Determining the Effectiveness, Limitations, and Operator Response for Very Early Warning Fire Detection Systems in Nuclear Facilities – Update to Event Tree Parameters (Alpha and Pi) and Integration of NUREG-2230 Methods

Supplement 1

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Determining the Effectiveness, Limitations, and Operator Response for Very Early Warning Fire Detection Systems in Nuclear Facilities – Update to Event Tree Parameters (Alpha and Pi) and Integration of NUREG-2230 Methods

NUREG-2180, Supplement 1

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NOTE

ABSTRACT

The methodology for modeling very early warning fire detection (VEWFD) systems is documented in NUREG-2180, *Determining the Effectiveness, Limitations, and Operator Response for Very Early Warning Fire Detection Systems in Nuclear Facilities* (DELORES-VEWFIRE), issued December 2016. Since issuance of that publication, the Electric Power Research Institute (EPRI) and the U.S. Nuclear Regulatory Commission (NRC) have published fire probabilistic risk assessment (PRA) methods and data updates seeking to increase the realism of selected modeling techniques. In addition, both organizations continue to collect fire event experience data from the U.S. commercial nuclear industry. These data are used for updating fire PRA input parameters and to further inform the development of realistic modeling methods. As such, this report describes updates to the methodology for modeling VEWFD in fire PRAs to (1) reflect the impact of new fire event data on parameters in NUREG-2180 and (2) integrate the models in NUREG-2180 with the methods in NUREG-2230, *Methodology for Modeling Fire Growth and Suppression Response for Electrical Cabinet Fires in Nuclear Power Plants*, issued in 2020, associated with modeling interruptible fires in electrical cabinets.

One key parameter for determining the non-suppression probability (NSP) for scenarios involving VEWFD systems is the fraction of fire events that have an incipient stage. The incipient phase of a fire refers to a non-flaming start of a potential fire event (often consisting of subcomponent overheating). In NUREG-2180, the alpha parameter, α (the fraction of fires that do not have an incipient stage), was determined based on the results of a review of electrical cabinet fire events in EPRI's Fire Events Database (FEDB) through 2009.

Recent electrical cabinet fire events have been compiled, and more detailed information regarding fire incidents at nuclear power plants has been collected. Using the new data, the parameter α is updated, starting with the NRC's existing classification of the fire event data in NUREG-2180, which covered events from 1990 through 2009. The update includes any new information (e.g., corrective action documentation, fire reports) about the fire events compiled after the publication of NUREG-2180. The update to the α parameter also includes 23 new fire events from 2010 through 2014 evaluated during the development of NUREG-2230.

This report also updates the suppression rate used to calculate the parameter π. This parameter represents the enhanced suppression probability in the event tree model. The π factor differs between in-cabinet (π_1) and area-wide (π_2) applications. The π_1 factor is applicable for the in-cabinet event tree and represents the probability that, given success of the technician/field operator to respond to the VEWFD system alert, suppression has failed to limit the fire damage to the enclosure of origin. The π_2 factor is applicable for the area-wide event tree and represents the probability that, given success of the technician/field operator in the room responsible for the VEWFD system alert, suppression activities fail to prevent damage to PRA targets outside the cabinet. The suppression data for the 2010–2014 events are used to update the enhanced suppression rate for VEWFD area-wide applications (for π_2 in NUREG-2180).

This report also describes a process for crediting the methods in NUREG-2230 for modeling interruptible fires in electrical cabinets within the NUREG-2180 incipient detection framework. The results of this research can be implemented in new and existing fire PRAs for a more realistic representation of the scenario progression and suppression end states.

Keywords

Fire events
Fire incipient stage
Fire probabilistic risk assessment (fire PRA)
Non-suppression probability (NSP)
Very early warning fire detection (VEWFD)
Smoke detection
Aspirated smoke detection
National Fire Protection Association (NFPA) 805
Fire Protection

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EXECUTIVE SUMMARY

PRIMARY AUDIENCE: Fire protection engineers and probabilistic risk assessment (PRA) engineers supporting the development or maintenance of fire PRAs.

SECONDARY AUDIENCE: Engineers and stakeholders who conduct, review, or manage fire protection programs or interface with fire PRAs.

KEY RESEARCH QUESTION

How should new fire event experience and updated methodologies interface with the methodology in NUREG-2180, *Determining the Effectiveness, Limitations, and Operator Response for Very Early Warning Fire Detection Systems in Nuclear Facilities (DELORES-VEWFIRE),* issued December 2016, for crediting incipient detection in fire PRAs?

RESEARCH OVERVIEW

The U.S. Nuclear Regulatory Commission (NRC) Office of Nuclear Regulatory Research published NUREG-2180 in 2016. NUREG-2180 documents testing of incipient detector performance, provides background on operating experience, standards, literature review, and a methodology to quantify incipient detection system performance in fire PRAs. One insight from NUREG-2180 is the sensitivity of the overall non-suppression probability to the alpha parameter (fraction of fires that do not have an incipient phase) when crediting incipient detection systems in fire PRAs. The alpha parameter is derived from actual U.S. electrical cabinet fire event experience documented in fire reports, condition reports, or reporting to the NRC (through licensee event reports or event notifications).

After the publication of NUREG-2180, a major effort was undertaken to better examine electrical cabinet operating experience. As part of this effort, additional details on existing events were collected and analyzed. NUREG-2230, *Methodology for Modeling Fire Growth and Suppression Response for Electrical Cabinet Fires in Nuclear Power Plants*, issued in 2020, includes additional fire event operating experience and introduces the interruptible fire classification and revised non-suppression event trees. Guidance on how to apply both NUREG-2180 and NUREG-2230 was deemed necessary to address potential dependencies between the two approaches. Additionally, NUREG-2230 added 5 more years of fire event data, and the α and π_2 (enhanced suppression probability in the event tree model for area-wide applications) parameters of NUREG-2180 should be updated to reflect the most recent operating experience.

This report specifically addresses how to integrate the methods of NUREG-2230 into NUREG-2180 and updates the alpha (α) and pi (π) parameters from NUREG-2180.

KEY FINDINGS

- The fraction of fires that do not have an incipient stage (α) is a key parameter in the reliability of the human response to a potential fire event.
- Electrical cabinet fire event data through 2014 have been added and considered in this report. Table 4-2 reports the updated α (fraction of electrical cabinet fires that do not have an incipient phase detectable by a very early warning fire detection system). The results are as follows:
    - power cabinets: 0.41
    - low-voltage control cabinets: 0.10

  Hence, there has been a decrease in the updated α for power cabinets and low-voltage control cabinets (the mean value calculated for the 1990-2009 range was, respectively, 0.5 and 0.28), i.e., 1 - α, the fraction of electrical cabinet fires that have an observed incipient phase detectable by a very early warning fire detection system, has increased.
- The updated suppression rate for in-cabinet enhanced suppression (π_1) is based on the main control room suppression rate which was updated in NUREG-2178 Volume 2, *Refining and Characterizing Heat Release Rates from Electrical Enclosures During Fire*: *Fire Modeling Guidance for Electrical Cabinets, Electric Motors, Indoor Dry Transformers, and the Main Control Board*, issued in 2020. The updated mean suppression rate, as reported in Table 4-3, is 0.385 (the original parameter value from NUREG-2180 was 0.324).
- The updated area-wide suppression rate (π_2) is based on events during which an operator was present in the room of origin when a flaming condition began. This rate is also updated and reported in Table 4-5. The updated mean suppression rate is 0.226 (the original parameter value from NUREG-2180 was 0.194).
- Section 5 provides guidance on integrating the methods in NUREG-2230 with NUREG-2180. The concepts in NUREG-2230 (interruptible fires) and NUREG-2180 (pre-flaming conditions) are considered independent. Section 5.1 contains more details.

WHY THIS MATTERS

This report updates the fire event operating experience that has been categorized and classified in NUREG-2230 so that the incipient parameters reliant on fire event operating experience are using the latest data that match the fire ignition frequencies.

HOW TO APPLY RESULTS

The event tree structure in NUREG-2180 provides the technical basis and framework for modeling very early warning fire detection systems in fire PRAs. This report updates the NUREG-2180 parameters calculated from fire event experience that was classified and considered after the publication of NUREG-2180. The updated values in this report are for alpha (α) (the fraction of fires that do not have an incipient phase) and the suppression rates used to calculate π (enhanced suppression). Section 4.2 gives the updated alpha parameter (fraction of fires that do not have an incipient stage). Section 4.3 provides the updated enhanced suppression values.

Section 5 includes guidance on how to credit incipient detection along with other fire protection capabilities.

LEARNING AND ENGAGEMENT OPPORTUNITIES

Users of this report may be interested in fire PRA training, which is offered periodically.

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ABBREVIATIONS AND ACRONYMS

AS	automatic suppression
DET	detection
EDG	emergency diesel generator
EPRI	Electric Power Research Institute
FAQ	frequently asked question
FB	fire brigade
FEDB	Fire Events Database
FI	fire ignition
GF	growing fire
IF	interruptible fire
MCR	main control room
MF	manual fixed suppression
NRC	Nuclear Regulatory Commission
NSP	non-suppression probability
PRA	probabilistic risk assessment
VEWFD	very early warning fire detection

1 INTRODUCTION

1.1 Background

The incipient phase of a fire refers to the early stages of component thermal decomposition during which no flame has occurred, and the heat generated is minimal and not expected to produce damage outside the component of interest. In the incipient phase, thermal decomposition produces gaseous materials that may be detected using selected technology such as very early warning fire detection (VEWFD) systems.

Several studies document the treatment of VEWFD systems in fire probabilistic risk assessment (PRA). NUREG-2180, *Determining the Effectiveness, Limitations, and Operator Response for Very Early Warning Fire Detection Systems in Nuclear Facilities*, documents the most comprehensive research in the nuclear industry [1]. This report summarized the previous efforts to quantify the performance of VEWFD systems, discussed an approach for quantifying smoke detector performance, and described a new approach to estimate the non-suppression probability (NSP) for scenarios involving VEWFD systems in a fire PRA.

The NSP for a scenario with an installed VEWFD system is calculated using an event tree with input parameters from NUREG-2180. One key parameter for determining the probability of non-suppression for these scenarios is the fraction of fire events that are not expected to present an incipient stage. This fraction is represented by the parameter alpha (α)[1].

The methodology to calculate the parameter α was first described in Frequently Asked Question (FAQ) 08-0046, *Incipient Fire Detection Systems* as documented in the November 23, 2009 Closure Memo [2], based on the number of fast-acting components present in electrical cabinets and was later revised in NUREG-2180. In NUREG-2180, α was determined based on a review of relevant fire events collected in the Electric Power Research Institute (EPRI) fire events database (FEDB) through 2009. After the publication of NUREG-2180, data and methods were examined and restructured to more realistically capture observed electrical cabinet fire growth and response. The results were published as NUREG-2230, *Methodology for Modeling Fire Growth and Suppression Response for Electrical Cabinet Fires in Nuclear Power Plants* [4]. In addition to obtaining more recent electrical cabinet fire-related operating experience, EPRI requested more detailed information for earlier fire events which may provide additional documentation to assist in more definitive incipient stage classification.

The suppression rates used to calculate the enhanced suppression probability in the event tree model (π) comprise another parameter in NUREG-2180 that is updated in this report. The π factor differs between in-cabinet (π_1) and area-wide (π_2) applications. The π_1 factor is applicable for the in-cabinet event tree and represents the probability that, given success of the technician/field operator to respond to the VEWFD system alert, suppression has failed to limit the fire damage to the enclosure of origin. The π_2 factor is applicable for the area-wide event tree and represents the probability that, given success of the technician/field operator in the

[1] Note that 1-α represents the fraction of fires that are expected to present an incipient stage.

room responsible for the VEWFD system alert, suppression activities fail to prevent damage to PRA targets outside the cabinet.

Section 12.2 of NUREG-2180 reviewed the sensitivity to the parameters α, β, τ, and ξ for various VEWFD systems. Figure 1-1, reproduced from NUREG-2180, presents the sensitivity of the time to damage for a cloud chamber VEWFD system to the incipient detection parameters. From Figure 1-1 the greatest sensitivity is in the α parameter (the fraction of fires that do not have an incipient phase). A similar trend is observed with other VEWFD systems (spot-type ionization, sensitive spot-type, and light scattering), as reviewed in NUREG-2180.

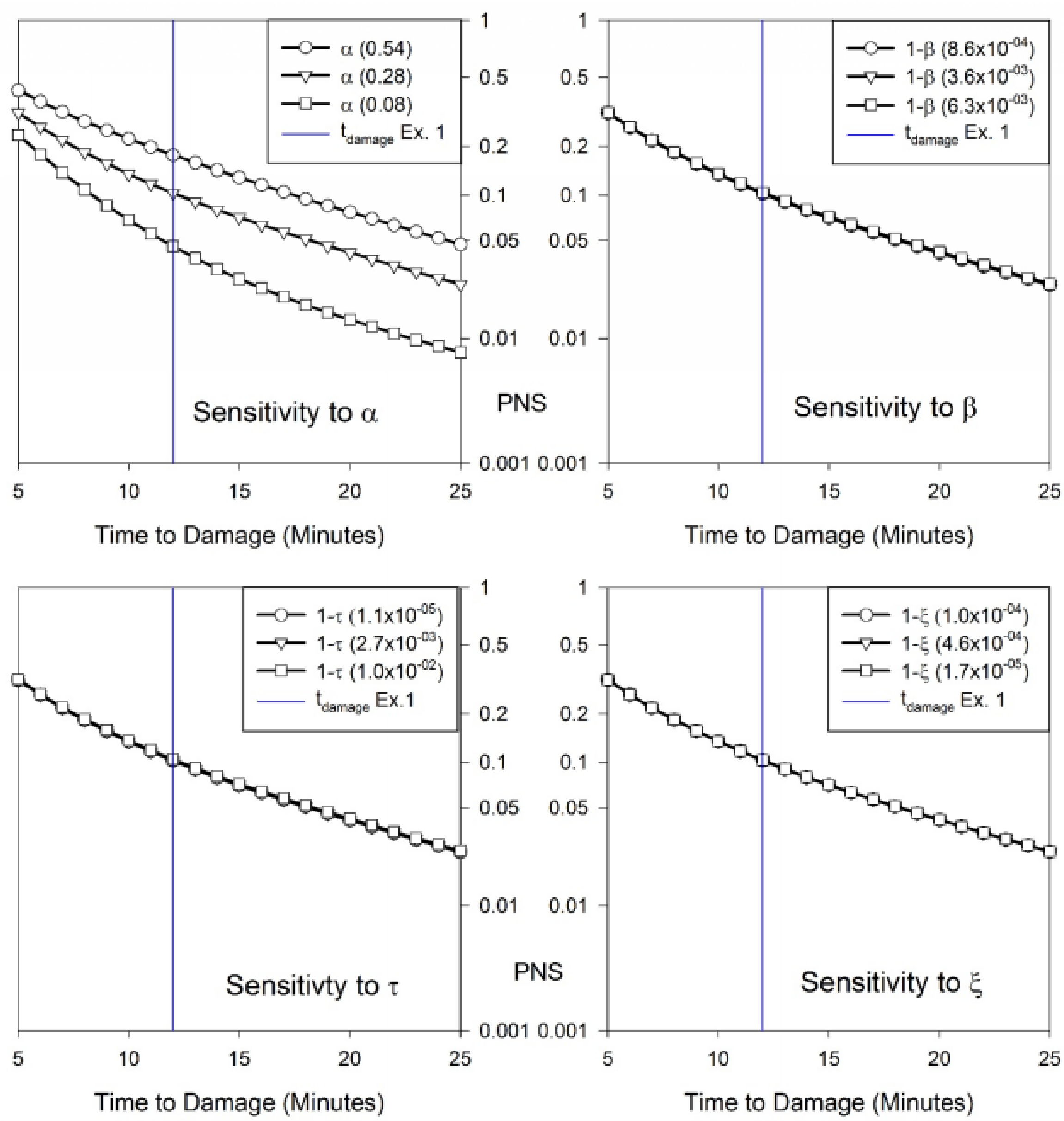

Figure 1-1
Probability Plots for Sensitivity of Cloud Chamber Aspirating Smoke Detection (Case 1, Reproduced From NUREG-2180 [1])

Experience implementing the event trees in NUREG-2180 further supports the sensitivity analyses in Figure 1-1, namely that α is the most sensitive parameter in the NSP calculation. This parameter is directly calculated from fire event data. The alpha parameter has been prioritized for updating with the most recent operating experience. Additionally, similar to α, the area-wide enhanced suppression rate supporting π_2 is developed from operating experience, and relevant fire event data is used to update this parameter.

This report updates the α parameter and the suppression rates used to calculate the π parameters. The U.S. Nuclear Regulatory Commission's (NRC's) existing classification of the fire event data in NUREG-2180 (67 fire events from 1990 through 2009) are supplemented with classifications from two EPRI reviewers. Additionally, 23 electrical cabinet fire events from 2010 through 2014 are added as part of the development of NUREG-2230. As part of further fire PRA realism efforts, additional classification changes and binning updates conducted after the publication of NUREG-2180 are also considered in this report. This impacts 8 events from 1990-2009 (one event removed, four events screened as non-challenging in NUREG-2230, and three events that were not previously in the NUREG-2180 data set). In total 26 new events are added. The methodology for updating α and the suppression rates used to calculate π is similar to that in NUREG-2180 and is described in Section 4 of this report. This report also describes a process for crediting the methods in NUREG-2230 for modeling interruptible fires in electrical cabinets within the NUREG-2180 incipient detection framework. The concept of interruptible fires refers to the progression in which a fire remains at a small heat release rate, or exhibits no to slow fire growth and spread for a period of time, so that the event can be *interrupted* before damage outside the ignition source occurs.

1.2 Purpose and Scope

The purpose of this report is twofold:

1. Update data for the parameters used for calculating the NSP for electrical cabinet fire scenarios with an installed VEWFD system, including the fraction of fires that do not have an incipient stage (α), and the suppression rates used to calculate the enhanced suppression parameters (π_1, π_2).
2. Provide guidance for integrating the methods in NUREG-2230 (modeling electrical cabinet fires) with NUREG-2180 (for incipient detection).

