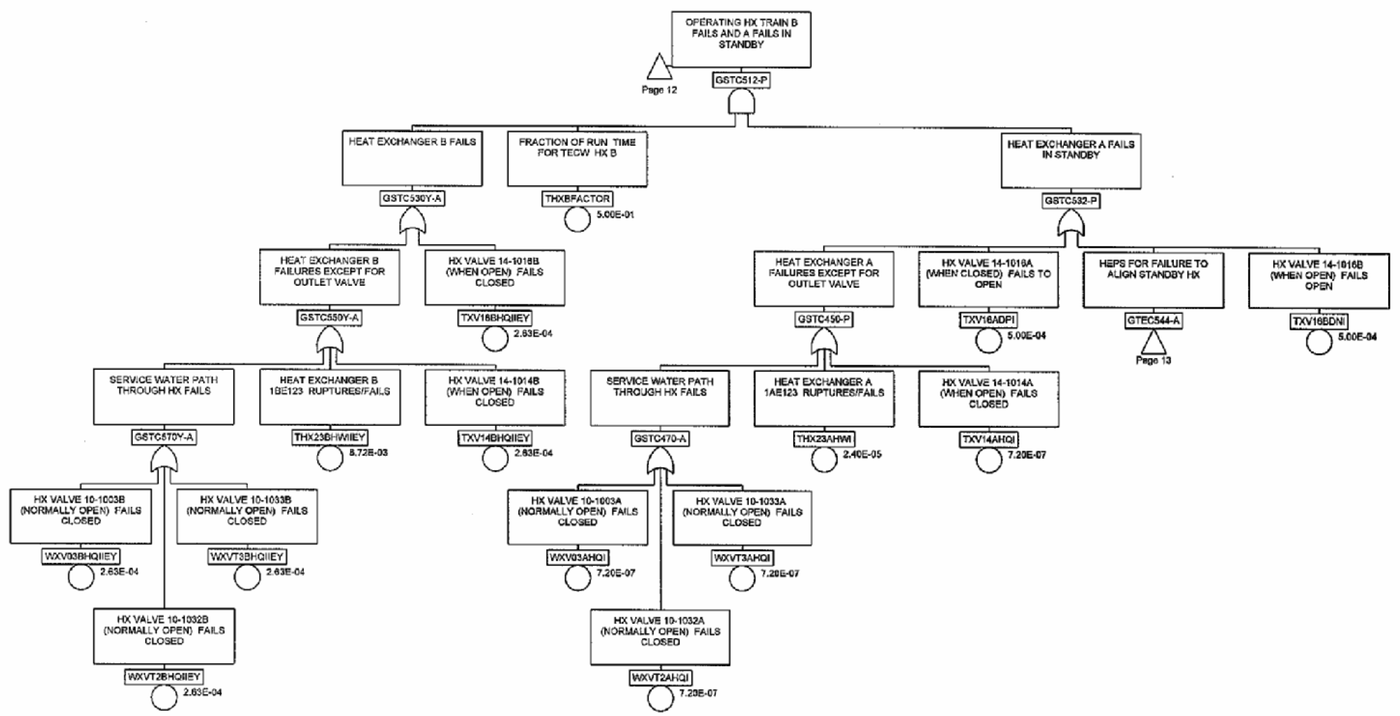

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%TCFACTOR	1	1	GEP2017CY-A	10	3
%TCFACTOR	2	4	GEP2017CY-A	11	2
%TCFACTOR	4	4	GEP21193-Q	4	3
%TCFACTOR	7	4	GEP21193-Q	5	2
%TCFACTOR	10	4	GSTC112-P	1	4
%TECW	1	2	GSTC120-P	1	3
EBS114HWI	8	1	GSTC150-P	1	2
EBS114HWIIEY	3	1	GSTC170-P	1	2
EBS124HWI	5	1	GSTC171-P	1	4
EBS124HWIIEY	11	1	GSTC212-P	1	3
ECB505HOI	8	2	GSTC212-P	7	3
ECB505HOIIEY	3	2	GSTC220-P	7	2
ECB605HOI	5	2	GSTC220Y-A	1	2
ECB605HOIIEY	11	2	GSTC220Y-A	2	2
ELB1GDHOI	7	4	GSTC240-A	7	2
ELB1GDHOIIEY	2	4	GSTC240Y-A	2	2
ELB2GDHOI	4	4	GSTC312-P	1	2
ELB2GDHOIIEY	10	4	GSTC312-P	4	3
EMC1GDHWI	7	3	GSTC320-P	4	2
EMC1GDHWIIEY	2	3	GSTC320Y-A	1	4
EMC2GDHWI	4	3	GSTC320Y-A	10	2
EMC2GDHWIIEY	10	3	GSTC340Y-A	10	2
EXM201HWI	8	2	GSTC412-P	1	3
EXM201HWIIEY	3	2	GSTC412-P	12	5
EXM202HWI	5	2	GSTC420-P	12	5
EXM202HWIIEY	11	2	GSTC430Y-A	12	3
GEP1011C-P	7	4	GSTC432-P	12	7
GEP1011CY-A	2	4	GSTC450-P	14	5
GEP1012C-P	7	3	GSTC450Y-A	12	2
GEP1012CY-A	2	3	GSTC470-A	14	5
GEP1015CY-A	2	3	GSTC470Y-A	12	2
GEP1015CY-A	3	2	GSTC512-P	12	6
GEP11193-Q	7	3	GSTC512-P	14	5
GEP11193-Q	8	2	GSTC530Y-A	14	3
GEP2012C-P	4	4	GSTC532-P	14	7
GEP2012CY-A	10	4	GSTC550-P	12	5
GEP2013C-P	4	3	GSTC550Y-A	14	2
GEP2013CY-A	10	3	GSTC570-A	12	5

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E
SSIE MODELING USING MULTIPLIER METHOD

E.1 Support System Initiating Event Fault Tree Model Development Considerations

Once the support system initiating events are identified, the model development can begin. There are two approaches which can be used to build a support system initiating event fault tree, each with advantages and disadvantages. The support system initiating event fault tree can be made by copying and revising the post-initiating event fault tree or it can be a new development. The first step in deciding on the approach for developing the support system initiating event model is to review the existing post-initiator model. The review needs to answer the following questions:

1. Are the system boundary and success criteria the same for the support system initiating event model and the post-initiator systems fault tree model?
2. Does the existing post-initiator model the necessary system configurations?
