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NUREG/CR-6850 Supplement 1

Fire Probabilistic Risk Assessment Methods Enhancements

Supplement 1 to NUREG/CR-6850 and EPRI 1011989

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1019259 **NUREG/CR-6850 Supplement 1**

Interim Report, December 2009

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PRODUCT DESCRIPTION

This report documents the interim guidance of the industry and the U.S. Nuclear Regulatory Commission (NRC) on several issues from the National Fire Protection Association (NFPA) Standard 805 Frequently Asked Questions (FAQs) Program arising from use of EPRI 1011989, NUREG/CR-6850 (a joint report of EPRI and the NRC Office of Nuclear Regulatory Research [NRC-RES]) fire PRA methodology for nuclear facilities. The FAQ program was established by the NRC Office of Nuclear Reactor Regulation (NRC/NRR) to support the NFPA 805 pilots' transition to the new voluntary rule, 10 CFR 50.48 (c), and is documented in NRC Regulatory Issue Summary RIS 2007-19, "Process for Communicating Clarifications of Staff Positions Provided in Regulatory Guide 1.205 Concerning Issues Identified During the Pilot Application of National Fire Protection Association Standard 805." The present report is expected to be the first in a series of reports that will cover all of the FAQs generated through the use of EPRI 1011989, NUREG/CR-6850 as well as future enhancements, clarifications, and additions to the fire PRA methods.

Results and Findings

Early, limited use of EPRI 1011989, NUREG/CR-6850 showed that some of the screening/ scoping approaches, methods, and assumptions introduced conservative estimates of fire PRA results. In an effort to improve the fire PRA methods, an NFPA 805 Frequently Asked Questions process collected and documented questions on the methods and technical analysis and their associated responses. This report documents the FAQs related to fire PRA methods and their responses. In general, the FAQ solutions improve our knowledge about these respective issues, and result in more realistic estimates of fire-induced core damage frequency.

Challenges and Objectives

The objective in resolving the FAQs is to provide clarifications and modifications to the EPRI/NRC-RES guidance report so that it leads to improvement in core damage frequency results. The challenge to accomplishing the objective is to achieve the most realistic approach possible while attempting to integrate deterministic and probabilistic factors into the analysis.

Applications, Value, and Use

The results of this report are eventually expected to be substantially incorporated into a revision to EPRI 1011989, NUREG/CR-6850. Importantly, these FAQ resolutions are considered interim and may undergo further enhancement prior to their inclusion in the revision to EPRI 1011989, NUREG/CR-6850. The revised report can be used by nuclear plant fire protection and risk engineers to perform fire PRAs. Use of the improved guidance will result in improvements in the results of fire PRAs.

EPRI Perspective

EPRI 1011989, NUREG/CR-6850 was written jointly by a team of EPRI and NRC contributors. The experience and best knowledge at the time were used to form an initial consensus by the team, which was then incorporated into the report. As is often the case in the development of guidance in new technical areas, subsequent limited use of the screening/scoping guidance in the report resulted in high fire-induced core damage frequencies that may not reflect the practical experience in the industry over the last fifty years. Accordingly, the original team undertook an effort to identify those areas in the guidance that contributed most to these high results.

The effort to address these methodology improvements was to develop FAQs under the auspices of NFPA 805 and have these issues addressed by a broader set of contributors than just the original authors of EPRI 1011989, NUREG/CR-6850. In fact, many of the FAQs were identified by the users of the guidance, and often the FAQ originator assisted in the development of the initial responses to the FAQs, if not the final resolution of the issue. The FAQs and their responses are expected to amend the current guidance for the interim and eventually be incorporated, possibly with updated resolutions, into a revision to EPRI 1011989, NUREG/CR-6850.

Although these FAQs represent interim solutions, it should be noted that not all solutions require longer-term research to develop a lasting and more complete solution. In addition, EPRI 1011989, NUREG/CR-6850 represents one way to develop a fire PRA. Alternative methods may be acceptable provided they can be supported by the state of the art in fire PRA model development.