The following activities were completed in support of these objectives:

- Review the fire event classification in NUREG-2180 (fire events from 1990 through 2009) to reconsider events with newly obtained information. During the development of NUREG-2230, EPRI requested additional information (e.g., cause analysis, corrective action, plant fire reports) to provide the details necessary for classification. This new information was reviewed and considered as part of the α update.
- Review and classify the 23 fire events from 2010 through 2014 evaluated as part of the development of NUREG-2230.
- Recalculate the α parameter based on the review and classification of fire events from 1990 through 2014.
- Identify the updated suppression rate used to calculate the parameter π_1 based on the update to the main control room (MCR) manual suppression rate calculated in NUREG-2178, Volume 2, *Refining and Characterizing Heat Release Rates from Electrical*

Enclosures During Fire: Fire Modeling Guidance for Electrical Cabinets, Electric Motors, Indoor Dry Transformers, and the Main Control Board [5].

- Recalculate the suppression rate for π_2 based on the review and classification of applicable fire events from 1990 through 2014.
- Describe how to apply the NSP event trees in NUREG-2230 within the NUREG-2180 framework.

The scope is limited to updating the α parameter and the suppression rates used to calculate π_1 and π_2 parameters for determining the NSP for electrical cabinet scenarios with VEWFD systems. This report does not update the event tree model structure in NUREG-2180 and the remaining input parameters (i.e., input parameters other than α, π_1, and π_2), and the guidance in NUREG-2180 remains valid. In addition, the assumptions and limitations described in NUREG-2180 remain valid (i.e., this report does not revise them).

2
TECHNICAL BACKGROUND ON ALPHA AND PI

2.1 Calculation of Alpha (α)

This section summarizes the treatment of alpha parameter in the previously published documents (including the current definition and assessment in NUREG-2180).

2.1.1 FAQ 08-0046

The fraction of fires that do not have an incipient stage (α) was initially estimated in FAQ 08-0046 [2], which follows EPRI 1016735, *Fire PRA Methods Enhancements: Additions, Clarifications and Refinements to EPRI 1011989* [6]. FAQ 08-0046 (and later NUREG-2180) refers to these components that do not exhibit an incipient degradation phase as “fast-acting.” The NRC staff modified the method in FAQ 08-0046 and the final approach was documented in NUREG/CR-6850 Supplement 1, *Fire Probabilistic Risk Assessment Methods Enhancements: Supplement 1 to NUREG/CR-6850 and EPRI 1011989* [3]. The method in FAQ 08-0046 was retired in 2016 [7] and superseded by NUREG-2180.

2.1.2 NUREG-2180

NUREG-2180 evaluates the use of VEWFD systems as a potential fire risk reduction measure for electrical cabinet fire hazards by providing enhanced warning of pre-flaming (incipient) fire conditions. NUREG-2180 provides a methodology that assess the effectiveness of the system and human response in fire PRAs.

One important change in NUREG-2180 compared to FAQ 08-0046 was the estimation of the fraction of fires that do not have an incipient stage (α). In NUREG-2180, this parameter is determined based on a review of electrical cabinet fire events in EPRI’s FEDB. Table 7-1 of NUREG-2180 (reproduced as Table 2-1) documents the results of the NRC’s review. For power cabinets, 0.50 of the fires did not exhibit an incipient stage. For low-voltage control cabinets, 0.28 of the fires did not exhibit an incipient stage.

Table 2-1
Fraction of Electrical Cabinets Fires That Do Not[2] Have An Incipient Phase From NUREG-2180 [1] (1990–2009)

Category	Fraction (alpha) **Mean** [lower/upper]
Power cabinets	**0.50** [0.36/0.64]
Low voltage control cabinets	**0.28** [0.08/0.54]

[2] The title of Table 7-1 in NUREG-2180 reads as “Summary of Fraction of Electrical Cabinet Fires (Bin 15) That **Have** an Incipient Stage Detectable by a VEWFD System,” but the parameter (fraction) alpha calculated in that table is actually the fraction that **do not have** an incipient stage as corrected in Table 2-1 of this report.

The mean for α is depicted in bold font, with the 5th and 95th percentiles shown in brackets. The mean input for either power cabinets or low-voltage control cabinets is entered as a constant input into the detection-suppression event trees in NUREG-2180.

2.2 Calculation of Enhanced Suppression (π) in NUREG-2180

The parameter π captures the effects of enhanced suppression for fire scenarios modeled with credit for VEWFD. The parameter is developed for in-cabinet and area wide applications. This section summarizes the treatment of π in NUREG-2180.

2.2.1 In-Cabinet, π_1

Section 11.1 of NUREG-2180 reviews the impact of an operator successfully responding to a VEWFD system alert in the area of a specific cabinet and promptly addressing the situation, preventing damage to targets outside that cabinet. Consistent with NUREG-2180, the MCR manual suppression rate is selected to reasonably represent a field operator or trained responder actively searching for the source of the alert. In NUREG-2180, at the time of publication, the mean MCR suppression rate was 0.324 as documented in NUREG-2169, *Nuclear Power Plant Fire Ignition Frequency and Non-Suppression Probability Estimation Using the Updated Fire Events Database: United States Fire Event Experience Through 2009* [8]. Using this suppression rate, the value of π_1 is determined as shown in Equation 2-1:

$$\boldsymbol{\pi_1 = e^{-\lambda t} = e^{-0.324t}} \qquad \textbf{Equation 2-1}$$

where *t* is the time to damage.

2.2.2 Area-wide, π_2

For an area wide application, during which an operator is successfully responding to a VEWFD system alert, but with the alert only at the room level (the alert indicated a fire in the room but is not specific to a cabinet or bank of cabinets), a new suppression rate was developed using events where it was determined that an operator was in the room of origin when flaming began. Table D-3 in Section D.3 of NUREG-2180 lists the events used to develop this suppression rate. The suppression rate in NUREG-2180 for area-wide applications was developed from six events with a combined suppression time of 31 minutes. The resulting mean value is 0.194. Similar to the enhanced suppression for an in-cabinet scenario, the value of π_2 is determined as shown in Equation 2-2:

$$\boldsymbol{\pi_2 = e^{-\lambda t} = e^{-0.194t}} \qquad \textbf{Equation 2-2}$$

3
TECHNICAL APPROACH FOR UPDATING THE ALPHA AND PI PARAMETERS IN NUREG-2180

This section describes the process for updating α and the suppression rates used to calculate the π parameters. The process for updating these values is similar to the process used in NUREG-2180 with some modifications. In NUREG-2180, the estimation of α and the suppression rate used to calculate π_2 were determined from a review of electrical cabinet fire events in EPRI's FEDB. The suppression rate used to calculate π_1 is based on the MCR suppression rate which has been updated through recent research (NUREG-2178, Volume 2).

3.1 Fire Event Review

The scope of fire events reviewed as part of updating the α parameter includes fire events involving Bin 15 (electrical cabinets) in EPRI's FEDB from 1990 through 2014. This includes all Bin 15 electrical cabinets that contribute to fire ignition frequency (i.e., challenging, potentially challenging, and undetermined). This includes the following:

- Fire events from 1990–2009 considered in NUREG-2180 Appendix D, updated with any classification changes from NUREG-2230 and NUREG-2178, Volume 2 (binning changes for events that were determined to be electrical cabinet (Bin 15) fires instead of main control board fires (Bin 4))
- 26 fire events (23 events added from 2010 through 2014 as part of NUREG-2230 and 3 new events that underwent a classification or binning change after the publication of NUREG-2180).

The modifications to the event review process from NUREG-2180 are as follows:

- Treatment of events occurring during work/maintenance activities (e.g., maintenance, inspection, testing, cleaning)
    - In NUREG-2180, events occurring during work activities (e.g., maintenance, inspection, testing, cleaning) were classified as "No" (i.e., no incipient phase).
    - Failures on demand (failures that immediately occur following the start of equipment) continue to be excluded since there is no advance warning of the component failure.
    - For this review, the criteria for assigning "No" during surveillance testing is clarified to include experiencing a failure on demand. This ensures that the classification aligns with the challenging fire classification criteria outlined in EPRI 1025284, *The Updated Fire Events Database: Description of Content and Fire Event Classification Guidance* [9]. It also allows for the event review to consider that, during surveillance testing, the location housing the components is typically staffed and, in some reports, there are clear indications of slow degradation documented in spans of several days or several hours. Two examples are discussed below:

        - Event 50784: The event occurred during relay testing, but a condition report was written 5 days before as the relay had an elevated temperature. During troubleshooting, a burning smell was noticed. The relay was misaligned and could have resulted in increased friction and then increased heating in the coil, which then led to its failure and resultant fire. Even though the fire happened during troubleshooting, there was documented evidence of prior detectable overheating.
        - Event 51332: During a 24-hour surveillance test of the emergency diesel generator (EDG), a fire started in the electrical cabinet and tripped the EDG offline. At 10:41 AM, the EDG was at full load. At 12:40 PM, an abnormal odor was documented. The "fix it now" team was in and out, with smoke visible to the eye during this time. At 1:26 PM, a fire was reported.

    In both event 50784 and event 51332, the conditions would have existed without the presence of personnel. The event narrative and context will assist in the classification, and the presence of work activities should not automatically disqualify events.

- Treatment of event duration:
    - Several sections of NUREG-2180 stated that the α parameter is determined through the review of the FEDB as the "fraction of fires that have an incipient stage of sufficient duration to allow for successful operator response," and the basis to define and support a sufficient duration is detailed in Section 7.1 of NUREG-2180. Consistent with NUREG-2180,[3] the authors acknowledge that the typical event description does not explicitly state specific durations. A reviewer should understand the failure mechanisms described for the event and make an informed decision based on the information and the objective of using a VEWFD system to provide sufficient time for operators to respond and be capable of providing suppression. That is, the event description or further information provided by the licensee suggested that a sufficient period of time existed to perform actions to mitigate a potential fire, such as de-energizing a cabinet, staging a fire watch, or evaluating internal components for overheating. Therefore, as part of the review, each event was classified as "Yes", "No" or "Undetermined" for the presence of an incipient phase, without an explicit duration threshold.

With these two clarifications during the event review, and consistent with NUREG-2180, the following review rules are carried forward:

- Emphasis is placed on making minimal assumptions regarding the event.
    - If the necessary information is not available, the reviewer ventures no guesses, and the classification is "Undetermined."
        - For example, many events identify a circuit breaker fault, but do not identify the component of the circuit breaker that failed. Since circuit breakers have numerous failure modes that could result in a circuit breaker fault, and because the various failure modes may or may not exhibit an incipient stage,

[3] The HRA analysis in NUREG-2180 is based on available operating experience (Table D-2) to determine the basis for the time available curves for operator response. The timing information, specifically incipient stage duration, remains valid with the inclusion of the new fire event data.

no assumption was made regarding any one failure mode; more-information was needed to make such a determination possible.

- An exception to this practice is associated with motor control center fires. Specifically, events were classified as "Yes" (i.e., an incipient stage occurred) if it could be concluded that the fire started at the control power transformer. This is based on observations from the events reviewed and the common failure mode observed, consistent with NUREG-2180 [1].

The following qualitative definitions for "Yes," "No," and "Undetermined" were used as the review criteria:

– **Yes**, the description of the event provides sufficient detail (information) to determine that an incipient stage occurred. Additionally, if the description of the event does not provide a direct indication of an incipient stage, but an incipient stage can be inferred from the component that failed, then it can still be classified as a "Yes".

  Readers should recall, as described in NUREG-2180, the incipient stage includes the preheating, gasification (also described as decomposition, degradation, or pyrolysis) and smoldering phases, which are all stages before flaming combustion.

  Examples: Overheating; smoldering.

– **No**, the description of the event identifies rapid failure or failure on demand (including during work activities), or the description of the event does not provide direct information regarding the timeframe for component degradation, but the timeframe can be inferred from other information presented.

  Examples: Water intrusion; excessive voltage, arc, or electrical discharges.

– **Undetermined**, the event description does not provide sufficient details to determine that an incipient stage did or did not occur.

The NRC and EPRI each conducted an independent review of events for the full data set (1990–2014). Each organization provided two reviewers. Initially, the analysts independently reviewed and classified events in accordance with the definitions provided above. The reviewers then compared their classifications and discussed those events for which their classifications differed. Based on this discussion, the reviewers may or may not have changed their classification. There was no attempt to force a consensus. The assessment includes events for which reviewers did not agree on a final classification using the ratio of classifications determined by the reviewers. For example, if two reviewers considered the event to be representative of an incipient event ("Yes") and the remaining two reviewers determined the event to be undetermined, then the event would be counted in the assessment with a weight of ½ "Yes" and ½ "Undetermined."

3.2 Calculation of Alpha (α)

The mean of α is calculated using a "one-stage" bayes approach (using a Jeffreys non-informed prior) assuming a binomial data set (the component either demonstrated an incipient stage or it did not). The posterior is a beta distribution with parameters "x" and "y", calculated as shown in equations 3-1, 3-2, and 3-3. The alpha (i.e., the probability of not having an incipient stage) is calculated from the x and y values:

$$\boldsymbol{x = N_{inc} + 0.5} \qquad \textbf{Equation 3-1}$$

$$\boldsymbol{y = N_{total} - N_{und} - N_{inc} + 0.5} \qquad \textbf{Equation 3-2}$$

$$\boldsymbol{\alpha}\ (\boldsymbol{mean}) = \mathbf{1} - \boldsymbol{x}/(\boldsymbol{x}+\boldsymbol{y}) \qquad \textbf{Equation 3-3}$$

where N_{inc} is the number of events with potential for an incipient stage, N_{und} is the number of events classified as undetermined, and N_{total} is the total number of events evaluated.

3.3 Calculation of Pi (π)

From Section 2.2, the enhanced suppression parameter π is determined using suppression rates calculated for both in-cabinet and area-wide applications. As in NUREG-2180, the enhanced suppression rate is calculated from a review of fire events. Events through 2014 are used to update the suppression rates for the in-cabinet and area-wide calculations for π_1 and π_2, respectively. Two inputs are needed to calculate a suppression rate: the number of fire events specific to the phenomena and the cumulative suppression time for these events. The resulting mean suppression rate is determined as the number of events divided by the cumulative suppression time.

Similar to the approach in NUREG-2169, the 5th, 50th, and 95th percentiles for a suppression rate are calculated using the chi-squared distribution shown in equation 3-4:

$$\boldsymbol{Suppression\ rate\ percentile} = \boldsymbol{P}(\boldsymbol{x},\boldsymbol{v})/\boldsymbol{t_D}/\mathbf{2} \qquad \textbf{Equation 3-4}$$

where $P(x, v)$ is the lower cumulative distribution function of the chi-squared distribution, x is the desired percentile, v is the number of degrees of freedom (equal to the number of events used in the suppression curve), and t_D is the total duration in minutes for the suppression curve.

4

UPDATED NUREG-2180 ALPHA AND PI PARAMETERS

4.1 Summary of Events Reviewed

This report reviews 93 events: 26 new events in addition to the 67 included in NUREG-2180:

- Of these, 88 of the events were classified and used in the α parameter calculation.
  - 62 included in NUREG-2180 (deletions are noted in the next main bullet)
  - 23 electrical cabinet fire events from 2010 through 2014 (see NUREG-2230 Table 3-7)
  - 3 new events from 1990 through 2009 not previously included in NUREG-2180
    - Addition of event 209 (event date 8/22/1990) that was missing from NUREG-2180 but considered in NUREG-2169 and NUREG-2230.
    - Reclassification of events 10394 (2/22/2005) and 20351 (6/21/1994) as part of the re-evaluation of main control board fire events in NUREG-2178 Volume 2 (both were previously classified as Bin 4 – main control board and on further investigation were determined to be Bin 15 – electrical cabinets)
- The remaining five events were removed from consideration as through further investigation the events did not meet the challenging fire classifications in EPRI 1025284. Four of these five events (20382, 30281, 30578, and 50467) were screened out from the frequency analysis in NUREG-2230. Table A-4 of NUREG-2230 contains the full details of the removal from the fire ignition frequency count. Event 83.2 was also removed (originally classified as part of NUREG-2180) as this is neither considered in NUREG-2169 nor NUREG-2230 as a challenging fire.

Table 4-1 summarizes the event classification. Appendix A provides the details on the classification of individual fire events. Recall, the event classification results are developed using the apportioned classifications from the four reviewers as described in Section 3.1 and may result in a non-integer value.

Table 4-1
Summary of Event Classification (1990–2014)

Category	Incipient Stage Detectable by VEWFD?			Total Number of Events
	Yes	No	Undetermined	
Power	27	18.75	17.25	63
Control	12.75	1	11.25	25
All	39.75	19.75	28.5	88

4.2 Fraction of Fires That Do Not Have an Incipient Stage (α)

4.2.1 Updated α

The calculation of α is made using the “one-stage” Bayesian (Jeffrey’s non-informed prior) assuming a binomial data set using equations 3-1, 3-2, and 3-3 from Section 3.2. Rather than update the α value from NUREG-2180 with the new events, the calculation is redone as the entire set of events is reviewed for this assessment.

The calculations are described for both power and low-voltage control cabinets.

Power Cabinets

$x = N_{inc} + 0.5$ = 27 + 0.5 = 27.5

$y = N_{total} - N_{und} - N_{inc} + 0.5$ = 63 – 17.25 - 27 + 0.5 = 19.25

$\alpha\ (mean) = 1 - x/(x + y)$ = 1 – 27.5/(27.5 + 19.25) = 0.41

where N_{inc} represents the count of events that have a detectable incipient phase (“Yes” in Table 4-1), N_{total} is the total count of events, and N_{und} is the count of undetermined events.

The percentiles are calculated using the Microsoft Excel function for the inversed beta distribution as follows:

5th percentile = 1-BETA.INV(0.95,27.5,19.25,0,1) = 0.30

95th percentile = 1-BETA.INV(0.05,27.5,19.25,0,1) = 0.53

where the inputs to the function are the percentage value, x, y, 0, and 1 (the last two define the range for the standard beta distribution).

Low-Voltage Control Cabinets

$x = N_{inc} + 0.5$ = 12.75 + 0.5 = 13.25

$y = N_{total} - N_{und} - N_{inc} + 0.5$ = 25 – 11.25 – 12.75 + 0.5 = 1.5

$\alpha\ (mean) = 1 - x/(x + y)$ = 1 – 13.25/(13.25 + 1.5) = 0.10

The percentiles are calculated using the Microsoft Excel function for the inversed beta distribution as follows:

> 5th percentile = 1-BETA.INV(0.95,13.25,1.5,0,1) = 0.01
>
> 95th percentile = 1-BETA.INV(0.05,13.25,1.5,0,1) = 0.25

where the inputs to the function are the percentage value, x, y, 0, and 1 (the last two define the range for the standard beta distribution).