3. Are the assumptions made for the post IE model valid for the extended mission time associated with the support system initiating event model?
4. Does the existing post-initiator model logic reflect the same operational philosophy/concerns (actuation, alignment, etc.)?
5. Which type of support system initiating event is involved (immediate plant trip, delayed trip, degraded operation leading to administrative shutdown as discussed in Section 2 of this report)?

Each of these questions, and the impact they may have on the development of the support system initiating event model, is discussed below.

<u>System Boundaries and Success Criteria</u>. If the system boundary and success criteria are the same between the two models, then the modeling of the support system initiating event can be similar to that of the post-IE model. Systems such as electrical buses often have the same success criteria. Systems such as service water often times require fewer pump trains to operate to satisfy the post-IE function due to isolation of loads considered to be non-essential. More pump trains may be required to meet the plant cooling requirements during normal power operation and the success criteria is different between the models. In this example the system boundary differs as well because of the non-isolation of loads during normal operation. Other examples of different success criteria/system boundaries are the instrument air system and DC power. For instrument air, safe shutdown loads which require instrument air typically have

receivers which are sized to supply sufficient air to accomplish the safety functions and represent a redundancy to the compressors. In the normally operating case, the receivers are not a complete redundancy as the compressors will ultimately be required prior to bleed down of the receiver inventory. Likewise for DC power, the batteries cannot provide power indefinitely in the absence of AC inverters and therefore do not represent a full redundancy in the context of a support system initiating event. The likelihood during power operation of an extended loss of the AC inverters may be negligible and therefore not modeled but it does represent potential success criteria issue differences to consider.