Approach

The approach taken by the resolution team followed the procedure given in RIS 2007-19. For the later FAQs identified under the RES/EPRI memorandum of understanding (MOU), a modified closure process was developed for resolution and is documented under ADAMS Accession No. ML090920045. In this later process NRC/NRR and RES develop a preliminary position. RES then interacts with EPRI under an established MOU to obtain feedback. NRR then makes changes, if appropriate, to the position and issues the FAQ resolution for public comment. Industry and public comments are received and appropriately incorporated. The FAQ resolution is then published by NRR; however, it remains an interim solution until formally endorsed in Regulatory Guide 1.205.

Keywords

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Probabilistic risk assessment (PRA)
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Fire risk
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1 INTRODUCTION

1.1 Background

In 2001, the National Fire Protection Association (NFPA) completed the development of NFPA 805, “Performance-Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants, 2001 Edition” [1]. Consequently, effective July 16, 2004, the U.S. Nuclear Regulatory Commission (NRC) amended its fire protection requirements to permit existing reactor licensees to voluntarily adopt fire protection requirements contained in NFPA 805 as an alternative to the existing deterministic fire protection requirements [2]. NFPA 805 and the voluntary rule 10 CFR 50.48(c) that adopts it require that a “change evaluation” be performed in the event of a change to a previously approved fire protection program element. Such changes may apply to a number of fire protection program elements including (but not limited to) fire protection system design, installation, maintenance, and operation; fire protection procedures; administrative controls; fire brigade; fire protection impairments; or plant post-fire safe shutdown strategy.

In 2002, the Electric Power Research Institute (EPRI) and the NRC Office of Nuclear Regulatory Research (RES) started a program to develop the state of the art for fire probabilistic risk assessment (PRA). In 2005, this program produced a joint EPRI/NRC report, EPRI 1011989, NUREG/CR-6850, “EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities” [3]. That report is a detailed compendium of methods and technical bases to estimate risk associated with internal fires in a nuclear power plant, covering a wide range of disciplines, including fire initiation and effects, impact of fire on plant cables and circuits, and plant response to fire-generated conditions. The EPRI/NRC-RES Fire PRA Methodology provides a powerful tool for use in risk-informed applications that include estimating change in risk associated with changes in plant design and or operational configuration, such as an NFPA 805 “Change Evaluation.”

In 2005, the Nuclear Energy Institute (NEI) developed NEI 04-02, “Guidance for Implementing a Risk-Informed, Performance-Based Fire Protection Program under 10 CFR 50.48(c)” [4]. Section 5.3 and Appendices I and J of that document provide significant guidance for conducting change evaluations. The guidance covers a) defining the plant change where a “change evaluation” is warranted; b) preliminary risk screening where changes with “No” or “Minimal” impact of the risk are eliminated from consideration; c) initial risk evaluation, using fire modeling or bounding risk assessment (Sections 5.3.4.1, 5.3.4.2, J.4); d) detailed risk evaluation, using detailed fire modeling or detailed fire risk analysis (Sections 5.3.4.3, J.5); and e) criteria for evaluation of the change. The guidance for bounding risk assessment (Sections 5.3.4.2, J.4.2) and detailed fire risk analysis (5.3.4.3, J.5.2) relies on existing fire risk assessments and methods such as the fire protection Significance Determination Process (SDP).[1] In May 2006, NRC published Regulatory Guide 1.205, Revision 0, "Risk-Informed, Performance-Based Fire Protection for Existing Light Water Nuclear Power Plants" [5], endorsing, with exceptions, NEI 04-02, Revision 1.

Following a proposal by NEI in 2006, an NFPA-805 Frequently Asked Questions (FAQ) process was established between the NRC and the industry, emulating a similar process that had been previously implemented for the Reactor Oversight Process (ROP) Performance Indicators program. The process is introduced in a letter from Sunil Weerakkody of the NRC to Alexander Marion of NEI [NRC ADAMS Accession No. ML061660105] and described in detail in RIS 2007-19 [NRC ADAMS Accession No. ML071590227]. As stated in RIS 2007-19, the purpose of the FAQ process is to provide a mechanism for resolving interpretation issues with NEI 04-02. Once closed out as dictated in RIS 2007-19, the resolved FAQs represent the NRC staff interpretations of the guidance for licensee transition to risk-informed, performance-based fire protection under NFPA 805. In addition, RIS 2007-19 states that the resolved FAQs (via NRC closure memos) are preliminary extensions of the implementation guidance in NEI 04-02, as approved by the NRC. RIS 2007-19 describes the FAQ process and provides a template for documenting the FAQs and their resolution.