Table 4-2 lists the updated α for both power cabinets and low-voltage control cabinets.

Table 4-2
Fraction of Electrical Cabinet Fires That Do Not Have an Incipient Phase Detectable by a VEWFD System (α) 1990–2014

Category	Fraction Alpha Mean (lower/upper)
Power cabinets	**0.41** [0.30/0.53]
Low-voltage control cabinets	**0.10** [0.01/0.25]

The mean for α is shown in **bold font**, with the 5^{th} and 95^{th} percentiles shown in brackets.

The alpha parameter is the fraction of electrical cabinet fires that do not exhibit an incipient stage, for both power and control cabinets.

4.3 Enhanced Suppression (π)

4.3.1 Updated Suppression Rate for the Calculation of Parameter π_1

NUREG-2178 Volume 2, provides an updated MCR suppression rate using fire events through 2014. This updated suppression rate is used for calculating the in-cabinet enhanced suppression parameter ($\pi_1 = e^{-\lambda_{MCR}t}$) for in-cabinet applications. Table 4-3 presents the suppression rate.

Table 4-3
Control Room Probability Distribution for Rate of Fires Suppressed Per Unit of Time (Reproduced from NUREG-2178 Volume 2)

Suppression Curve	Rate of Fire Suppressed (λ_{MCR})			
	Mean	5^{th} Percent	50^{th} Percent	95^{th} Percent
Control Room	0.385	0.209	0.372	0.604

4.3.2 Updated Suppression Rate for the Calculation of Parameter π_2

As in NUREG-2180, fire events were reviewed to identify those for which an operator was present in the room of origin when a flaming condition began. From these events, an updated suppression rate for use with area-wide applications was developed. Table 4-4 summarizes the events. The suppression times have been previously assessed in NUREG-2169 and NUREG-2230. Table A-1 describes the events in detail.

Table 4-4
Suppression Times for Events Used to Develop Area-Wide Enhanced Suppression

Fire ID	Event Date	Suppression Time (min)
83.1	4/4/1996	9
161	4/22/2009	5
253	7/6/1995	10
20270	6/7/1990	2
209	8/22/1990	2
20272	9/10/1990	5
30276	7/24/2006	2
50914	6/8/2010	3
51007	1/6/2013	8
51090	2/15/2013	1
51118	4/12/2011	4
51332	10/6/2014	2

Table 4-5 presents the resulting suppression rate for use with the area-wide enhanced suppression parameter, π_2.

Table 4-5
Area-wide Enhanced Suppression Rate for Use With The Area Wide Enhanced Suppression Parameter π_2

Suppression Curve	Rate of Fire Suppressed (λ)			
	Mean	5^{th} Percent	50^{th} Percent	95^{th} Percent
Area-wide, enhanced suppression	0.226	0.131	0.220	0.344

5

COMBINING INCIPIENT DETECTION WITH OTHER FIRE PROTECTION CAPABILITIES

The purpose of this section is to provide guidance on integrating NUREG-2230 [3] with the methodology for incipient detection in NUREG-2180. Integrating these models is possible as each is focused on distinct detection capabilities. Specifically, NUREG-2230 did not include VEWFD in the event tree models for calculating NSPs. Similarly, the methodology in NUREG-2180 focuses on modeling incipient detection and does not limit the ability to appropriately credit other detection and suppression systems in applicable fire scenarios.

The methodologies in NUREG-2230 and NUREG-2180 involve the use of relatively complex event tree models that are described in detail in their respective reports, including practical examples. As such, this section assumes that those event tree models and their corresponding input parameters are well understood.

The event tree model in NUREG-2180 calculates the NSP for a scenario considering both conventional detection and incipient detection capabilities. The parameters η_1, η_2, and η_3 capture the impact of a conventional detection/suppression system in the event tree models in NUREG-2180. At the time NUREG-2180 was published, these parameters were calculated using the detection/suppression event tree model in Appendix P of NUREG/CR-6850, *EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities* [10], which was the only guidance available at the time. However, given recent fire PRA realism research, the electrical cabinet NSP model in NUREG-2230 may also be used to determine the values for parameters η_1, η_2, and η_3. Using the model in NUREG-2230 allows for the consideration of interruptible fires (the consideration of interruptible fires is not considered in NUREG/CR-6850 Appendix P).

5.1 Evaluation of Independence Between Methodologies

5.1.1 Incipient Criteria and Interface with Interruptible and Growing Fire Classifications

Several parameters in NUREG-2180 and NUREG-2230 may be interpreted to capture similar detection and suppression capabilities. This section reviews these elements, describes the appropriate use of each when the methods are combined, and evaluates the assumed independence between these models.

NUREG-2230 introduced the concepts of “interruptible” and “growing” fires. An “interruptible” fire is one that presents flaming conditions and has a relatively slow growth stage that could be (1) detected and (2) controlled before growth and propagation occur outside the ignition source. A “growing” fire refers to a faster growing fire that may not be controlled before propagating outside the ignition source. NUREG-2230 calculated a split fraction characterizing the percentage of electrical cabinet fires that may present “interruptible” conditions versus “growing” conditions. Both the “interruptible” and “growing” fraction of fires may exhibit an incipient phase —no occurrence of flame.

That is, the concept of an "interruptible" fire as defined in Combining Incipient Detection with Other Fire Protection Capabilities.

NUREG-2230 is *assumed independent* of an ignition source that may present an incipient phase.

Comparing the interruptible fire classification criteria in Section 3.3.1 of NUREG-2230 with the incipient criteria identified in Section 3.1 of this report, there is no overlap in the individual criteria elements. This is expected as the classification to determine whether an event had an incipient phase focuses on characteristics such as the preheating, gasification, and smoldering phases that occur before the start of flaming combustion. In contrast, the classification of an interruptible or growing fire focuses solely on the development and response to a fire after the start of flaming combustion.

Using the incipient fire event classification results (documented in Appendix A) and the event classification information documented in NUREG-2230, Table 5-1 summarizes the count of electrical cabinet fires from 1990–2014 that have been classified as having or not having an incipient phase and further leading to an interruptible or growing fire.

Table 5-1
Number of Electrical Cabinet Fires (1990–2014) With/Without an Incipient Phase, Interruptible and Growing

Cabinet Type	Incipient, Interruptible	Incipient, Growing	Not Incipient, Interruptible	Not Incipient, Growing
Power	12	5.5	13	5
Control	7.75	4	0	1

The counts in Table 5-1 do not sum to the 88 events that were reviewed to calculate alpha in Section 4.1. This count is lower as events were excluded when there was insufficient information to definitively classify the fire as either incipient/not incipient or growing/interruptible, particular in the 1990s. Table 5-2 presents a similar exercise, but using the data selected to develop the interruptible/growing split fraction in NUREG-2230 (data period 2000–2014).

Table 5-2
Number of Electrical Cabinet Fires (2000–2014) With/Without an Incipient Phase, Interruptible and Growing

Cabinet Type	Incipient, Interruptible	Incipient, Growing	Not Incipient, Interruptible	Not Incipient, Growing
Power	10	4	8	2
Control	7.75	4	0	1

5.1.2 Statistical Tests for Determining the Independence of Incipient and Interruptible/Growing Fire Classifications

The chi-squared test, a widely used distribution for tests of variance, supports the treatment of independence between events with/without an incipient phase leading to interruptible or growing fires. Table 5-3 summarizes the total observed, estimated expected values, and test statistics used to perform the chi-squared test for independence of two categories (incipient/not incipient and interruptible/growing) from the same population of power cabinet fire events. In this assessment, the null hypothesis, H_0, is that the two categories are independent. For the null hypothesis to be taken as true, the test statistic, shown in Equation 5-1;

$$\chi^2 = \sum_{i=1}^{I} \sum_{j=1}^{J} \frac{\left(N_{ij} - \hat{E}_{ij}\right)^2}{\hat{E}_{ij}} \qquad \textbf{Equation 5-1}$$

is assumed to follow a chi-squared distribution and (I-1)×(J-1) degrees of freedom. Here, N_{ij} is the total number of observed counts of fire events classified as incipient/not incipient/interruptible/growing, and $\hat{E}_{ij}$ is the estimated expected counts of events for each category. The term I is the number of incipient possibilities (incipient or not incipient is a total of two possibilities), and J is the total number of fire growth classifications (two). Therefore, the degrees of freedom are (2-1) × (2-1) = 1.

Table 5-3
Observed, Expected, and Total Counts for Power Cabinets

Power Cabinets	Incipient	Not Incipient	Totals, N_i
Growing (observed)	4	2	4 + 2 = 6
Interruptible (observed)	10	8	10 + 8 =18
Totals (observed), N_j	**4 + 10 = 14**	**2 + 8 = 10**	**6 + 18 = 24**
Growing (expected)	(14 × 6) / 24 = 3.5	(10 x 6) / 24 = 2.5	3.5 + 2.5 = 6
Interruptible (expected)	(14 x 18) / 24 = 10.5	(10 x 18) / 24 = 7.5	10.5 + 7.5 = 18
Totals (expected)	**3.5 + 10.5 = 14**	**2.5 + 7.5 = 10**	**6 + 18 = 24**
Test statistic (growing)	$(4 – 3.5)^2$ / 3.5 = 0.07	0.10	Sum Test Statistic: 0.22
Test statistic (interruptible)	0.02	0.03	

Similarly, Table 5-4 summarizes the total observed, estimated expected values and test statistics used to perform the chi-squared test for independence of two categories (incipient/not incipient and interruptible/growing) for control cabinets.

Table 5-4
Observed, Expected, and Total Counts For Control Cabinets

Control Cabinets	Incipient	Not Incipient	Totals, N_i
Growing (observed)	4	1	5
Interruptible (observed)	7.75	0	7.75
Totals (observed), N_j	**11.75**	**1**	**12.75**
Growing (expected)	4.61	0.39	5
Interruptible (expected)	7.14	0.61	7.75
Totals (expected)	**11.75**	**1**	**12.75**
Test statistic (growing)	0.08	0.95	Sum Test Statistic: 1.69
Test statistic (interruptible)	0.05	0.61	

The resulting chi-squared statistics are 0.22 and 1.69 for power and control, respectively. The null hypothesis is rejected (i.e., no evidence to support factors are independent) if the sum of the chi-squared statistics is greater than the chi-squared value at the desired confidence level:

$$\chi^2 \geq \chi^2_{\propto,1}$$

For a 95 percent confidence level (α = 0.05,) the chi-squared statistic with a single degree of freedom at a 95 percent confidence level ($\chi^2_{0.05,1}$) is 3.84. This is greater than the calculated test statistics (0.22 from Table 5-3 and 1.69 from Table 5-4). Therefore, the null hypothesis is not rejected and the two categories—incipient/not incipient and interruptible/growing—are independent. These results support the hypothesis that the incipient behavior is independent of whether a fire is classified as interruptible or growing.

The practical interpretation of the chi-squared test for independent factors is that the difference between the observed and expected values is relatively small. Therefore, no trend or pattern in the data is observed. In the context of this case, if there is a relationship (dependence) between the two categories (incipient/not incipient and interruptible/growing), the observed and expected counts should result in a significant difference. If there is no relationship (independence) between the two categories, the observed and expected counts should be similar.

For example, Table 5-3 suggests that the observed number of events with a potential incipient phase resulting in growing fires is four. At the same time, the expected number of events is 3.5. As mentioned above, such a small difference among all the categories supports a conclusion of independence as no patterns or trends are observed that deviate from the expected values.

The chi-squared test tends to be less reliable with small data samples. That is the case with the control cabinet data. However, the application of the chi-squared test denotes independence between the two categories. In addition, the same conclusion of independence is reached when combining the power and control cabinet data and with the power data only.

Therefore, when combining the methods (NUREG-2180 and NUREG-2230), the fraction of electrical cabinet fires that do not have an incipient phase detectable by VEWFD (α) and the fraction of fires that do have an incipient phase detectable by VEWFD (1-α) should be modeled with the interruptible and growing fire split fractions consistent with NUREG-2230, and these concepts should be considered independent.

5.1.3 Detection System Ineffectiveness

The incipient system ineffectiveness, τ, in NUREG-2180 and the automatic smoke detection ineffectiveness parameter in NUREG-2230 are independent. The parameter τ in NUREG-2180 is applicable to incipient detection systems. The parameter in NUREG-2230 is applicable to traditional automatic smoke detection mostly intended for detecting flaming fires.

For scenarios in which redundant and independent automatic smoke detection systems are located within the electrical cabinet, the ineffectiveness term introduced in NUREG-2230 may be set to zero. As described in NUREG-2230, this parameter was introduced to capture the probability of a fire not capable of producing a detectable signature. This parameter was developed as a function of multiple factors, including fire size and separation of the smoke detector from the fire. It may be assumed that a detector located within the enclosed space of an electrical cabinet while flaming combustion occurs is sufficient to activate that detector.

5.1.4 Operator Responses

The successful MCR response parameter, μ, in NUREG-2180 is independent of the MCR operator response in NUREG-2230. In NUREG-2180, this parameter captures the failure of an operator to respond to an incipient fire alarm. In NUREG-2230, this parameter captures the failure of an operator to respond to a non-fire trouble alarm.

5.1.5 Personnel Detection

Credit for personnel detection in NUREG-2230 is not negatively impacted in the event of a failure of a VEWFD system. Personnel detection in NUREG-2230 is developed around the likelihood of personnel being present in an area of a fire and is not dependent on the success of an incipient detection system.

5.2 η_1: Failure of the VEWFD System, Redundant Detection/Suppression Capability

In NUREG-2180, the term η_1 captures the event in which the incipient detection system has failed or the MCR has failed to recognize the alert. Specifically, the guidance for developing η_1 states that the calculation represents event tree sequences F through N in NUREG/CR-6850 Appendix P. The detection/suppression event trees in NUREG-2230 can be substituted directly in the NUREG-2180 model to determine the value for η_1 with no modification necessary. With the introduction of personnel detection in NUREG-2230, the opportunity for personnel detection (which was referred as “prompt” detection sequences A through E in Appendix P to NUREG/CR-6850) is now captured in the first detection step of the NUREG-2230 event tree.

5.3 η_2: Prompt Alert by VEWFD System, Redundant Detection/Suppression Capability

The term η_2 captures the case in which the VEWFD system has not provided *advanced warning*—detection within the incipient phase—but still provides an *alert* that allows for crediting “prompt” detection. When applying NUREG-2230, the probability of first detection should be modeled as completely successful for both the interruptible and growing fires given the prompt detection provided by the VEWFD system. Given the prompt detection provided by the VEWFD system (e.g., the fire has already been detected), it is not necessary to apply the redundant automatic smoke detection ineffectiveness parameter, automatic smoke detection unavailability or unreliability, non-fire trouble alarm MCR indication, non-fire trouble alarm MCR operator response, or the probability that personnel are present. This results in the value of 1.0 used in the NUREG-2230 detection-suppression event tree for the first detection event. Figure 5-1 shows an example of the interruptible fire detection-suppression event tree crediting prompt detection using a value of 1 for first detection. The same credit applies to the growing fire detection-suppression event tree.

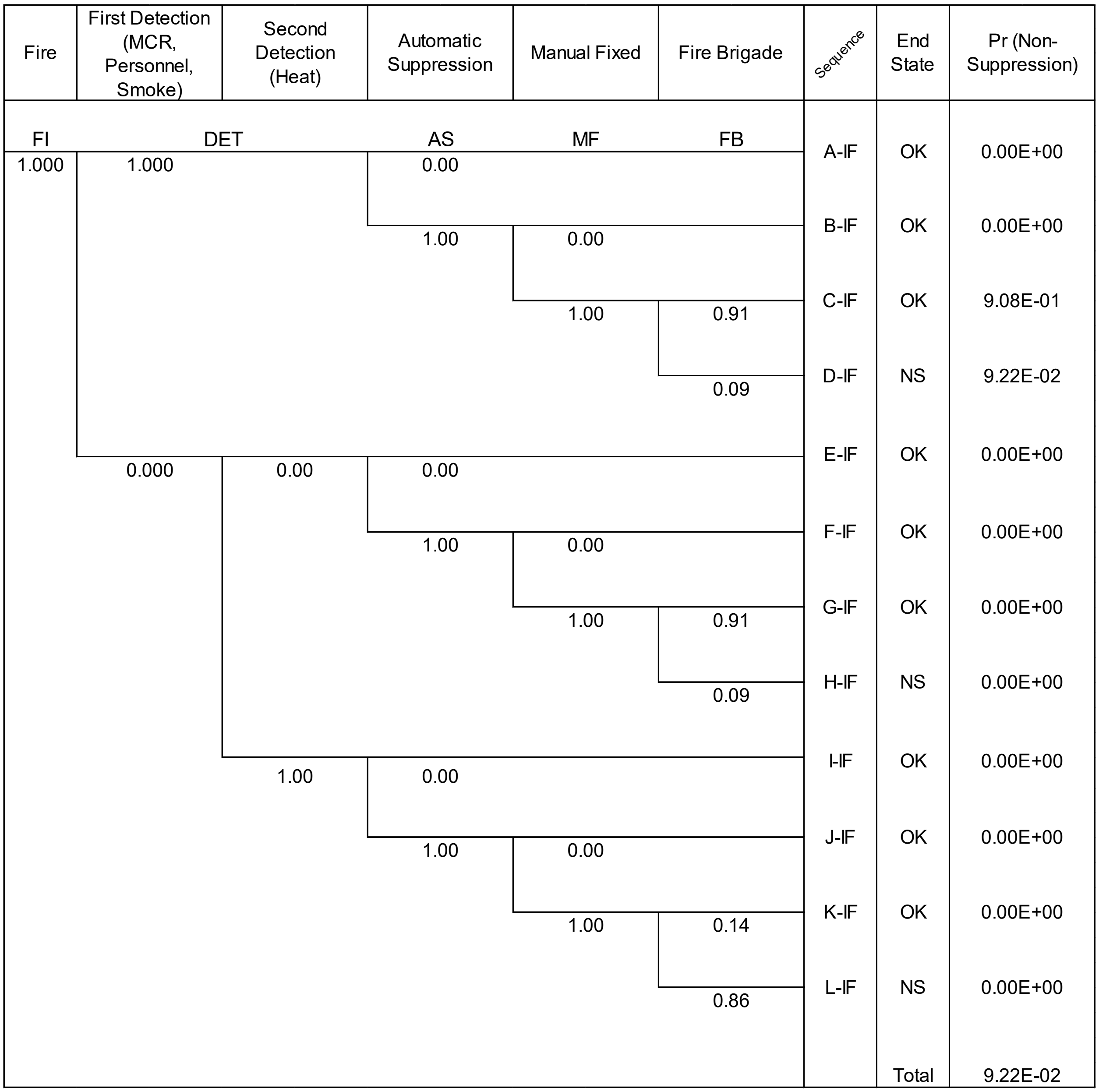

Figure 5-1
η_2, Example of Interruptible Fire NSP Crediting Prompt Detection

5.4 η_3: Failure of an Independent Suppression System

There is no change in the failure of an independent automatic suppression system to suppress a fire before damage, η_3, as described in NUREG-2180.