System Configurations. The issue of modeling of different configurations during normal operations may result in needing to re-examine the post-initiator model to make sure it is consistent with the current system operational states. Some PRA models selected a "representative" configuration for the initial state of the system. If these post-initiator models have not been updated to reflect the various expected operational configurations, they are not recommended as the basis for the support system initiating event model and will likely require revision.

Assumptions. The post-initiator fault trees of a PRA are developed based on assumptions, and these assumptions determine what failure modes of components are considered, which can affect whether a component is included in the model or not. The increased exposure time when using a model to evaluate support system initiating events may invalidate some of these assumptions and require additional modeling or revisions to modeling. For example, plugging of some classes of components is often excluded due to the short exposure time. When the exposure time is extended to a year for the support system initiating event models, assumptions of these types may no longer be valid.

Actuation. Actuation may differ as well for systems in the support system initiating event model versus the post IE model. Components that are modeled as starting, opening, closing, or ensured to continue running by a safety signal in the post IE model may not have the same automatic actuation available during normal plant operation. If automatic signals are used in the post-initiator model, their applicability to the support system initiating event model needs to be evaluated. Additionally, during normal operation running components may be more prone to actuation of component protection trips and interlocks that may normally blocked in a post-initiator response by actuation based on a safety signal.

Type of Plant Trip/Shutdown. The type of support system initiating event to be modeled (immediate plant trip, delayed trip, degraded operation leading to administrative shutdown as discussed in Section 2 of this report) may result in different modeling than for the post IE model. In the case of delayed trip or degraded operation, the time frames of interest may differ significantly between the support system initiating event and post IE. For example, the time frame to provide certain areas with room cooling for the post-IE case may be sufficiently long due to reduced heat loads that it is not modeled where in the support system initiating event case the restoration of room cooling is critical to avoiding the support system initiating event.

The recommended approach to developing a support system initiating event model is discussed below, including a consideration of advantages and disadvantages of modifying existing post-IE models or developing new models.

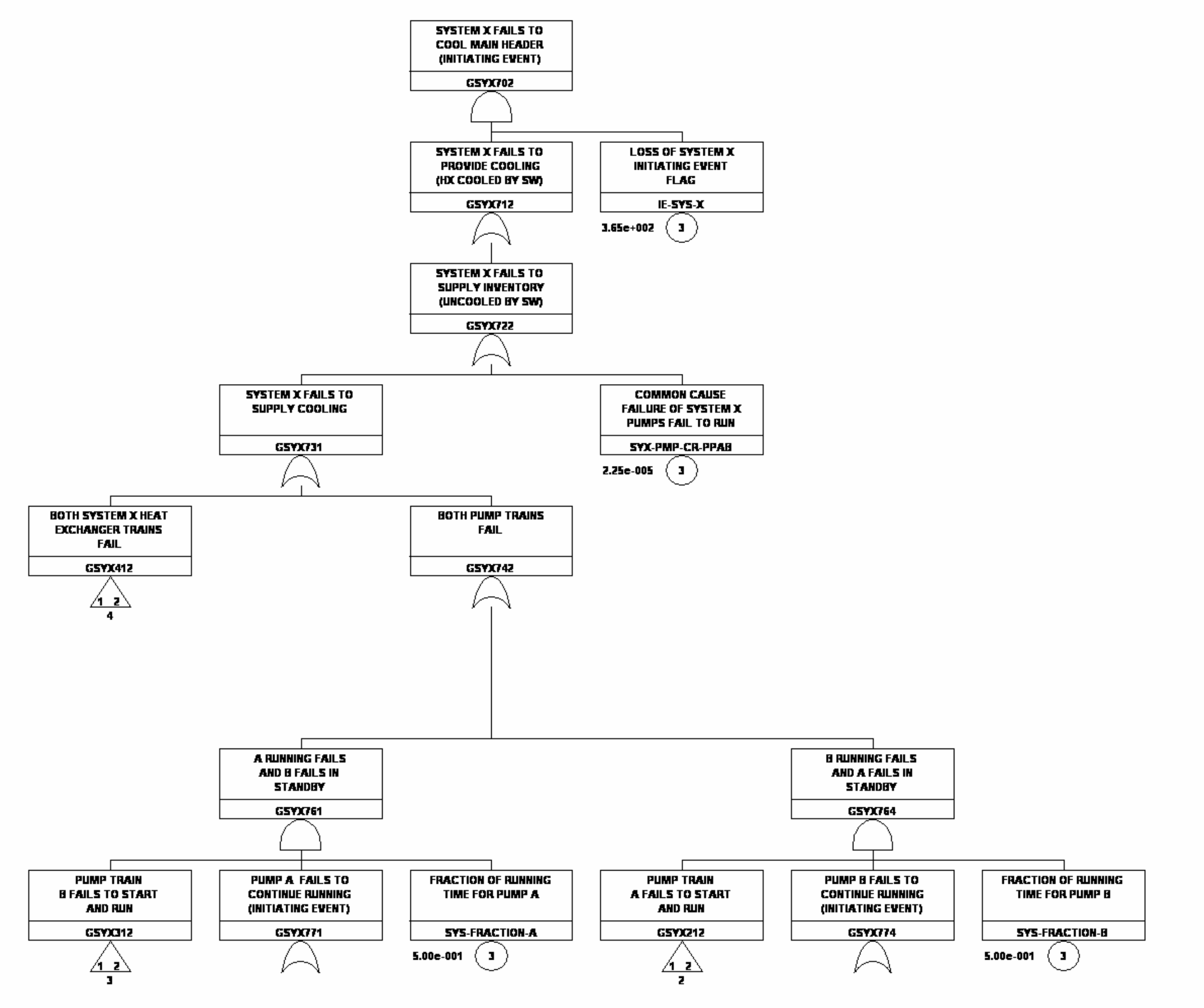
Advantages and Disadvantages of Using a Modified Post-IE Fault Tree Model for Support System Initiating Event. The benefit of copying and revising the post IE fault tree for use as the support system initiating event fault tree is that the structure of the tree will typically remain similar and later revisions to each tree are more straightforward, improving the long term model maintenance. Additionally, the basic event names associated with the running equipment will be identical in both the initiating event equation and the post-initiator functional equation, thus dependencies associated with running components are captured directly. Conversely, if there are differences in the above mentioned areas, even when minor, the modeling used to fit the new situation into the old structure can often lead to shortcuts in modeling and a reduction in clarity.