6
CONCEPTUAL EXAMPLES

This section provides conceptual examples of how the updated parameters in this report impact the NSP calculation. The examples in NUREG-2180 are reproduced and the impact of the updated parameters is compared. The details of the human reliability analysis in Section 10 of NUREG-2180 still apply, including the definition of success criteria and human failure events, and the details and assumptions in the qualitative analysis, timing analysis, and quantification. As with NUREG-2180, the examples in this section are generic and may not represent specific plant conditions or designs.

6.1 NUREG-2180, Case 1

This scenario considers a control cabinet (low-voltage) ignition source with an in-cabinet VEWFD system. The ignition source is part of a bank of 10 cabinets that are naturally ventilated. The estimated time to damage, *t*, is 12 minutes from the example's introduction in NUREG-2180.

Only one type of VEWFD system is reviewed. For this example, the VEWFD system is a cloud chamber. No redundant automatic detection or suppression credit is considered. Table 6-1 summarizes the parameters for this example as described in Section 12.1.1 of NUREG-2180 and updated in this report.

Table 6-1
Case 1 Input Parameters

Parameter	Original Parameter Value from NUREG-2180	Updated Parameter Value (NUREG-2180 & NUREG-2180 Supplement 1)
β	3.6E-03	3.6E-03
α	2.8E-01	**1.0E-01**
τ	2.7E-03	2.7E-03
μ	1E-04	1E-04
ξ	4.6E-04	4.6E-04
π_1	$e^{-\lambda_{MCR} \times t} = e^{-0.324 \times 12}$ = 2.0E-02	$e^{-\lambda_{MCR} \times t} = e^{-\mathbf{0.385} \times 12}$ = **9.85E-03**
η_1	1.0	1.0
η_2	3.1E-01	3.1E-01
η_3	1.0	1.0

6.1.1 Non-Suppression Probability Calculated Using NUREG-2180

The NSP for Case 1 in NUREG-2180 is calculated using the NSP event tree for an in-cabinet system as shown in Figure 6-1. The redundant detection/suppression capability, η_1, and the redundant detection/suppression capability with prompt notification by the VEWFD system, η_2, are determined following the NUREG/CR-6850 Appendix P, detection-suppression event tree as shown in Figure 6-2 and Figure 6-3, respectively. The NSP for Case 1 is 1.1E-01.

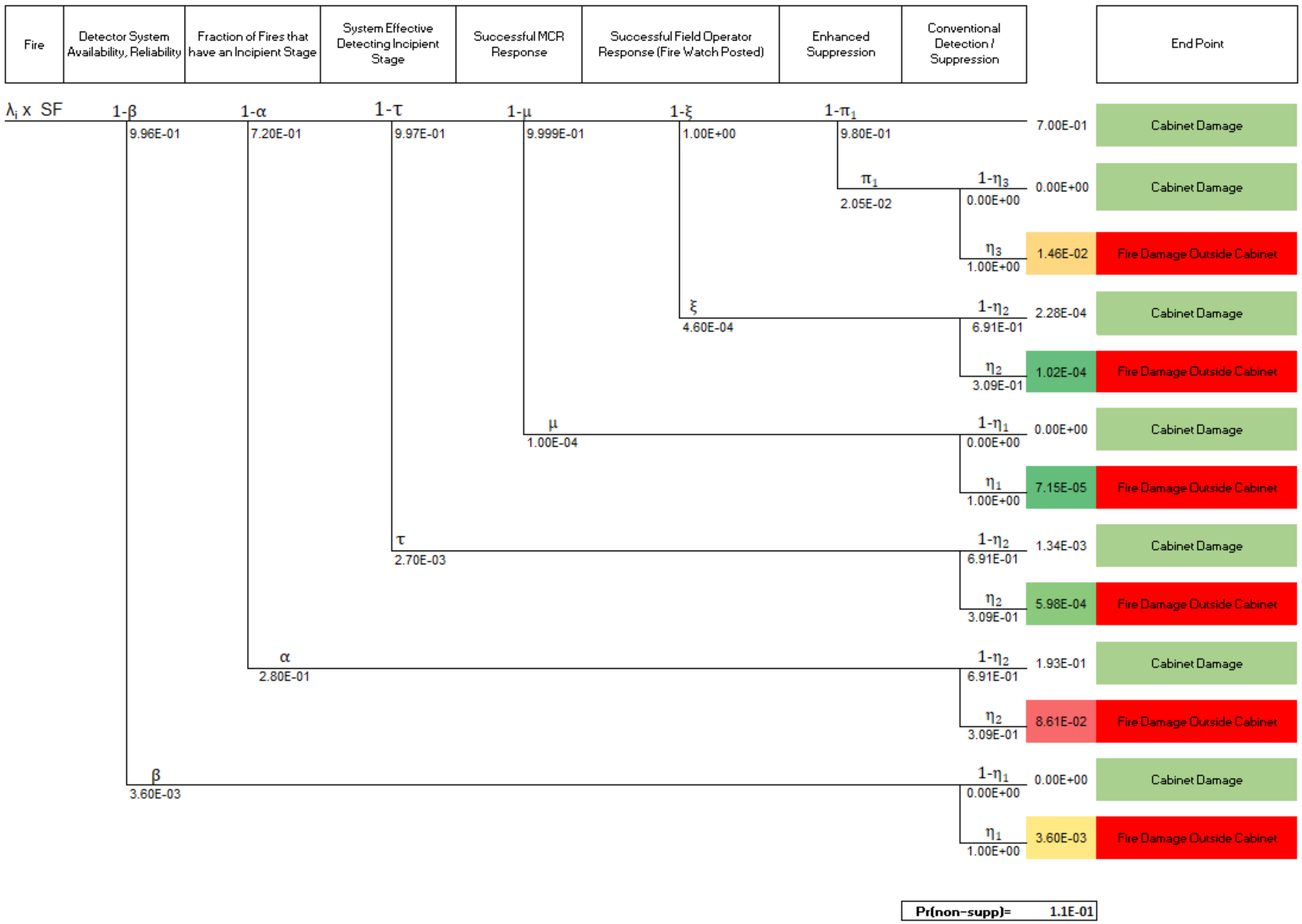

Figure 6-1
NUREG-2180, In-Cabinet NSP Event Tree for Case 1

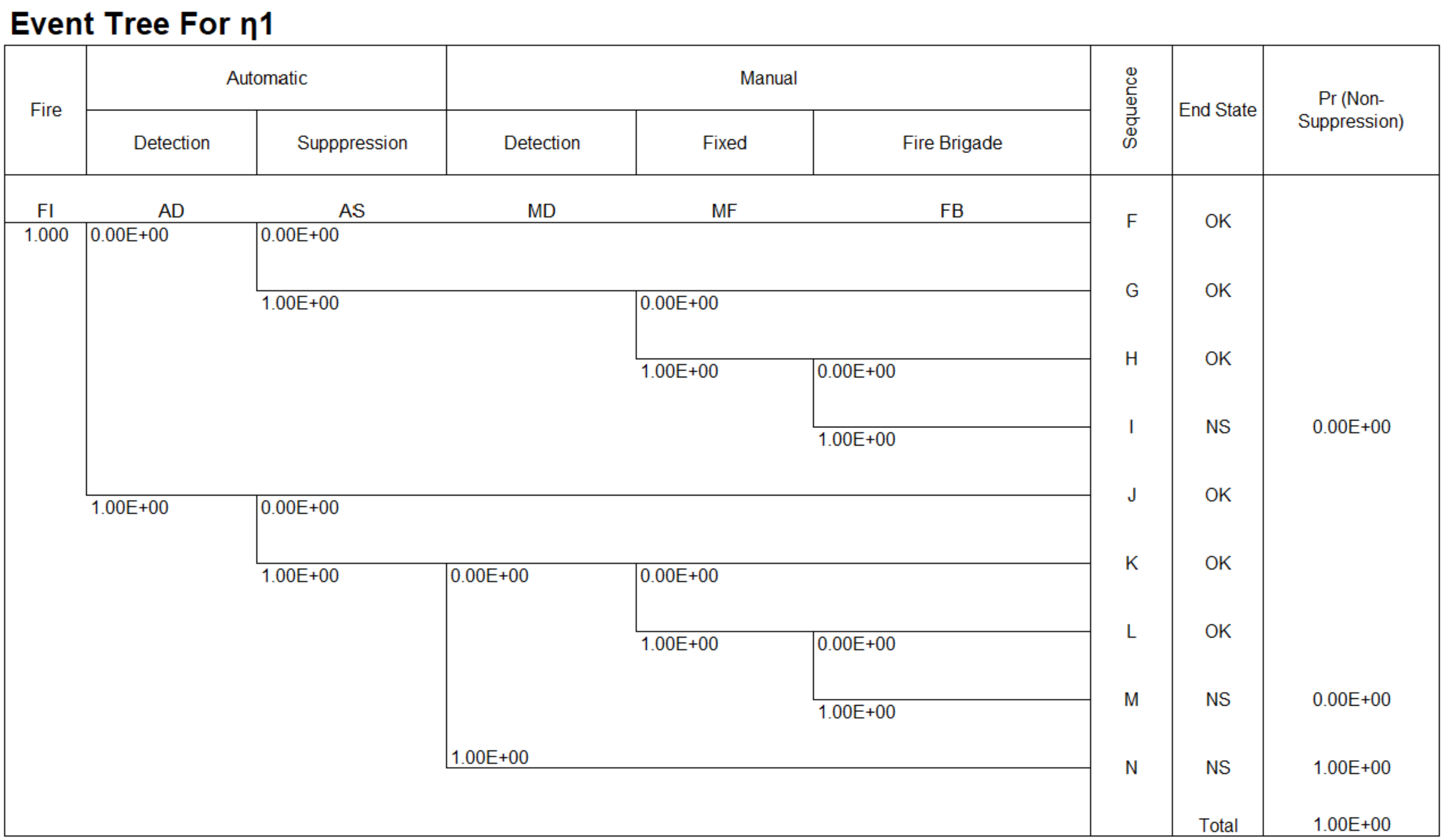

Figure 6-2
NUREG/CR-6850 Appendix P, Detection-Suppression Event Tree for η_1

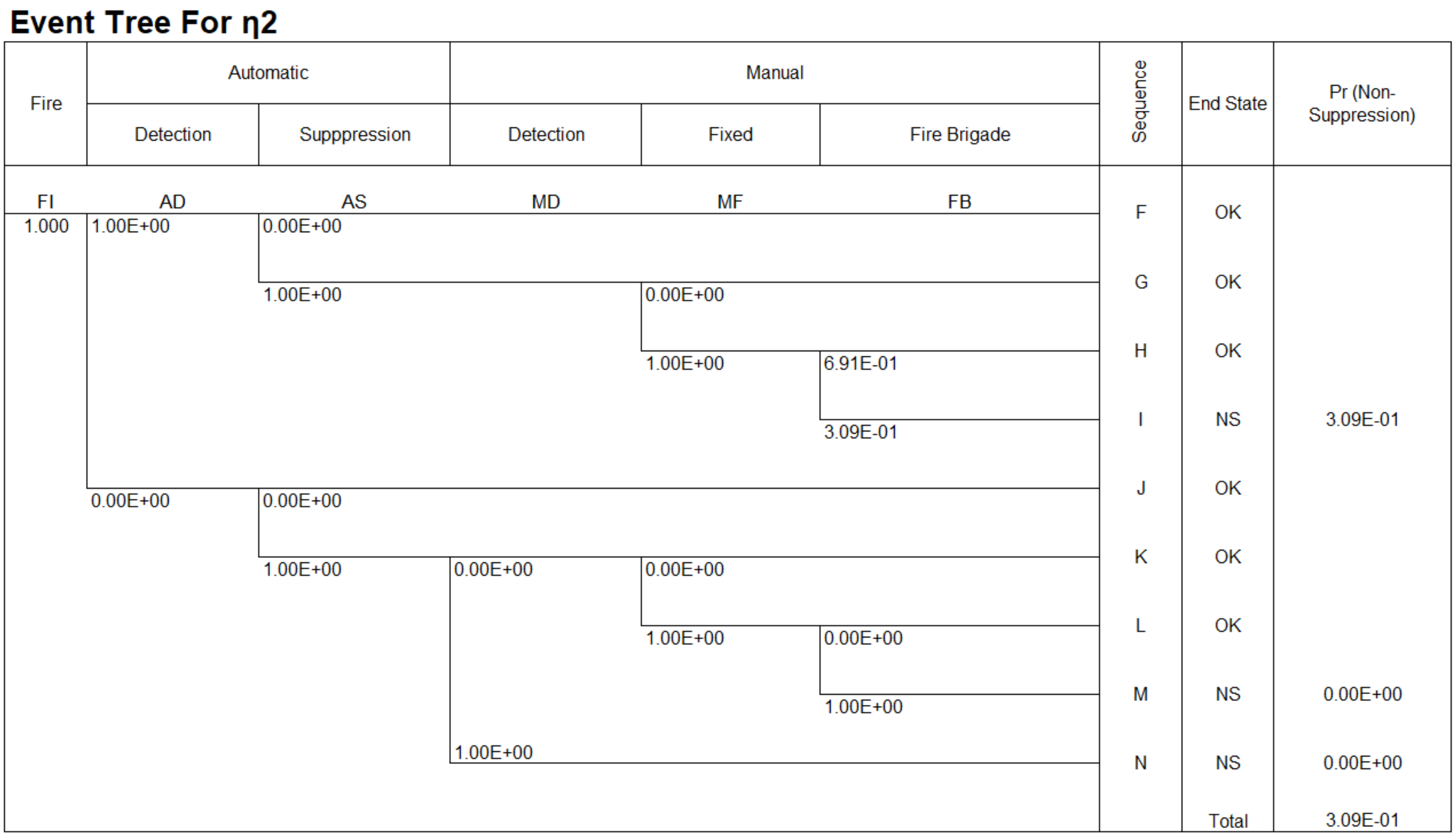

Figure 6-3
NUREG/CR-6850 Appendix P, Detection-Suppression Event Tree for η_2

6.1.2 *Non-Suppression Probability Calculated Using NUREG-2180 Supplement 1*

When the updated values for α and π_1 are used in the event tree for in-cabinet NSP estimation (Figure 6-4), an NSP of 4.41E-02 is calculated. This is a reduction of approximately 58 percent compared to the NSP of 1.1E-1 from Figure 6-1. Note, that the values calculated in Section 6.1.1 for η_1 and η_2 are unchanged in this example.

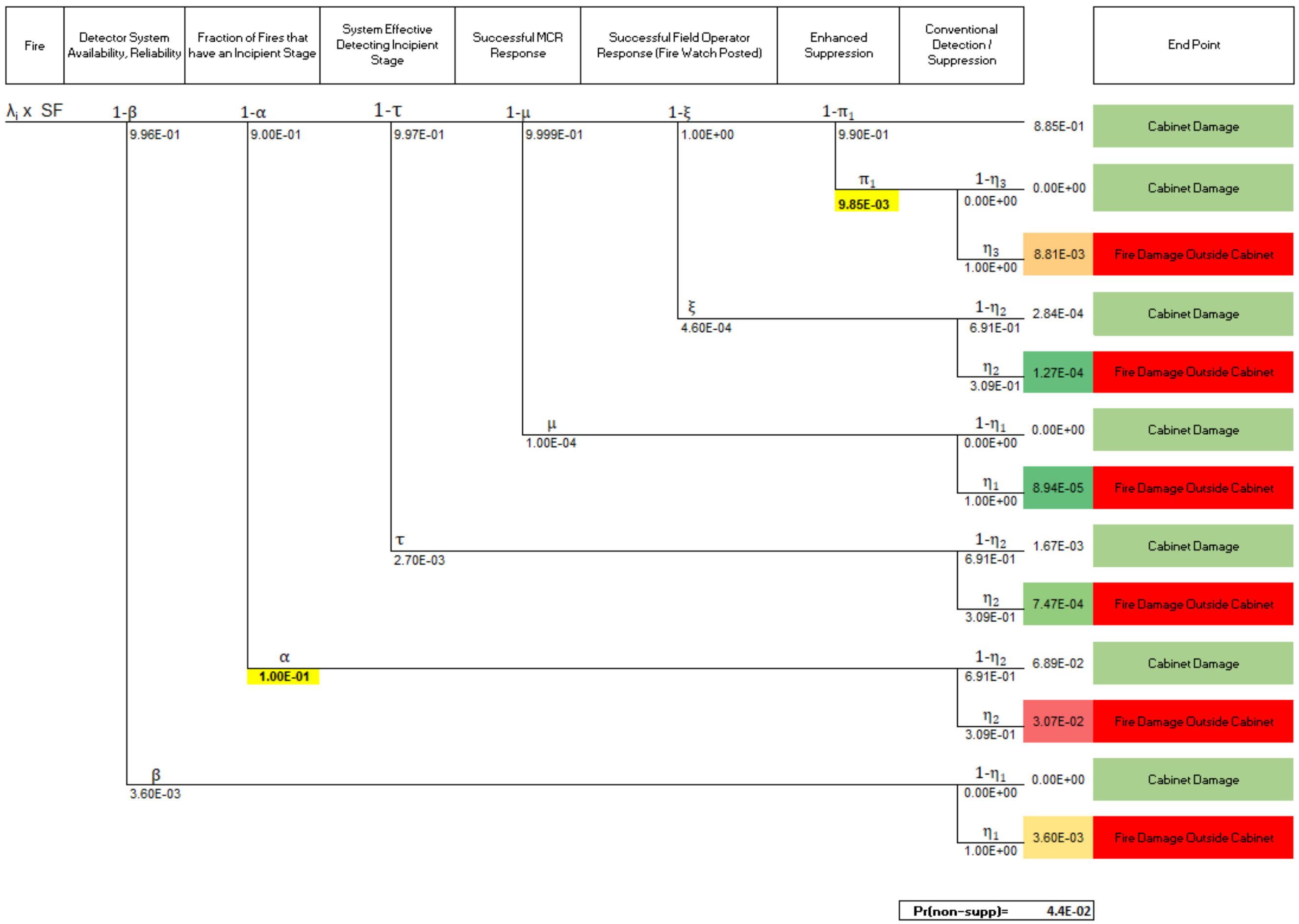

Figure 6-4
NUREG-2180, In-Cabinet NSP Event Tree for Case 1 With Updated α and π_1

6.2 NUREG-2180, Case 3

In Case 3, the scenario considers a power cabinet with an in-cabinet VEWFD system. The ignition source is part of a bank of 10 cabinets that are naturally ventilated. The time to damage is 12 minutes.

The VEWFD system is a cloud chamber, and no redundant automatic detection or suppression credit is considered. Table 6-2 presents the parameters for this example, as described in Section 12.1.3 of NUREG-2180 and updated from this report.

Table 6-2
Case 3 Input Parameters

Parameter	Original Parameter Value from NUREG-2180	Updated Parameter Value (NUREG-2180 & NUREG-2180 Supplement 1)
β	3.6E-03	3.6E-03
α	5E-01	**4.1E-01**
τ	2.7E-03	2.7E-03
μ	1E-04	1E-04
ξ	4.6E-04	4.6E-04
π_1	$e^{-\lambda_{MCR} \times t} = e^{-0.324 \times 12} =$ 2.0E-02	$e^{-\lambda_{MCR} \times t} = e^{-\mathbf{0.385} \times 12} =$ **9.85E-03**
η_1	1.0	1.0
η_2	3.1E-01	3.1E-01
η_3	1.0	1.0

6.2.1 Non-Suppression Probability Calculated Using NUREG-2180

Similar to Case 1, the NSP for Case 3 is calculated using the in-cabinet NSP event tree from NUREG-2180. The redundant detection/suppression capabilities, η_1 and η_2, are calculated using the NUREG/CR-6850 Appendix P, detection-suppression event tree. The Case 3 NSP is 1.7E-01.

6.2.2 Non-Suppression Probability Calculated Using NUREG-2180 Supplement 1

Applying the updated values for α and π_1 for the in-cabinet event tree, an NSP of 1.36E-01 is calculated. This is a reduction of approximately 19 percent.

6.3 NUREG-2180, Case 1 Using Event Tree Models in NUREG-2230

The Case 1 results updated with the data in Supplement 1 (this report) are further explored by also integrating the detection-suppression event trees and data from NUREG-2230. Case 1, from Section 6.1 of this report and detailed in Section 12.1.1 of NUREG-2180, provides the "base case," and this example is intended to show the impact of crediting personnel detection and interruptible fires (NUREG-2230).

In this example, in addition to the updated α and π_1, the parameters η_1 (failure probability of a redundant detection or automatic suppression system), and η_2 (failure of a redundant detection or automatic suppression system if the VEWFD system is not able to provide enhanced detection) are updated with the use of NUREG-2230 detection-suppression event trees. Table 6-3 presents the parameters for the base case (using NUREG-2180 only) with the updated parameters using the latest methods (NUREG-2180, NUREG-2180 Supplement 1, and NUREG-2230). Sections 6.3.1 and 6.3.2 step through the calculation of η_1 and η_2, respectively. Section 6.3.3 summarizes the scenario NSP.

For the application of the parameters in NUREG-2230, the following conditions are assumed:

- There is a control cabinet (low-voltage) ignition source with an in-cabinet VEWFD system (cloud chamber).
- There is no redundant fire detection (fixed smoke detector) credited.
- The control cabinet is not monitored in the MCR (and there is no non-fire trouble indication of a fault in the cabinet before or concurrent with the automatic fire detection).
- The cabinet is in a room that has medium occupancy and medium maintenance rating levels. An adjacent space is also classified with medium occupancy and maintenance ratings. This results in a probability of 0.231 that personnel are not present to detect the fire (from Table 5-7 of NUREG-2230).
- The time to damage is 12 minutes (from NUREG-2180 and Section 6.1)
- A pre-growth period of 4 minutes is included in the fire modeling of the interruptible fraction of fires (option 2 timing profile from NUREG-2230).
- The interruptible fire and growing fire suppression rates are 0.149 and 0.1, respectively (from Section 3.5 of NUREG-2230).
- The split between interruptible and growing fire profiles is 0.723/0.277, respectively (from Section 3.4 of NUREG-2230).

Table 6-3
Case 1 Input Parameters

Parameter	Original Parameter Value from NUREG-2180	Updated Parameter Value (NUREG-2180, NUREG-2180 Supplement 1, & NUREG-2230)
β	3.6E-03	3.6E-03
α	2.8E-01	**1.0E-01**
τ	2.7E-03	2.7E-03
μ	1E-04	1E-04
ξ	4.6E-04	4.6E-04
π_1	$e^{-\lambda_{MCR}\times t} = e^{-0.324\times 12}$ = 2.0E-02	$e^{-\lambda_{MCR}\times t} = e^{-\mathbf{0.385}\times 12}$ = **9.85E-03**
η_1	1.0	**3.23E-01***
η_2	3.1E-01	**1.50E-01^**
η_3	1.0	1.0

* See Section 6.3.1 for calculation using NUREG-2230 event trees for non-suppression
^ See Section 6.3.2 for calculation using NUREG-2230 event trees for non-suppression

6.3.1 Calculation of η_1 Using NUREG-2230 with NUREG-2180 Supplement 1

The resulting detection failure probabilities for the failure probability of the redundant detection or suppression system, η_1, following NUREG-2230 are as follows:

- First interruptible: 2.31E-01
  - The probability of no personnel present for detection (from NUREG-2230 Table 5-7)
- Second interruptible: 1.0
  - No automatic detection
- First growing: 2.31E-01
  - The probability of no personnel present for detection (from NUREG-2230 Table 5-7)
- Second growing: 1.0
  - No automatic detection

For the interruptible path, the NSP for the fire brigade branch (D-IF) is calculated as shown in Equation 6-1.

$$e^{-\lambda t} \rightarrow e^{-0.149\cdot(12+4)} = 0.09$$ **Equation 6-1**

Note that 4 minutes are added to the time to damage (12 minutes) to represent the pre-growth time associated with an interruptible fire using the Option 2 timing profile from NUREG-2230.

Following a failure in the first detection branch, because there is no second detection (and therefore no probability of reaching sequences E to H), the next calculations are associated with delayed detection shown in Equation 6-2:

$$e^{-\lambda t} \rightarrow e^{-0.149\cdot(12+4-15)} = 0.86$$ **Equation 6-2**

The growing path is similar to the interruptible path with two changes: no credit for the 4-minute pre-growth time and the use of the electrical cabinet growing fire suppression rate (0.100). The NSP for the fire brigade branch (D-GF) following the first detection path is calculated as shown in Equation 6-3:

$$e^{-\lambda t} \rightarrow e^{-0.100\cdot(12)} = 0.30$$ **Equation 6-3**

Since a conventional, redundant, detection system is not credited, there is no calculation performed to determine the NSP for the second detection path. However, if a redundant detection system was credited in the example, the calculation of the NSP would follow, similar to the calculation shown in Equation 6-3. For the growing fire, there is not enough time to credit delayed detection (branch L-GF). The assumed delayed detection time is 15 minutes and the time to damage is 12 minutes, so damage occurs before the fire is detected.

Figure 6-5 through Figure 6-7 illustrate the solution for the NSP event tree.

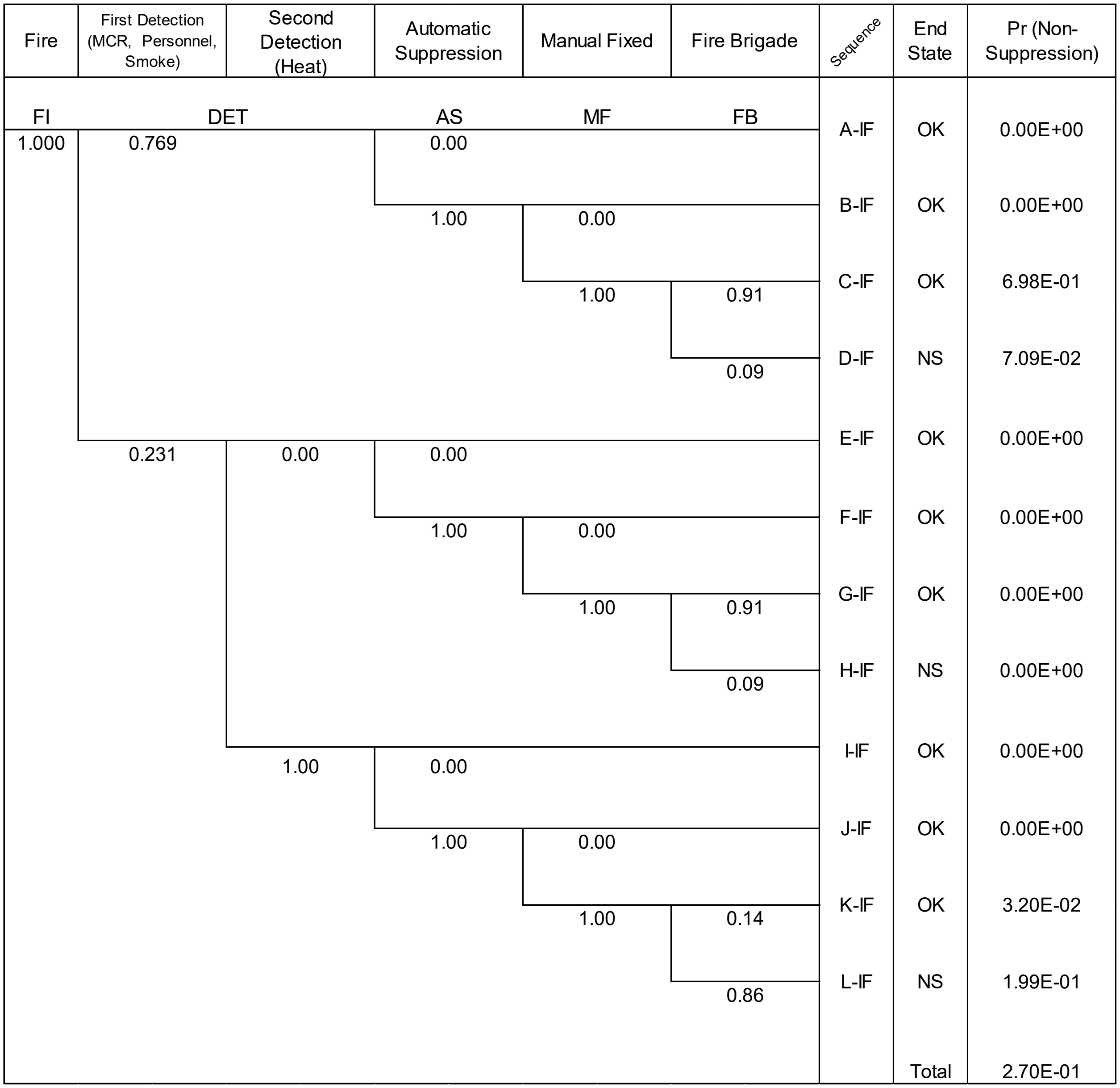

Figure 6-5
η_1, Interruptible Fire NSP

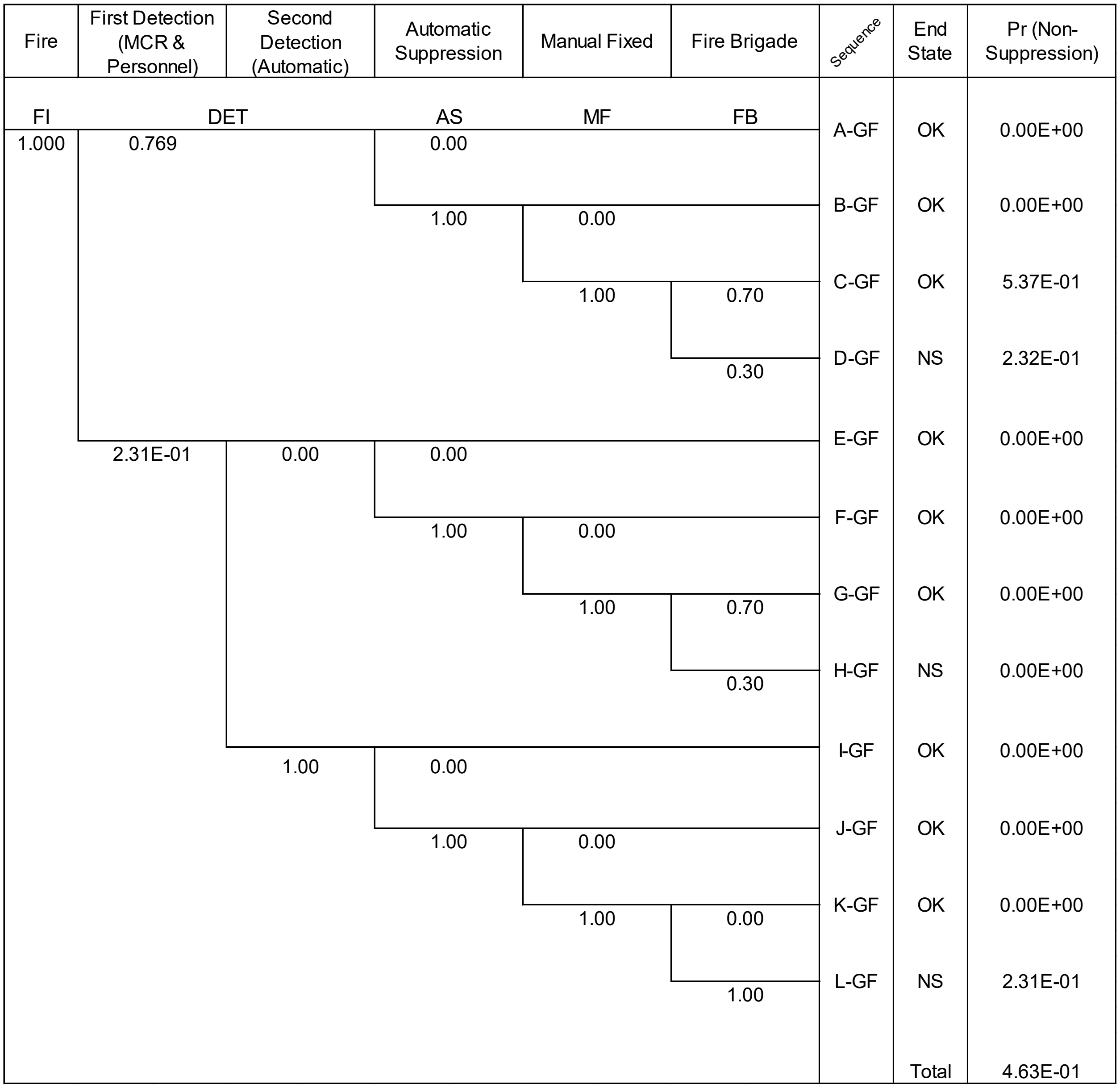

Figure 6-6
η_1, growing fire NSP

The scenario NSP is calculated as follows:

7.09E-02 + 0.00 + 1.99E-01 = 2.70E-01 for an interruptible fire (Figure 6-5), and

2.32E-01 + 0.00 + 2.31E-01 = 4.63E-01 for a growing fire (Figure 6-6).

Considering the split fraction for interruptible and growing fire profiles, the total scenario NSP is 3.23E-01 for η_1 as shown in Figure 6-7.

Fire	Interruptible Fire	Event Tree	Pr (Non-Suppression)
FI	Yes 0.723	Interruptible 0.270	1.95E-01
	No 0.277	Growing 0.463	1.28E-01
		Total	**3.23E-01**

Figure 6-7
η_1, Total Scenario NSP

Next, the η_2 term is calculated following the NUREG-2230 detection-suppression event tree.

6.3.2 Calculation of η_2 Using NUREG-2230 with NUREG-2180 Supplement 1

The detection failure probabilities for the redundant detection or suppression systems given that the VEWFD system provided prompt detection, η_2, following NUREG-2230 are as follows:

- First interruptible: 0
  - Crediting the VEWFD system to provide prompt detection is modeled as 100 percent successful first detection (fire already detected by VEWFD).
- Second interruptible: 1.0
  - There is no automatic detection (since the fire is detected by the incipient system, this end state is never reached, but provided for completeness).
- First growing: 0
  - Crediting the VEWFD system to provide prompt detection is modeled as 100 percent successful first detection (fire already detected by VEWFD).
- Second growing: 1.0
  - There is no automatic detection (since the fire is detected by the incipient system, this end state is never reached, but provided for completeness).

For the interruptible path, the NSP for the fire brigade branch (D-IF) is calculated as shown in Equation 6-4:

$$e^{-\lambda t} \rightarrow e^{-0.149\cdot(12+4)} = 0.09$$ **Equation 6-4**

Note that 4 minutes are added to the time to damage to represent the pre-growth time associated with an interruptible fire. There is no failure of the first detection branch as the VEWFD system is credited as being completely successful at promptly detecting the fire.

The NSP for the fire brigade branch (D-GF) following the first detection path is calculated as shown in Equation 6-5.

$$e^{-\lambda t} \rightarrow e^{-0.100\cdot(12)} = 0.30 \qquad \textbf{Equation 6-5}$$

Figure 6-8 through Figure 6-10 illustrate the solution for the NSP event tree.