Advantages and Disadvantages of Using a New Fault Tree Model for Support System Initiating Event. The benefits of starting a new model allows the analyst to lay the tree out in a manner which is more coherent with respect to the different case associated with the support system initiating event. The disadvantage of this approach is that the tree structures differ significantly between the two models for the same system and if later modifications to the model are required based on system changes the modeling of the change sometimes differs between the two. Additionally, other modeling techniques need to be used to capture dependencies associated with running components.

Recommended Approach. The recommended approach is to generate a new top logic model which accurately depicts the support system initiating event scenario. The following procedure is written from that perspective, but the philosophy can be adapted to either approach. It is assumed that the user is familiar with the fault tree modeling process and capable of developing a fault tree from system information. In this procedure, 8760 hours or 365 days are used to denote the time frame of interest. In practice, the values used for a particular plant should be adjusted to account for the plant availability factor so the calculations resulting from use of the models are on a reactor-year basis.

E.2 Support System Initiating Event Fault Tree Development Procedure

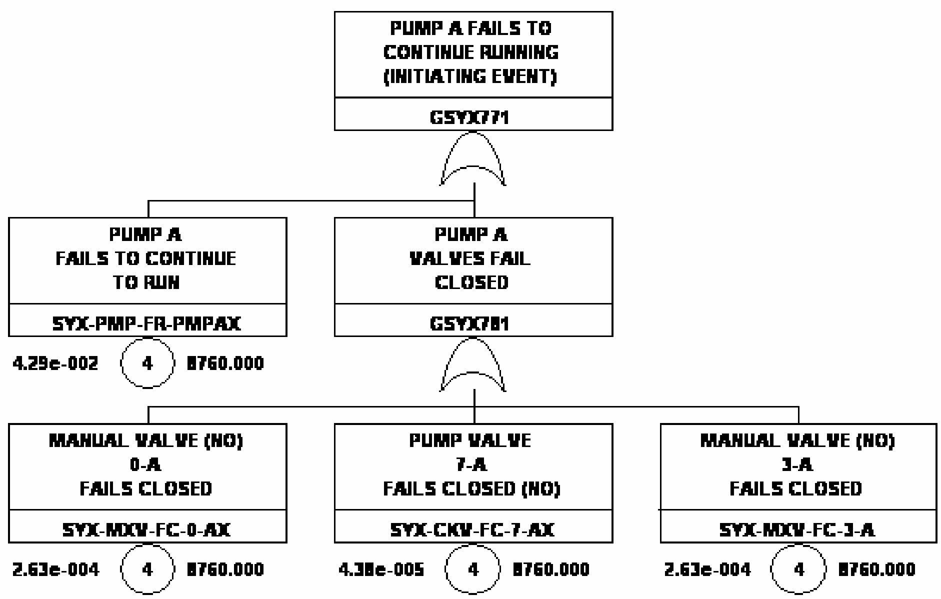
- Review the normal operation of the system and identify the various operational configurations that may exist for the system to be modeled.
- Identify any differences in the system configuration, operation, time constraints, and assumptions between the normal operation mode and the post IE operation mode.
- Explicitly define the success/failure criteria to be modeled in terms of the required systems/trains.
    - e.g., Failure of the operating train of “System X” and failure of the standby train to function
- Translate the success/failure criteria into the top logic to be modeled. Note this task involves separating the running failures from the demand-related failures.



The above example is for a two train water cooling system with the pump trains rotated equally. Note that under gate GSYX742 each possible operational pump train configuration is addressed. This approach can be readily adapted to model more complex logic (e.g., 2/4 required for success, 3/4 required for success). For support system initiating events which result in immediate plant trip, the model is reduced to the operating train portion. Common cause failure events can be either brought to the top of the fault tree as shown in the example or included in each component's logic. The flag event IE-SYS-X is used to identify the cutsets generated as initiator cutsets. The value shown in the above example associated with the flag event is representative of the multiplier approach which is discussed below under the operating train model.

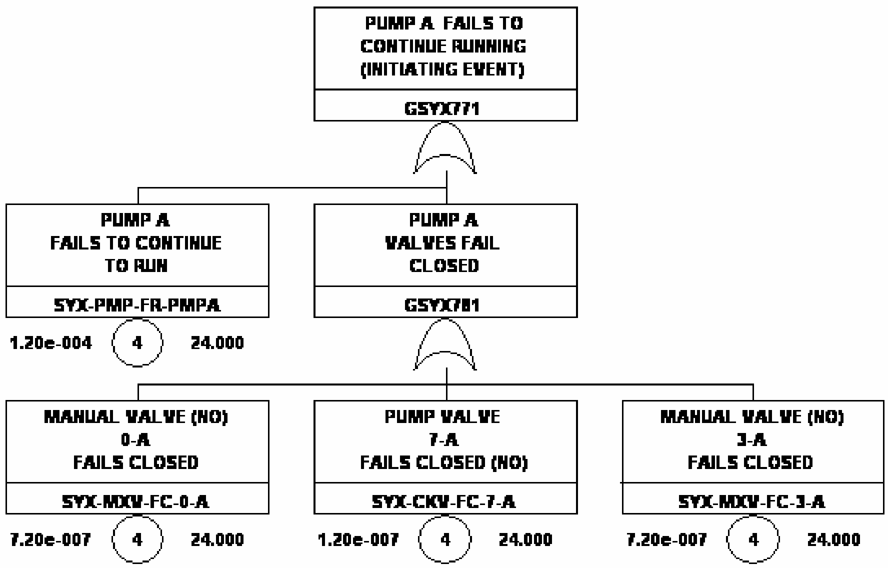
- Develop the operating train model using an 8760 hour mission time for the time related components. There are two approaches to applying the 8760 mission time. The modeling structure is identical in either case however, note the cautions below each example.

- Create new basic events to use in the support system initiating event fault tree whose values are calculated using a mission time of 8760 hours. If this approach is used the flag event is set to a value of 1.0. For ease of comparison, it is recommended that the new event names be the same as the other names but with an additional character added to the end or the last character changed if the basic event name is already at the event name limit. In the example below an X has been added to the end of each name.



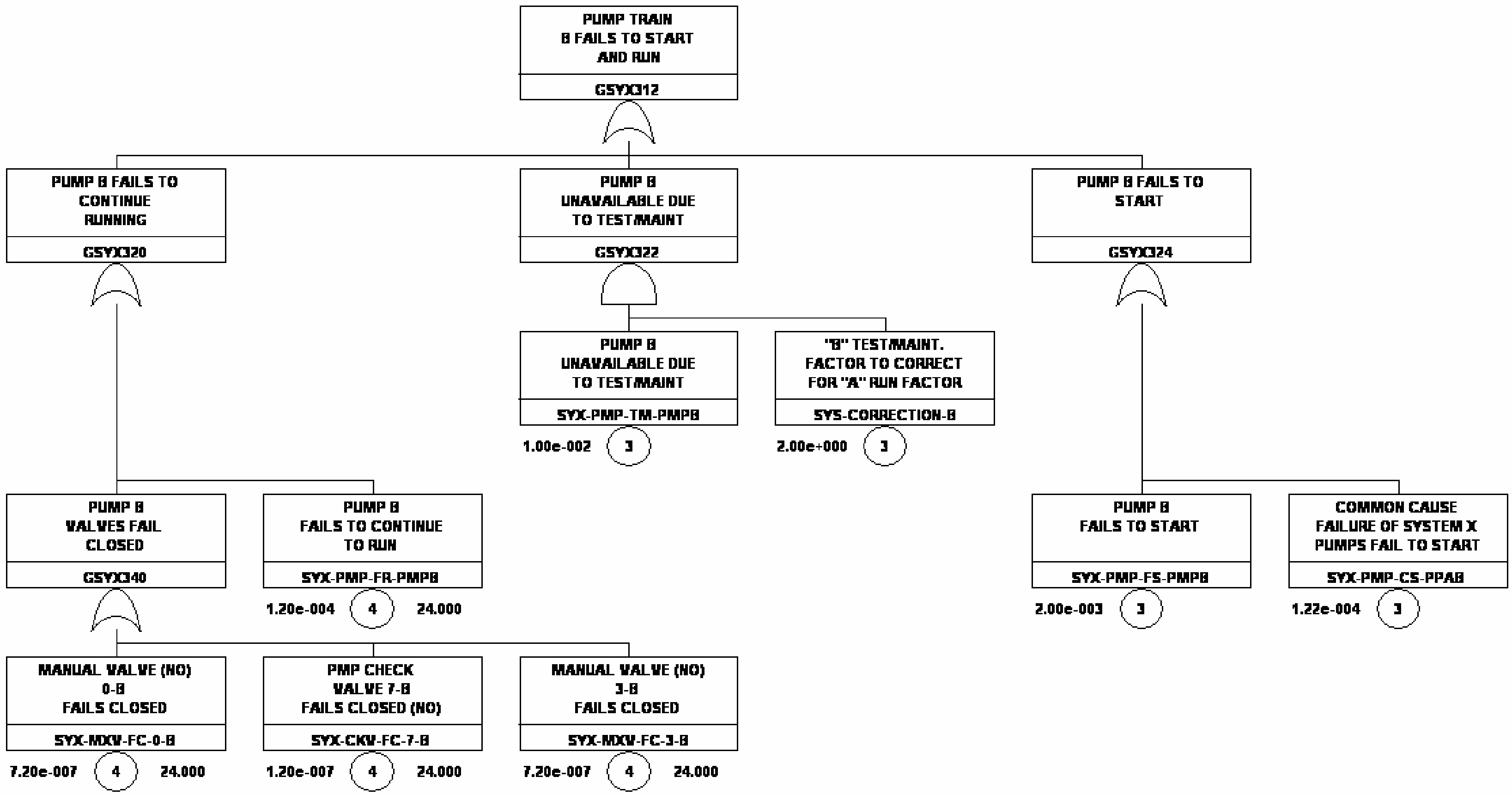
Caution – when using this approach, in order to accurately account for dependencies, the support system initiating event fault tree must be ORed with the top event in the post IE fault tree model and the success criteria must be the same for the support system initiating event fault tree and the post IE fault tree.