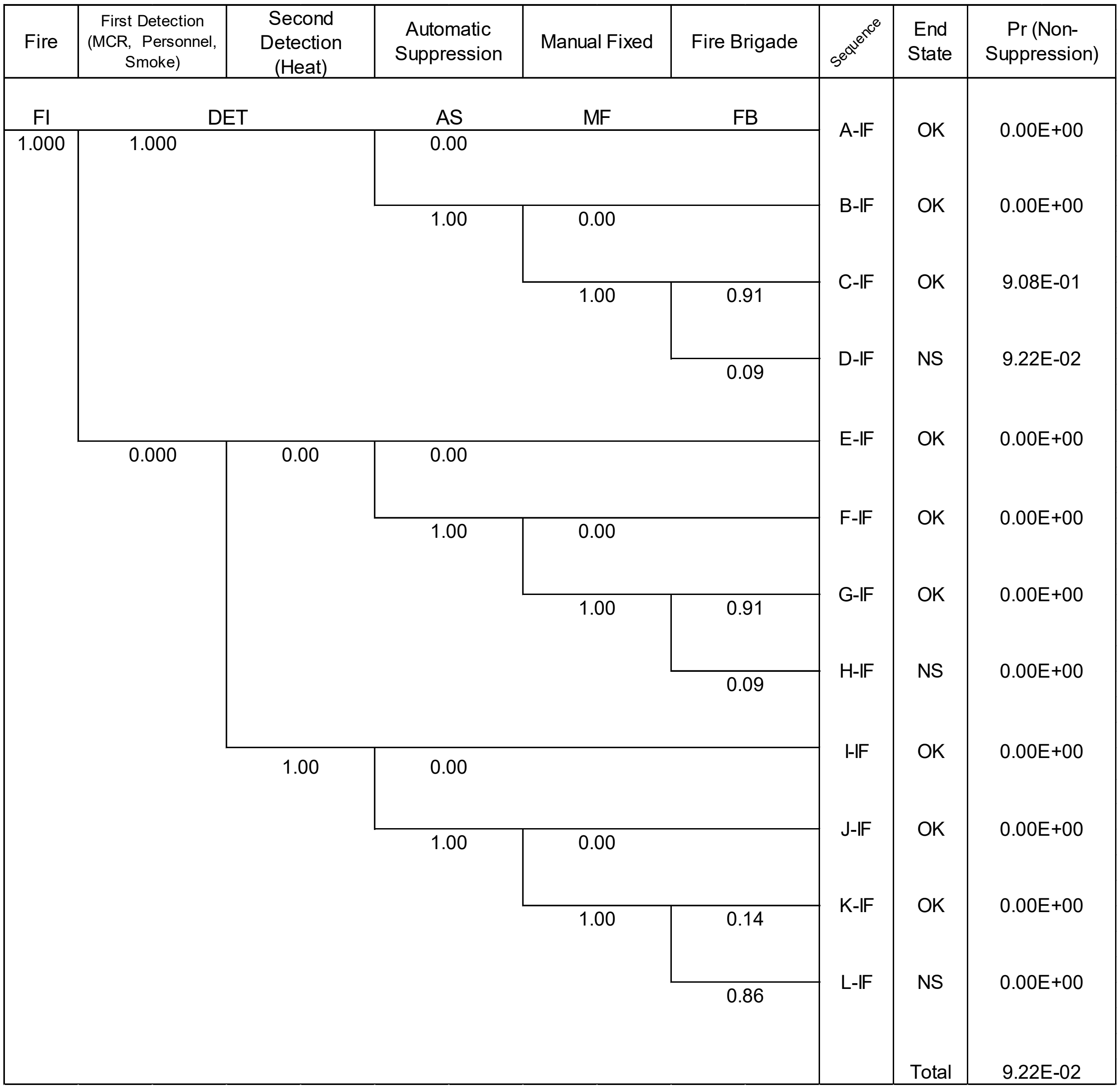

Figure 6-8
η_2, Interruptible Fire NSP

Fire	First Detection (MCR & Personnel)	Second Detection (Automatic)	Automatic Suppression	Manual Fixed	Fire Brigade	Sequence	End State	Pr (Non-Suppression)
FI	DET		AS	MF	FB			
1.000	1.000		0.00			A-GF	OK	0.00E+00
			1.00	0.00		B-GF	OK	0.00E+00
				1.00	0.70	C-GF	OK	6.99E-01
					0.30	D-GF	NS	3.01E-01
	0.00E+00	0.00	0.00			E-GF	OK	0.00E+00
			1.00	0.00		F-GF	OK	0.00E+00
				1.00	0.63	G-GF	OK	0.00E+00
					0.37	H-GF	NS	0.00E+00
		1.00	0.00			I-GF	OK	0.00E+00
			1.00	0.00		J-GF	OK	0.00E+00
				1.00	0.00	K-GF	OK	0.00E+00
					1.00	L-GF	NS	0.00E+00
							Total	3.01E-01

Figure 6-9
η_2, Growing Fire NSP

The interruptible and growing NSPs are calculated as follows:

9.22E-02 + 0.0 + 0.0 = 9.22E-02 for an interruptible fire (Figure 6-8), and

3.01E-01 + 0.0 + 0.0 = 3.01E-01 for a growing fire (Figure 6-9).

Considering the split fraction for interruptible and growing fire profiles, the total NSP becomes 1.50E-01 for η_2 as shown in Figure 6-10.

Fire	Interruptible Fire	Event Tree	Pr (Non-Suppression)
FI	Yes 0.723	Interruptible 0.092	6.66E-02
	No 0.277	Growing 0.301	8.34E-02
		Total	**1.50E-01**

Figure 6-10
η_2, Total Scenario NSP

6.3.3 Calculation of Scenario Non-Suppression Probability Combining NUREG-2230 with NUREG-2180 Supplement 1

The parameters from Table 6-4 are input into the NUREG-2180 event tree. The scenario NSPs are calculated as follows:

- NUREG-2180 scenario NSP: 1.1E-01 (refer to Figure 6-1 for NUREG-2180 NSP calculation)
- NUREG-2180 Supplement 1 scenario NSP: 4.4E-02 (refer to Figure 6-4 for the NSP calculation using NUREG-2180 Supplement 1 updated parameters)
- NUERG-2180 Supplement 1 and NUREG-2230 scenario NSP: 2.54E-02 (calculated in Figure 6-11 for using NUREG-2180 Supplement 1 updated parameters and NUREG-2230 methods)

The methods in NUREG-2230 provide additional time to growth for interruptible fires along with a more targeted suppression rate specific for interruptible fires. Additionally, credit is taken for personnel detection, which results in smaller values of non-suppression. Using NUREG-2180 Supplement 1 with NUREG-2230 results in a 76 percent reduction than the base case (NUREG-2180) and a 42 percent reduction using the updated data parameters in NUREG-2180 Supplement 1.

Table 6-4
Summary of Parameters and Scenario NSP Using the Various Methods

Parameter	Original Parameter Value from NUREG-2180	Updated Parameter Value (NUREG-2180 & NUREG-2180 Supplement 1)	Updated parameter value (NUREG-2180, NUREG-2180 Supplement 1, & NUREG-2230)
β	3.6E-03	3.6E-03	3.6E-03
α	2.8E-01	**1.0E-01**	**1.0E-01**
τ	2.7E-03	2.7E-03	2.7E-03
μ	1E-04	1E-04	1E-04
ξ	4.6E-04	4.6E-04	4.6E-04
π_1	$e^{-\lambda_{MCR}\times t}$ $= e^{-0.324\times 12}$ = 2.0E-02	$e^{-\lambda_{MCR}\times t}$ $= e^{-\mathbf{0.385}\times 12}$ = **9.85E-03**	$e^{-\lambda_{MCR}\times t}$ $= e^{-\mathbf{0.385}\times 12}$ = **9.85E-03**
η_1	1.0	1.0	**3.23E-01**
η_2	3.1E-01	3.1E-01	**1.50E-01**
η_3	1.0	1.0	1.0
Scenario NSP	**1.1E-01**	**4.4E-02**	**2.54E-02**

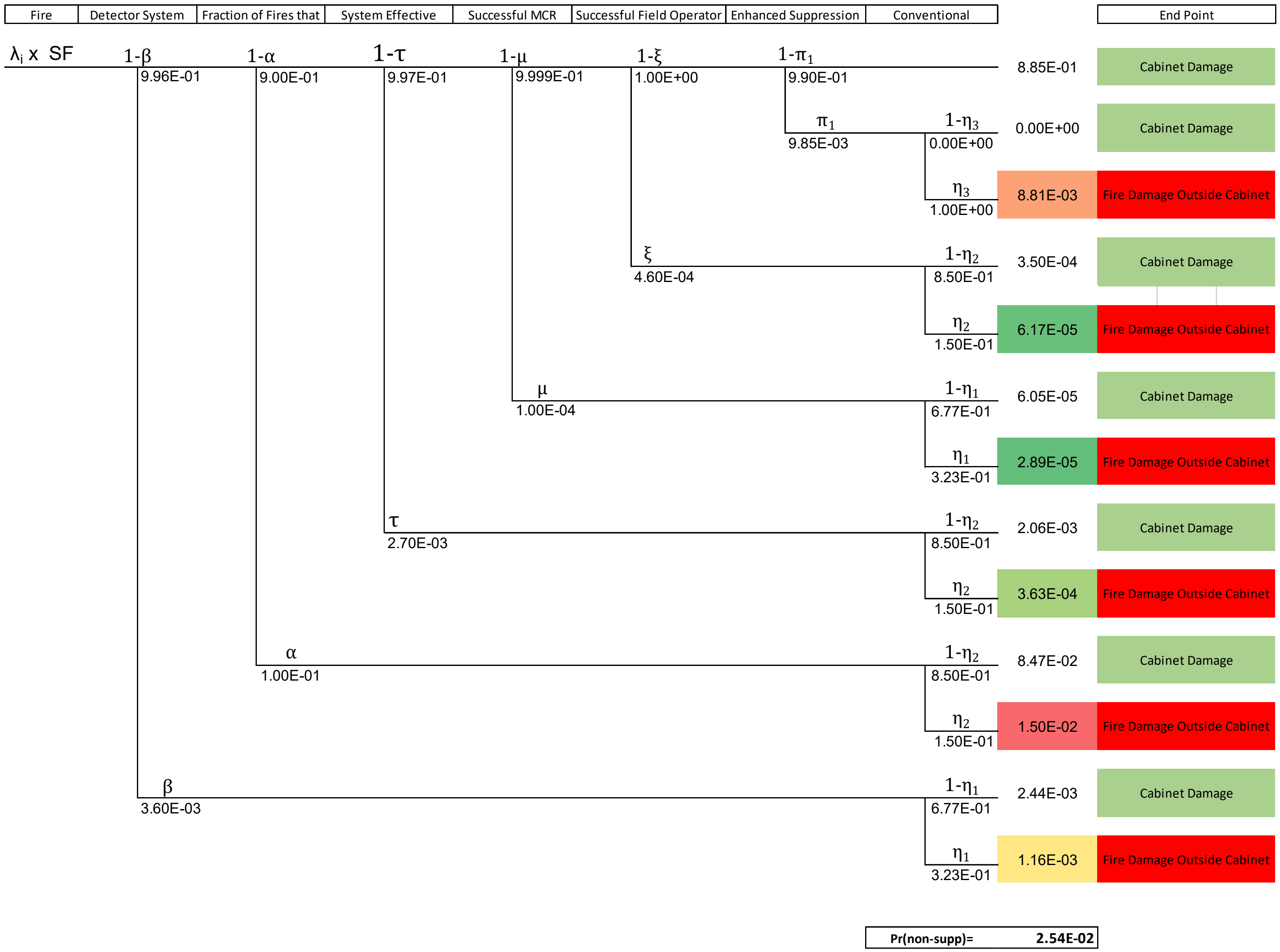

Figure 6-11
NUREG-2180 Supplement 1 with NUREG-2230 η_1 and η_2

7 CONCLUSIONS

The event trees in NUREG-2180 provide a structure to estimate the NSP for fire scenarios in which VEWFD systems are used to provide advanced detection capabilities for electrical cabinets. Since publication of NUREG-2180, EPRI and the NRC have collaborated and published fire PRA methods and data intended to increase the realism of selected ignition sources. In addition, both organizations have continued collecting fire event data from the U.S. commercial nuclear industry. As such, this report describes updates to the methodology for modeling VEWFD systems in fire PRAs to reflect (1) the impact of new fire event data on parameters used in the methodology and (2) integrate the models in NUREG-2180 with the research later published in NUREG-2230 associated with modeling “interruptible” fires in electrical cabinets.

Of the parameters developed for use in the NUREG-2180 event trees, the fraction of fires that do not have an incipient stage (α) has the greatest impact on the NSP calculations.

To update α, the existing NRC classification of the fire event data in NUREG-2180 was used as a starting point. The original review considered electrical cabinet fire events from 1990 through 2009. The original review was supplemented with additional information obtained during the development of NUREG-2230. Two new reviewers from EPRI provided classifications for the 1990–2009 fire events. Additionally, both EPRI and the NRC classified 26 events (23 from 2010 through 2014 added as part of NUREG-2230 and 3 events that underwent a classification or binning change after the publication of NUREG-2180).

Table 7-1 reproduces the results from Section 4.2.1. The updated alpha parameter (the analyst selects either the power or the control cabinet category) is intended to be applied to the event tree model in NUREG-2180. In both cases (i.e., power and low-voltage control cabinets), the fraction of fires that do not have an incipient stage (α) decreased with the current review. This translates to a higher percentage of fires that can be detected by VEWFD systems in the early stages of fire development.

Table 7-1
Fraction of Electrical Cabinets Fires That Do Not Have An Incipient Phase Detectable by a VEWFD System (α) 1990–2014

Category	Fraction Alpha Mean (lower/upper)
Power	**0.41** [0.30/0.53]
Low voltage control cabinets	**0.10** [0.01/0.25]

Additionally, electrical cabinet events from 2010 through 2014 in NUREG-2230 are used to update the enhanced suppression rates for calculating the enhanced suppression parameter, π_2, for area-wide applications. The MCR suppression rate used to calculate the in-cabinet enhanced suppression parameter, π_1, was updated in NUREG-2178, Volume 2. Updated with additional events, both the in-cabinet and area-wide enhanced suppression rates have improved (addition of fire events that took less time to suppress than previous experience). This results in reduced manual NSPs. Table 7-2 reproduces the results from Section 4.3 for the updated suppression rates used in the calculation of both π_1 and π_2.

Table 7-2
Probability Distribution for Rate of Fires Suppressed Per Unit of Time for Enhanced Suppression Terms π_1 (In-Cabinet) And π_2 (Area-Wide)

Suppression Curve	Rate of Fire Suppressed (λ)			
	Mean	5th Percent	50th Percent	95th Percent
In-cabinet, enhanced suppression rate	0.385	0.209	0.372	0.604
Area-wide, enhanced suppression rate	0.226	0.131	0.220	0.344

Section 5 provides guidance for crediting the methods in NUREG-2230 within the NUREG-2180 incipient detection framework. Specifically, it describes how to apply the NUREG-2230 interruptible and growing fires detection-suppression event tree within the NUREG-2180 conventional suppression terms η_1, η_2, and η_3. This guidance clarifies the interpretation and independence of key input parameters in both models so that they can be integrated comprehensively.

8 REFERENCES

1. *Determining the Effectiveness, Limitations, and Operator Response for Very Early Warning Fire Detection Systems in Nuclear Facilities (DELORES-VEWFIRE).* U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, Washington, DC: December 2016. NUREG-2180.
2. *Closure of National Fire Protection Association 805 Frequently Asked Question FAQ 08-0046, Incipient Fire Detection Systems*, 2008. Agencywide Documents Access and Management System (ADAMS) Accession No. ML093220426.
3. *Fire Probabilistic Risk Assessment Methods Enhancements: Supplement 1 to NUREG/CR-6850 and EPRI 1011989*. Electric Power Research Institute, Palo Alto, CA, and U.S. Nuclear Regulatory Commission, Washington, DC: December 2009. NUREG/CR-6850 Supplement 1 and EPRI 1019259.
4. *Methodology for Modeling Fire Growth and Suppression Response for Electrical Cabinet Fires in Nuclear Power Plants*. Electric Power Research Institute, Palo Alto, CA and U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research (RES), Washington, DC: 2020. EPRI 3002016051 and NUREG-2230.
5. *Refining and Characterizing Heat Release Rates from Electrical Enclosures During Fire, Volume 2: Fire Modeling Guidance for Electrical Cabinets, Electric Motors, Indoor Dry Transformers, and the Main Control Board*, U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, Washington, DC, and Electric Power Research Institute, Palo Alto, CA: 2019. NUREG-2178, Volume 2 and EPRI 3002016052.
6. *Fire PRA Methods Enhancements: Additions, Clarifications and Refinements to EPRI 1011989*, Electric Power Research Institute, Palo Alto, CA: 2008. EPRI 1016735.
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10. *EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities: Volume 2: Detailed Methodology*. Electric Power Research Institute, Palo Alto, CA, and U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, Washington, DC: 2005. EPRI 1011989 and NUREG/CR-6850.

APPENDIX A
EVALUATION OF OPERATING EXPERIENCE DATA

A.1 Evaluation of Fire Events That Have a Detectable Incipient Stage

Appendix A documents the review of potentially challenging or greater electrical cabinet fires from the Electric Power Research Institute (EPRI) Fire Events Database (FEDB). Table A-1 summarizes the results and includes the elements described below:

Fire ID	Record number from the EPRI FEDB
Date	Date of fire event
Fire Severity	Severity class, as updated by NUREG-2230 [A.1]
Fire Cause	Apparent cause of fire event
Detected by	How the event was detected
Cabinet Type	Type of cabinet where the event occurred
Ignition Component	Subcomponent that ignited
Power or LV Control	Category of electrical cabinets; power cabinets include electrical distribution equipment such as motor control centers, load centers, distribution panels, and switchgear; low-voltage (LV) control includes cabinets with control equipment less than 250 volts (V) from NUREG-2180 [A.2] Section 7.1.
Fire Termination	How the fire was extinguished: automatic suppression, fire brigade, de-energized, extinguisher, self-extinguished, blew out, or unknown
Fire Growth Classification	From NUREG-2230, either interruptible, growing, or unknown.
Description of Event	Summary of the event
Incipient Stage by Reviewer	Whether the event involved an incipient failure mode: Yes, No, or Undetermined, as defined in Section 3.1.

A.2 References and Acronyms in Appendix A

A.2.1 References

A.1 *Methodology for Modeling Fire Growth and Suppression Response for Electrical Cabinet Fires in Nuclear Power Plants*. Electric Power Research Institute, Palo Alto, CA and U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research (RES), Washington, DC: 2020. EPRI 3002016051 and NUREG-2230.