Use the same basic events as used in the post IE fault tree which are based on a 24-hour mission time and use the IE flag as a multiplier with a value of 365.



Caution – when using this approach, if there are any non-time-dependent demand type failures, those demand failures must be ANDed with a multiplier equivalent to the reciprocal of the value used for the flag event.

- Develop the standby train model using the 24-hour mission time similar to the post IE fault tree modeling. It is acceptable in some cases to utilize transfers to existing models rather than explicitly model the standby train if the operation of the standby equipment is the same for the normal plant operational state and the post IE response state.
  - Caution care must be used when utilizing transfers as oftentimes numerous systems are linked and any links that lead to support systems which are part of other support system initiating event should not be included. The example explicitly includes the events into the support system initiating event fault tree rather than providing links to the post IE model. This is the preferred method of modeling of the standby equipment.


PUMP TRAIN B FAILS TO START AND RUN
GSYX312
PUMP B FAILS TO CONTINUE RUNNING
GSYX320
PUMP B UNAVAILABLE DUE TO TEST/MAINT
GSYX322
PUMP B FAILS TO START
GSYX324
PUMP B UNAVAILABLE DUE TO TEST/MAINT
SYX-PMP-TM-PMPB
1.00e-002 3
"B" TEST/MAINT. FACTOR TO CORRECT FOR "A" RUN FACTOR
SYS-CORRECTION-B
2.00e+000 3
PUMP B VALVES FAIL CLOSED
GSYX340
PUMP B FAILS TO CONTINUE TO RUN
SYX-PMP-FR-PMPB
1.20e-004 4 24.000
PUMP B FAILS TO START
SYX-PMP-FS-PMPB
2.00e-003 3
COMMON CAUSE FAILURE OF SYSTEM X PUMPS FAIL TO START
SYX-PMP-CS-PPAB
1.22e-004 3
MANUAL VALVE (NO) 0-B FAILS CLOSED
SYX-MXV-FC-0-B
7.20e-007 4 24.000
PMP CHECK VALVE 7-B FAILS CLOSED (NO)
SYX-CKV-FC-7-B
1.20e-007 4 24.000
MANUAL VALVE (NO) 3-B FAILS CLOSED
SYX-MXV-FC-3-B
7.20e-007 4 24.000

- Quantify the support system initiating event fault tree model and review the resultant cutsets to ensure that the success/failure criteria are accurately reflected. If using the 8760 mission time approach above, each cutset should only contain one term with an 8760 hour mission time. If the 365 multiplier approach is used, demand failures for operational components should be coupled with a correction factor for the multiplier. In the example case, each cutset should contain a running component failure and a standby component failure.
- Determine how dependencies are to be accounted for when solving accident sequences and integrate into the plant PRA model.
    - If the 365 multiplier approach is used, the dependencies should be accounted for automatically by strict adherence to the naming convention.
    - If the 8760 terms are used, the support system initiating event fault tree will need to be ANDed with the corresponding post IE fault tree for the sequence solutions if the success criteria are the same for the support system initiating event and post IE fault trees or alternately automatic cutset editing rules must be set up to replace combinations of a support system initiating event failure term (8760 hr mission time) and the corresponding 24-hour term from the post IE fault tree with the single support system initiating event failure term. Other more complex methods may need to be developed for unusual cases.

Quantify the support system initiating event tree model sequences and review the resultant cutsets to ensure that the dependencies are accurately reflected and the cutsets are realistic for the sequences. If using the 8760 mission time approach above, each cutset should only contain one term with an 8760 hour mission time. If the 365 multiplier approach is used, demand failures for normally operational components should be coupled with a correction factor for the multiplier. Additionally, if using the 8760 mission time approach and including the support system initiating event logic in the post IE fault tree, other non support system initiating event initiator sequences which are dependent on the support system should be reviewed to assure that the inclusion of the support system initiating event logic in the post IE function does not introduce incorrect cutsets for the non support system initiating event sequences.

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