A.2 *Determining the Effectiveness, Limitations, and Operator Response for Very Early Warning Fire Detection Systems in Nuclear Facilities (DELORES-VEWFIRE).* U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, Washington, DC: December 2016. NUREG-2180.

A.2.2 Acronyms

CH	challenging
CO_2	carbon dioxide
CPT	control power transformer
CVT	constant voltage transformer
EDG	emergency diesel generator
HGA	hinged armature auxiliary relay
HVAC	heating, ventilation, and air conditioning
kV	kilovolt
LV	low-voltage
MCC	motor control center
MCR	main control room
PC	potentially challenging
PSI	pounds per square inch
RC	resistor-capacitor
RCP	reactor coolant pump
U	undetermined
UPS	uninterruptible power supply
V	volts

Table A-1
Evaluation of Bin 15 Events for Incipient Stage

Fire ID	Date	Fire Severity (from NUREG-2230)	Fire Cause	Detected by	Cabinet Type	Ignition Component	Power or LV Control	Fire Termination	Fire Growth Classification (from NUREG-2230)	Description of Event	Incipient Stage by Reviewer (Y/N/U)			
											R1	R2	R3	R4
29	2/23/1991	PC	Stab misalignment	Control room instrumentation / annunciator	MCC	MCC breaker	Power	Extinguisher	Interruptible	Failure on demand. Following start of the main turbine turning gear motor a fire occurred in the 480V Engineered Safety Features MCC. Cause is attributed to design of breaker cubicle, which allowed misalignment when installing the breaker without providing a method of verifying proper breaker position.	N	N	N	N
38	3/21/1992	CH	Run contactor short damaged CPT	Control room instrumentation / annunciator	Motor generator set breaker	CPT	Power	Deenergized	Interruptible	Failure during testing. During a bus undervoltage and Emergency Core Cooling System integrated functional test for the diesel generator, a short in the run contactor coil to the Reactor Protection System motor generator set drive motor breaker caused excessive current flow through the CPT, which caught fire. This resulted in a loss of power on the Reactor Protection System bus (because the reserve Reactor Protection System power supply was out of service for a modification), a half scram, and an unplanned Engineered Safety Features actuation.	N	N	N	N

Fire ID	Date	Fire Severity (from NUREG-2230)	Fire Cause	Detected by	Cabinet Type	Ignition Component	Power or LV Control	Fire Termination	Fire Growth Classification (from NUREG-2230)	Description of Event	Incipient Stage by Reviewer (Y/N/U)			
											R1	R2	R 3	R4
41	6/17/1992	PC	Stab misalignment	Fire alarm	MCC	Breaker	Power	Extinguisher	Interruptible	Failure on demand. Immediately following start of the “D” river water supply pump, a fire alarm was received. Investigation identified inadequate fit between the breaker primary disconnects and the associated breaker cubicle stabs. Poor fit resulted in arcing in the breaker cubicle and subsequent fire. Breaker had been recently replaced as part of a design modification package and insufficient in-house review of the breaker interface design specification is the apparent root cause.	N	N	N	N
45	7/29/1992	PC	Undetermined	Control room instrumentation / annunciator	MCC	MCC	Power	Extinguisher	Growing	Electrical fire in intake structure affecting two MCCs.	U	U	U	U
69	8/29/1994	U	Overheating wire	Control room instrumentation / annunciator	Control cabinet	Electrical cable insulation	Control	Deenergized	Undetermined	Breaker self-closing caused by breakdown of insulation in breaker control cabinet. Breakdown caused by insulation contact with protruding tap of a wire wound power resistor, associated heat from resistor and deterioration caused by water intrusion (cabinet located in switchyard). Failure is a result of accumulated effects of 25 years of deterioration.	Y	Y	Y	Y

Fire ID	Date	Fire Severity (from NUREG-2230)	Fire Cause	Detected by	Cabinet Type	Ignition Component	Power or LV Control	Fire Termination	Fire Growth Classification (from NUREG-2230)	Description of Event	Incipient Stage by Reviewer (Y/N/U)			
											R1	R2	R3	R4
83.1	4/4/1996	N/A	Ground fault	Plant personnel	Power	Essential lighting UPS/ distribution panel	Power	Deenergized	Undetermined	Smoke was discovered in the back boards area of the control room by a security officer performing an hourly fire watch tour. Smoke was emanating from the emergency lighting uninterruptible power supply (UPS) and the essential lighting distribution panel. Cause was short circuit current in the plant ground system because of inadequate grounding procedures. Fire was self-extinguished by removal of power by opening the breaker.	Y	Y	Y	Y
83.2	4/4/1996	N/A	Ground fault	Plant personnel	Power	Essential lighting isolation transformer	Power	Extinguisher	Undetermined	Following event 83.1, auxiliary operator was surveying duty area and found smoke and fire in the train B DC equipment room (different room and elevation from event 83.1). Fire was contained to essential lighting isolation transformer. Fire required removal of 480V power by manually opening circuit breaker, and application of carbon dioxide extinguisher by the auxiliary operator and fire brigade.	Not part of frequency in NUREG-2169 or NUREG-2230			
89	10/15/1996	PC	CPT & relay failure	Unknown	MCC	CPT & HGA relay	Power	Deenergized	Interruptible	Internal short in the CPT, which caused the failure of the HGA control relay.	Y	Y	Y	Y

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											R1	R2	R 3	R4
98	10/8/1998	PC	Undetermined	Plant personnel & fire alarm	Control cabinet	Undetermined	Control	Deenergized	Interruptible	During a 24 hour post-maintenance run of the EDG an operator noticed heavy smoke coming from the EDG control panel. Initiation component and cause of event were not identified.	U	U	U	U
131	1/14/2005	PC	Undetermined	Plant personnel	Master distribution panel	Breaker	Power	Deenergized	Interruptible	Fire reported by two instrumentation and control technicians who heard a loud banging. While attempting to investigate the source of the noise, sparks and smoke were observed. The root cause was water intrusion into the master distribution panel and circuit breaker resulting from high winds and rain entering through a gap in the building’s skin and entering the non-watertight panel. A pre-cursor event happened on 12/1/2004, but the building opening was not repaired.	Y	Y	Y	Y

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											R1	R2	R 3	R4
144	10/30/2006	PC	Stab misalignment/ ground fault	Control room / plant personnel	MCC	Breaker stabs	Power	Blew out	Interruptible	Failure on demand. Concurrent with attempted start of containment cooling fan (closing of breaker), supply circuit breakers for 480V MCC tripped as a result of a bus to ground electrical fault. Responding operators discovered a small fire in the MCC. Root cause identified inadequate design, which resulted in improper placement of circuit breaker in MCC. One stab did not mate up to its associated bus bar correctly, resulting in a high resistance connection.	N	N	N	N
146	2/27/2007	PC	Breaker to bus stab high resistance	Control room / plant personnel	Load center	Breaker stabs	Power	Deenergized and extinguisher	Interruptible	Failure on demand. Breaker failure following placing breaker in-service after restoration steps from a test of the automatic start feature of an isophase bus cooling fan. Failure because of high resistance connection between bus bar stabs and breaker assembly.	N	N	N	N
152	10/23/2007	PC	Breaker to bus stab high resistance	Fire alarm	MCC	Breaker stabs	Power	Arc flash self-extinguished when breaker tripped	Growing	Failure on demand following maintenance. MCC failure concurrent with charging pump starting. Root cause identified high resistance connection at the stab/bus interface likely because of less than adequate preventive maintenance and original design inadequacy.	N	N	N	N

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											R1	R2	R 3	R4
161	4/22/2009	PC	Undetermined	Plant personnel	MCC	Undetermined	Power	Extinguisher	Interruptible	"D" control rod drive mechanism fan tripped. Approximately 30 minutes later operations locally opened the breaker after identifying a strong odor and that the breaker associated with the control rod drive mechanism fan was smoldering. Upon opening the cabinet, a 6-inch flame was observed.	Y	Y	Y	Y
175	11/22/2009	CH	Undetermined	Undetermined	7.2kV switchgear	Undetermined	Power	Fire brigade	Growing	While attempting to energize the main transformer, faults to ground occurred in the switchgear, resulting in smoke in the switchgear and a loss of all balance of plant power. The grounding straps and grounding cart were still installed in the switchgear causing the event.	N	N	N	N
187	8/16/1999	PC	Undetermined	Plant personnel	Control cabinet	Undetermined	Control	Deenergized	Interruptible	Smoke from condensate demineralizer control panel. Power supply in the panel was unplugged to extinguish the fire.	U	U	U	U
188	8/24/1999	PC	Lightning strike	Plant personnel	Power control cabinet	Undetermined	Power	Deenergized	Growing	Lightning strike caused a fire in a power control center. De-energized the bus supplying power to extinguish.	N	N	N	N
203	4/6/1990	CH	Undetermined	Plant personnel	MCC	Undetermined	Power	Unknown	Growing	Two MCCs burned.	U	U	U	U

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											R1	R2	R 3	R4
206	6/11/1990	U	Missing component	Plant personnel	Breaker	Breaker	Power	Deenergized	Interruptible	Fire in recirculation motor generator field breaker caused by missing extension piece for the center phase shorting bus. This allowed the field to be continuously shorted during operation.	U	U	U	U
209	8/22/1990	PC	Foreign material in contact with bus bars	Plant personnel	MCC	Phase to phase short on bus bar	Power	Extinguisher	Interruptible	Failure on demand. Operator was removing clearance and placed MCC pan back on bus, closed cubicle door, and turned line starter on. At local pump controller, the operator noted the green “off” light flickering. When control switch was placed to “on,” a loud explosion was heard.	N	N	N	N
211	11/2/1990	PC	Undetermined	Plant personnel	MCC	CPT	Power	Deenergized	Undetermined	CPT failure in MCC.	Y	Y	Y	Y
219	9/27/1991	PC	Undetermined	Roving fire watch	MCC	CPT	Power	Deenergized	Interruptible	CPT failure in MCC.	Y	Y	Y	Y
224	3/8/1992	U	Human error	Plant personnel	MCC	Undetermined	Power	Deenergized	Growing	Electrical fault in 480V MCC cubicle caused by human error during maintenance/cleaning.	N	N	N	N
253	7/6/1995	PC	Breaker failure	Plant personnel	Switchgear	Trip coil	Power	Extinguisher	Interruptible	Breaker failed to open, causing excessive current in trip coil.	N	N	N	N
254	9/25/1995	PC	Undetermined	Plant personnel	MCC	Undetermined	Power	Deenergized	Interruptible	MCC electrical overload.	U	U	U	U
303	3/1/2000	PC	High resistance	Plant personnel	Control cabinet	Fuse disconnect	Control	Extinguisher	Growing	Plant heater boiler control cabinet on fire caused by high resistance connection in the 60-amp fuse disconnect. Cabinet doors were found open with flames coming out	Y	Y	Y	Y

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											R1	R2	R3	R4
										of the cabinet and paint burning off the top.				
320	10/24/2000	PC	Breaker failure	Plant personnel	MCC	Breaker	Power	Extinguisher	Interruptible	Feeder breaker tripped when operator attempted to start “B” main chill water pump. Local breaker was observed to be on fire and had not tripped.	N	N	N	N
381	3/6/2005	PC	Breaker cooling fan failure	Control room instrumen-tation/ annunciator	MCC	Cooling fan	Power	Deenergized	Interruptible	Auxiliary cooling equipment fan motor shorted out with fan motor assembly on fire.	U	U	U	U
411	3/8/2001	PC	Water intrusion	Plant personnel	Breaker box	Breaker	Power	Self-extinguished	Interruptible	Breaker box failure caused by water intrusion.	N	N	N	N
517	3/23/2006	PC	Transformer fault	Control room annunciator & smoke alarm	UPS	Transformer	Power	Fire brigade	Interruptible	Fire in emergency response facility data acquisition and display computer UPS. Apparent cause was a turn-to-turn fault in the top winding. Vibration, temperature, and age are contributing factors to this failure.	Y	Y	Y	Y

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											R1	R2	R3	R4
520	6/6/2006	PC	Inverter fault	Control room annunciator & smoke alarm	UPS	Unknown	Power	Deenergized	Interruptible	Several alarms (which cleared immediately), then a smoke alarm came, followed by a second smoke alarm. Fire in emergency response facility data acquisition and display inverter. The cause was a turn-to-turn fault in the top harmonic winding, which evolved to a turn-to-ground fault. Vibration and temperature over the past 18 years contributed to the fault. Due to fault condition, transformer saw excessive current and very high temperatures that further damaged the insulation and caused fire.	Y	Y	Y	Y
588	11/30/2006	CH	Ground fault	Control room annunciator & smoke alarm	480V switchgear	Unknown	Power	Automatic suppression	Growing	Ground fault on 480V switchgear.	U	U	U	U
10338	9/13/2001	PC	Breaker fault	Plant personnel	MCC	Breaker	Power	Extinguisher	Growing	On 9/10/2001 the pump breaker tripped. Work order written to investigate. Motor tested over the next few days with no issues. During a start of pump, the breaker flashed and resulted in a small fire in cubicle with door forced open.	Y	Y	Y	Y
10394	2/22/2005	PC	Undetermined	Plant personnel	Control	Annunciator card	Control	Self-extinguished	Interruptible	Annunciator card burned out. Flames could be seen coming from the end of the annunciator card.	U	U	U	U

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											R1	R2	R3	R4
20264	1/19/1990	U	MCC coil fault	Plant personnel	MCC	Coil	Power	Extinguisher	Undetermined	Smoke observed coming out of MCC. Hold in coil overheated.	U	U	Y	Y
20267	3/12/1990	U	Breaker fault	Plant personnel	MCC	Undetermined	Power	Unknown	Undetermined	Breaker malfunction.	U	U	U	U
20268	4/19/1990	U	Overheated component	Plant personnel	MCC	CPT	Power	Unknown	Undetermined	CPT overheated.	Y	Y	Y	Y
20269	4/30/1990	U	Undetermined	Plant personnel	Electrical lighting panel	Undetermined	Power	Extinguisher	Undetermined	Electrical lighting panel failure.	U	U	U	U
20270	6/7/1990	U	Transformer failure	Fire watch	MCC	Transformer	Power	Unknown	Undetermined	MCC breaker transformer failure.	Y	Y	Y	Y
20272	9/10/1990	U	Relay failure	Plant personnel	Electrical panel	Relay	Control	Unknown	Undetermined	Electrical panel relay.	U	U	U	U
20273	9/18/1990	PC	Trip coil failure	Plant personnel	Switchgear	Breaker trip coil	Power	Unknown	Undetermined	Heavy smoke was observed in the train "A" switchgear room caused by a faulted trip coil.	N	U	N	N
20275	10/11/1990	U	Overheating	Plant personnel	MCC	CPT	Power	Unknown	Undetermined	CPT burned up causing the diesel generator lube oil heater MCC to smoke.	Y	Y	Y	Y
20276	10/12/1990	U	Breaker	Plant personnel	Switchgear	Undetermined	Power	Deenergized	Undetermined	RCP breaker cubicle	U	U	U	U
20282	9/17/1991	U	Overheating	Plant personnel	MCC	CPT	Power	Unknown	Undetermined	Operator saw smoke coming from an MCC for the main steam isolation valve hydraulic pump; transformer fault.	Y	Y	Y	Y
20287	2/29/1992	U	Overheated	Roving fire watch	MCC	CPT	Power	Unknown	Undetermined	Overload on transformer caused failure.	Y	Y	Y	Y
20295	10/12/1992	U	Overheated	Plant personnel	MCC	CPT	Power	Unknown	Undetermined	CPT overheated	Y	Y	Y	Y
20302	7/25/1993	U	Ground fault	Plant personnel	MCC	Undetermined	Power	Extinguisher	Undetermined	Ground fault on main or reserve feed breakers, or both caused fire.	U	U	U	U

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											R1	R2	R3	R4
20312	7/27/1994	U	Overheating meters from open circuit	Smoke alarm	Switchgear	Switch	Power	Extinguisher	Undetermined	EDG roto test switch damaged and failed causing a fire.	U	U	U	U
20325	1/16/1998	U	Chemical spill	Plant personnel	Heat trace wiring	Heat trace wiring	Power	Extinguisher	Growing	Acid spill on heat trace wiring.	Y	Y	Y	Y
20328	5/6/1999	U	Undetermined	Smoke alarm	Electrical distribution	Undetermined	Power	Extinguisher	Growing	Sudden electrical distribution panel failure with smoke.	U	U	U	U
20329	9/1/1999	U	Relay fault	Plant personnel	Switchgear	Relay	Power	Blew out	Growing	Relay stuck in intermediate position.	U	U	Y	Y
20334	2/20/1990	U	Breaker	Plant personnel	MCC	Breaker	Power	Unknown	Undetermined	MCC breaker.	U	U	U	U
20346	3/30/1994	U	Breaker	Plant personnel	MCC	Breaker	Power	Self-extinguished	Undetermined	Breaker in 4kV room.	U	U	U	U
20351	6/21/1994	U	Undetermined	Plant personnel	Control	Unknown	Control	Extinguisher	Interruptible	Operators noticed smoke coming from a control room panel. Door to panel was opened and flames from the bottom rear cabinet were visible.	U	U	U	U
20356	2/19/1995	PC	Internal short	Plant personnel	MCC	Light bulb	Power	Deenergized	Interruptible	Short in light bulb.	U	U	U	U
20357	5/24/1995	PC	Human interaction, improper maintenance	Plant personnel	MCC	MCC internals fell on power phase	Power	Self-extinguished	Growing	Ground fault inside a non-safety-related MCC caused by equipment improperly restored to service. Internal plane cover not properly secured and fell during investigations and caused ground fault.	N	N	N	N
20362	3/2/1997	PC	High resistance	Other equipment failure	MCC	Insulation/fuse block	Power	Deenergized	Undetermined	Insulation burned off one lead to motor starter contactor and fuse block severely melted. Termination screw loose on starting input terminals.	Y	Y	Y	Y
20382	10/23/2000	Removed	Undetermined	Plant personnel	Switchgear	Undetermined	Power	Deenergized	N/A	No description provided.	Screened out in NUREG-2230			

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											R1	R2	R 3	R4
30276	7/24/2006	PC	Defective charging board	Plant personnel	Emergency lighting	Power transformer	Power	Self-extinguished	Interruptible	Emergency lighting battery box failed during annual inspections. Power transformer inside the box was observed to have sparked and caused a fire. Failure caused by bad charging board and one bad cell.	U	U	Y	Y
30281	6/5/2008	Removed	Procedure error	Plant personnel	Control panel	Insulation	Control	Extinguisher	N/A	Screened out in NUREG-2230 using smoke event criteria.	Screened out in NUREG-2230			
30338	3/30/2006	PC	Inadequate preventive maintenance	Control room instru-mentation/ annunciation	Control panel	Panel blower	Control	Extinguisher	Interruptible	Panel blower (fan) failure. Blower found to be full of dust and dirt.	Y	Y	Y	Y
30478	9/9/2005	PC	Relay failure	Plant personnel	Control	Relay	Control	Extinguisher	Growing	Condensate demineralizer panel fire and smoke from affected relays.	U	U	Y	Y
30513	5/27/2008	PC	Overheat	Fire alarm	Control	Constant voltage transformer (CVT)	Control	Extinguisher	Growing	CVT inside rod action control cabinet in back panels of MCR ignited combustible materials located inside transformer housing.	Y	Y	Y	Y
30522	9/12/2000	PC	Undetermined	Fire alarm	Control	Undetermined	Control	Extinguisher	Interruptible	Cathodic protection cabinet fire.	U	U	U	U
30578	2/27/2003	Removed	Undetermined	Plant personnel	Power supply	Undetermined	Power	Unknown	N/A	This location is within the protected area (waste processing building); however, it contains no fire PRA related equipment or cables. This event is re-classified as nonchallenging as this is an event that is not of interest to the fire PRA and is not in a location relevant to plant operations or safety.	Screened out in NUREG-2230			

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											R1	R2	R3	R4
50467	2/4/2006	Removed	Breaker fault	Plant personnel	Switchgear	Closing coil	Power	Deenergized	N/A	Screened out in NUREG-2230 using smoke event criteria.	Screened out in NUREG-2230			
50473	6/26/2000	PC	Water intrusion	Equipment trouble alarm	Electrical panel	Relay	Control	Deenergized	Interruptible	Small fire discovered in electrical panel while investigating burning odor while responding to alarm from same electrical panel. Flames and smoke were observed emanating from relay. Failure was a result of water intrusion from HVAC condensate drain line.	Y	Y	Y	Y
50784	11/20/2005	U	Relay misalignment	Plant personnel	Control cabinet	Relay	Control	Deenergized	Growing	During relay testing, the relay began to smoke. During de-energization activities, the relay caught fire. Fuses were pulled, and CO_2 was used to extinguish. Suspected cause was a slight misalignment of the relay and contact structure.	U	U	Y	Y
50811	1/9/2001	PC	Relay failure	Control room instrumentation / annunciator	Control cabinet	Relay	Control	Extinguisher	Interruptible	Received numerous alarms in control room related to fire protection filter low-flow alarm. Found fire protection pump tripped, and pressure drop. Smoke observed in room. Investigation found a relay burning. Extinguished with portable extinguisher.	U	U	U	U
50874	7/12/2002	PC	Breaker failure	Plant personnel	Switchgear	Trip coil	Power	Unknown	Interruptible	During shutdown of recirc motor generator set, the field breaker failed to open. Trip coil smoking and on fire. Fire extinguished and fuses pulled.	N	N	N	N

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											R1	R2	R3	R4
50912	5/5/2010	CH	Fault	Automatic suppression	4.16kV switchgear	Breaker	Power	Automatic suppression	Growing	Electrical fault occurred on the 4160V bus. The 4160V bus is a non-emergency bus. The feeder breaker for the bus tripped open and cleared the fault. CO_2 actuated in the 4160V switchgear. No fire was reported.	Y	Y	Y	Y
50914	6/8/2010	PC	Degradation of capacitor	Plant personnel	Nuclear instrument-ation cabinet	Resistor-capacitor	Control	Extinguisher	Interruptible	Following a reactor trip from 100 percent power and a safety injection, a fire occurred in the MCR inside the nuclear instrumentation system channel II cabinet. Flames were observed on a RC (resistor-capacitor) suppressor at the listed terminals. As the flames were being observed, a second RC suppressor, located directly above the first, was ignited by the flames from below. The fire was extinguished with a hand-held CO_2 extinguisher.	Y	Y	Y	Y
50916	7/13/2010	PC	Infant mortality	Fire caused by plant personnel during test and maintenance	Control room annun-ciator panel	Annunciator card	Control	Extinguisher	Growing	Instrumentation and control technicians were installing new annunciator cards in a control room annunciator panel. Several minutes later one of the cards that had just been installed started smoking and caught fire.	N	N	N	N
50921	10/11/2010	PC	Board failure	Plant personnel	Control panel for chiller	Transistor	Control	Extinguisher	Interruptible	Arcing and smoke was reported coming from the refueling waste storage tank control panel chiller. The feeder breaker was opened,	Y	Y	Y	Y

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											R1	R2	R3	R4
										and smoke was present in the cable fault.				
50923	12/19/2010	PC	Poor terminal connection	Control room instrumentation & fire alarm	Heater control panel	Wiring	Control	Deenergized	Interruptible	A fire occurred in the fuel handling building normal supply heater control panel. The fire team was dispatched, and the fire was contained in the heater control panel.	Y	Y	Y	Y
50925	2/8/2011	PC	Resistor degradation	Control room instrumentation /annunciator	Statalarm panel	Resistor on alarm card	Control	Extinguisher	Interruptible	Failure of circuit board/card in annunciator system audio/visual annunciator, resulting in small fire. The fire damaged two adjacent point cards. Fire brigade responded and extinguished the fire with a CO_2 fire extinguisher. A carbon resistor on the alarm card failed due to a decrease in resistance value from age, resulting in increased current and power dissipation in excess of the resistor rated value until catastrophic failure occurred.	Y	Y	Y	Y

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											R1	R2	R 3	R4
50936	6/25/2011	CH	Inadequate preventive maintenance	Fire alarm	MCC	Breaker	Power	Deenergized	Growing	Unit 1 was operating at 100 percent power when the control room received a fire alarm. The fire brigade leader was dispatched and reported heavy smoke from the heater board. After exceeding the 15-minute requirement for not extinguishing a fire, an Unusual Event was declared. Subsequently, the fire brigade leader reported that the supply breaker to the heater board had tripped and the fire was extinguished.	Y	Y	Y	Y

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											R1	R2	R3	R4
50939	10/4/2011	PC	Short	Fire alarm	Computer inverter	Third harmonic choke	Power	Automatic suppression	Interruptible	During a scheduled unit shutdown, smoke and fire were discovered emitting from the computer inverter approximately 30 minutes after completing inverter startup. Local breakers were opened, and the fire was extinguished within minutes. Upon cabinet inspection, the third harmonic choke was found to be the component on fire. The apparent cause of the equipment failure was identified as a susceptibility of the varnish used to coat the transformer to age-related degradation. This varnish deficiency allowed vibrations within the transformer to degrade the insulating coating of the transformer over time to the point of creating a short between windings.	Y	Y	Y	Y

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											R1	R2	R 3	R4
50944	11/16/2011	PC	Water intrusion	Plant personnel	MCC	MCC	Power	Deenergized	Interruptible	The demineralized water system, normally at 100 psi, received a pressure surge of up to 310 psi when switching the auxiliary boiler make-up from demineralized water to condensate. A check valve located in the demineralized water system failed and pressurized the demineralized water system to 310 psi. The over pressurization caused several diaphragm valves to relieve system pressure, spraying water. This resulted in water entering a safety related MCC that caused an electrical short and fire. The MCC and associated essential loads were de-energized and the plant declared an Alert.	N	N	N	N

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											R1	R2	R3	R4
50946	1/23/2012	PC	Component failure	Plant personnel	Motor control cabinet	Dynamic braking module	Control	Deenergized	Interruptible	Small electrical fire that occurred while operating the containment polar crane. Containment was promptly cleared of all personnel. The fire brigade responded, disconnected power to the equipment, and confirmed the fire was extinguished. Inspection of the polar crane revealed that the bridge drive components experienced a severe electrical transient, smoke damage, and burned wiring as a result of a dynamic braking module failure. The braking resistors for the bridge drive were also damaged.	U	U	Y	Y
50956	10/22/2012	CH	Inadequate preventative maintenance	Plant personnel	MCC	Transformer	Power	Deenergized	Interruptible	The fire brigade leader observed heavy smoke coming from one of the cubicles of the MCC. The shift manager directed the power board to be de-energized. Since the fire could not be extinguished within 15 minutes, an Unusual Event was declared. The 480V load breaker experienced extensive damage, including the melting of insulation on each phase of the breaker.	Y	Y	Y	Y

Fire ID	Date	Fire Severity (from NUREG-2230)	Fire Cause	Detected by	Cabinet Type	Ignition Component	Power or LV Control	Fire Termination	Fire Growth Classification (from NUREG-2230)	Description of Event	Incipient Stage by Reviewer (Y/N/U)			
											R1	R2	R 3	R4
51007	1/6/2013	PC	Component failure	Plant personnel / automatic suppression	Motor control cabinet	Dynamic braking module	Control	Extinguisher	Interruptible	A fire occurred at the service water structure gantry crane during post-maintenance testing. The fire brigade responded and extinguished the fire. The source of the fire was an electrical box associated with the crane.	Y	U	Y	Y
51090	2/15/2013	PC	Stuck contact	Plant personnel	MCC	CPT	Power	Deenergized	Interruptible	During screen wash operations, the 480V supply breaker to the screen drive motor failed to trip due to a stuck contactor. The CPT caught fire and melted. There were no consequences to the unit.	U	U	Y	Y
51118	4/12/2011	PC	Physical wiring configuration	Plant personnel	Heat trace control cabinet	Circuit card	Control	Extinguisher	Interruptible	Maintenance personnel in the area notified the control room and used a fire extinguisher on the fire. On the second attempt the fire went out. The fire brigade responded and de-energized the equipment by opening the breaker that supplies the panel on the MCC.	U	U	Y	Y

Fire ID	Date	Fire Severity (from NUREG-2230)	Fire Cause	Detected by	Cabinet Type	Ignition Component	Power or LV Control	Fire Termination	Fire Growth Classification (from NUREG-2230)	Description of Event	Incipient Stage by Reviewer (Y/N/U)			
											R1	R2	R 3	R4
51146	4/3/2013	PC	Inadequate preventative maintenance	Control room instrumentation & fire alarm	Inverter	Transformer	Power	Deenergized	Interruptible	A 120V alternating current essential inverter output transformer failed, resulting in a small fire within the transformer winding. Load was not lost due to automatic transfer to the alternate supply by the static switch. An Unusual Event was declared due to a fire not extinguished within 15-minutes. When the transformer was de-energized, the fire/smoke ceased. The apparent cause is that the transformer life is non-conservatively estimated and the transformer should be replaced periodically.	Y	Y	Y	Y
51172	3/21/2013	PC	Breaker did not trip	Plant personnel	Motor-operated valve board	Breaker	Power	Extinguisher	Interruptible	Fire was reported in a breaker of the 480V turbine building motor-operated valve board. Fire was extinguished by the auxiliary operator with a CO_2 extinguisher. The fire burned approximately 5-minutes. The most likely cause was an equipment failure. An evaluation determined that the closing coil remained energized excessively and the breaker did not trip as expected.	N	N	N	N

Fire ID	Date	Fire Severity (from NUREG-2230)	Fire Cause	Detected by	Cabinet Type	Ignition Component	Power or LV Control	Fire Termination	Fire Growth Classification (from NUREG-2230)	Description of Event	Incipient Stage by Reviewer (Y/N/U)			
											R1	R2	R3	R4
51180	5/16/2010	PC	Undetermined	Control room instrumentation /annunciator	Blowdown de-mineralized control panel	Light socket	Control	Blew out	Interruptible	The rad waste operator went to the blowdown demineralized control panel in the remote shutdown panel room and noticed an acrid odor. When he attempted to acknowledge and reset the alarm, he noted that multiple valve status lights were flickering. The operator then went to the back panel and noted that a valve status light socket was on fire. The operator blew out the fire.	U	U	U	U
51190	4/2/2012	PC	Component failure	Fire alarm	Inverter	Chokes and transformers	Power	Extinguisher	Interruptible	An operator was dispatched to investigate and discovered light smoke and a small flame from the transformer area at the bottom of the inverter cabinet. The fire brigade leader was dispatched and the fire brigade was activated. The fire was extinguished at 6:33 AM with CO_2 under the direction of the fire brigade leader.	Y	Y	Y	Y
51216	1/3/2010	PC	Fault	Plant personnel	Control panel	Timing relay	Control	Extinguisher	Interruptible	A fault in the master screen control timing relay caused a small fire in the outer screen control panel.	U	U	U	U

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											R1	R2	R 3	R4
51304	1/18/2014	CH	Inadequate preventive maintenance	Control room instrumentation & fire alarm	Inverter	Polar crane	Power	Automatic suppression	Growing	The control room received an inverter trouble alarm. One minute later, at 3:46 AM, the control room received simultaneous alarms, including PLANT CMPTR INVRTR FAIL, plant computer INVERTER COMMON TRBL, and fire alarms in the plant computer room. Operators immediately dispatched the fire brigade, which observed smoke coming from inside the UPS inverter/battery charger room. At 3:48 AM, it was determined that the smoke was from the 50 kilo-volt-amperes inverter inside the room. Fire brigade indicated excessive smoke coming out of the inverter, but no visible flames were detected. At 3:50 AM, the control room received alarm PLANT CMPTR BATT ROOM FLOW LO and plant computer BATT ROOM FLOW LO. The computer room inlet isolation damper closed due to halon actuation in the plant computer room.	Y	Y	Y	Y

Fire ID	Date	Fire Severity (from NUREG-2230)	Fire Cause	Detected by	Cabinet Type	Ignition Component	Power or LV Control	Fire Termination	Fire Growth Classification (from NUREG-2230)	Description of Event	Incipient Stage by Reviewer (Y/N/U)			
											R1	R2	R 3	R4
51324	5/23/2014	PC	Inadequate preventive maintenance	Control room instrumentation annunciator	Inverter	Paper wound transformer	Power	Deenergized	Interruptible	Control room received several alarms including one indicating trouble in the integrated control system Inverter System Trouble. An auxiliary operator was dispatched to the equipment room to determine the cause for the integrated control system inverter trouble alarm. The auxiliary operator reported that an essential inverter had failed, and smoke was emanating from the inverter. The fire brigade leader was dispatched to the equipment room to assist. The control room received a fire alarm and a fire detector panel alarm. The essential inverter was isolated, and the fire was extinguished.	Y	Y	Y	Y
51332	10/6/2014	CH	Inadequate preventive maintenance	Plant personnel	EDG control cabinet	Power rectifier diodes	Control	Extinguisher	Growing	The operations staff was performing a required 18-month, 24-hour surveillance test run on the EDG. Approximately 3 hours into the test, local operators reported a fire in one of the generator electrical cabinets. The EDG tripped while being secured by operators. The fire was extinguished by operations staff using a portable CO_2 extinguisher.	Y	Y	Y	Y

Fire ID	Date	Fire Severity (from NUREG-2230)	Fire Cause	Detected by	Cabinet Type	Ignition Component	Power or LV Control	Fire Termination	Fire Growth Classification (from NUREG-2230)	Description of Event	Incipient Stage by Reviewer (Y/N/U)			
											R1	R2	R3	R4
51377	12/12/2013	PC	Inadequate PM	Plant personnel	MCC		Power	Extinguisher	Interruptible	While starting the steam generator blowdown building ventilation exhaust fan, a loud buzzing noise was noted. Upon entering the building to investigate, heavy black smoke and a bright light were identified emanating from the MCC. An electrical worker in the area extinguished the fire using a single portable CO_2 fire extinguisher. The supply breaker for the MCC was noted as tripped, and the fire was verified extinguished. The fire charred the first two rows of the MCC; inspections identified loose connections on the load side of the molded case circuit breaker.	N	N	N	N

NRC FORM 335 (12-2010) NRCMD 3.7 **U.S. NUCLEAR REGULATORY COMMISSION** **BIBLIOGRAPHIC DATA SHEET** *(See instructions on the reverse)*	1. REPORT NUMBER (Assigned by NRG, Add Vol., Supp., Rev., and Addendum Numbers, if any.) NUREG-2180, Supplement 1
2. TITLE AND SUBTITLE Determining the Effectiveness, Limitations, and Operator Response for Very Early Warning Fire Detection Systems in Nuclear Facilities – Update to Event Tree Parameters (Alpha and Pi) and Integration of NUREG-2230 Methods	3. DATE REPORT PUBLISHED MONTH: May YEAR: 2024 4. FIN OR GRANT NUMBER
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10. SUPPLEMENTARY NOTES

G. Taylor, NRC Project Manager

11. ABSTRACT (200 words or less)

The methodology for modeling very early warning fire detection (VEWFD) systems is documented in NUREG-2180, Determining the Effectiveness, Limitations, and Operator Response for Very Early Warning Fire Detection Systems in Nuclear Facilities (DELORES VEWFIRE), issued December 2016. Since issuance of that publication, the Electric Power Research Institute (EPRI) and the U.S. Nuclear Regulatory Commission (NRC) have published fire probabilistic risk assessment (PRA) methods and data updates seeking to increase the realism of selected modeling techniques. In addition, both organizations continue to collect fire event experience data from the U.S. commercial nuclear industry. These data are used for updating fire PRA input parameters and to further inform the development of realistic modeling methods. As such, this report describes updates to the methodology for modeling VEWFD in fire PRAs to (1) reflect the impact of new fire event data on parameters in NUREG 2180 and (2) integrate the models in NUREG 2180 with the methods in NUREG 2230, Methodology for Modeling Fire Growth and Suppression Response for Electrical Cabinet Fires in Nuclear Power Plants, issued in 2020, associated with modeling interruptible fires in electrical cabinets.

12. KEY WORDS/DESCRIPTORS (List words or phrases that will assist researchers in locating the report.)	
Fire Events Fire Incipient Stage Fire Probabilistic Risk Assessment (fire PRA) Non-Suppression Probability (NSP) Very Early Warning Fire Detection (VEWFD) Smoke Detection Aspirated Smoke Detection National Fire Protection Association (NFPA) 805 Fire Protection	13. AVAILABILITY STATEMENT: unlimited 14. SECURITY CLASSIFICATION *(This Page)* unclassified *(This Report)* unclassified 15. NUMBER OF PAGES: 98 16. PRICE

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