Between 2006 and 2009, a number of early applications of EPRI 1011989, NUREG/CR-6850 resulted in seemingly conservative fire-induced risk estimates. These early results necessitated timely development of clarification and enhancements to the document, to support the plants transitioning to the risk-informed and performance-based fire protection rule. This led to increased focus on the NFPA-805 FAQs related to fire PRA methods and applications. Meetings in 2008 and early 2009 regarding these FAQs indicated that there were still important technical considerations that needed to be resolved in order to generate timely resolution to support plants transitioning to NFPA 805. In June 2009, the NRC instituted a revised closure process for the FAQ that had been identified under the NRC/EPRI MOU. This process is documented in a letter from Jack Grobe (NRC) to Alexander Marion (NEI) [NRC ADAMS Accession No. ML090920045].

1.2 Objectives

In order to document the responses and final resolution of NFPA-805 FAQs related to the Fire PRA Methodology, specifically those in EPRI 1011989, NUREG/CR-6850, a revision of this joint document will be undertaken by EPRI and RES once sufficient clarification and enhancements to the methods documented in the EPRI 1011989, NUREG/CR-6850 are developed.

[1] U.S. Nuclear Regulatory Commission, Inspection Manual Chapter 0609, Appendix F, February 28, 2005.

1.3 Overview of the FAQ Process

RIS 2007-19 describes the FAQ process for fire PRA FAQs not identified under the NRC/EPRI MOU. ADAMS Accession No. ML090920045 describes the approach to resolve the existing FAQs related to the EPRI 1011989, NUREG/CR-6850 NRC/EPRI MOU, as follows.

1. *NRR staff, in consultation with RES staff, will develop an Interim Position for each specific FAQ related to EPRI 1011999, NUREG/CR-6850 in accordance with the schedule provided in the enclosures* [enclosures may be found in ML09090045]. *This is the start of the process.*
2. *NRR will transmit the draft Interim Position to RES within two weeks after the start of the process.*
3. *RES will engage EPRI under the MOU to obtain comments on the specific FAQ Interim Position within two weeks from receipt of the NRR draft. The MOU Team (RES and EPRI) may agree, disagree, or concur on additional confirmatory research.*
4. *RES will return the specific FAQ Interim Position to NRR with recommendations, as appropriate, within five weeks after the start of the process.*
5. *NRR will appropriately incorporate recommendations generated through review under the RES/EPRI MOU and provide a proposed resolution of the FAQ for industry and other public stakeholder consideration within seven weeks after the start of the process.*
6. *Industry and other public stakeholder comments will be received and appropriately considered in finalizing the FAQ resolution and issuing the final FAQ closure documentation within sixteen weeks of the start of the process.*

1.4 Report Structure

Table 1-1 contains a summary of the status of the issues related to the fire PRA and EPRI 1011989, NUREG/CR-6850. FAQs 16, 17, 18, 31, 35, 42, 43, 44, 46, 48, 49, 50, 51, and 52 were solved under the closure process described in Section 1.3.

Table 1-1
Summary of the Status of the FAQs Related to EPRI 1011989, NUREG/CR-6850

FAQ No.	Title	Status (As of December 2, 2009)	In This Report
FAQ 06-0016	Ignition Source Counting Guidance for Electrical Cabinets	NRC Closure Memo, 10/05/07 (Ref. NRC ADAMS ML072700475 and ML070580334)	Chapter 3
FAQ 06-0017	Ignition Source Counting Guidance for High-Energy Arcing Faults (HEAF)	NRC Closure Memo, 09/26/07 (Ref. NRC ADAMS ML072500300 and ML071570255)	Chapter 4
FAQ 06-0018	Ignition Source Counting Guidance for Main Control Board (MCB)	NRC Closure Memo, 09/26/07 (Ref. NRC ADAMS ML072500273)	Chapter 5
FAQ 07-0031	Miscellaneous Binning Issues	NRC Closure Memo, 12/17/07 (Ref. NRC ADAMS ML072840658)	Chapter 6
FAQ 06-0035	Bus Duct Counting Guidance for High-Energy Arcing Faults	NRC Closure Memo, 07/24/09 (Ref. NRC ADAMS ML091620572)	Chapter 7
FAQ 08-0042	Fire Propagation from Electrical Cabinets	NRC Closure Memo, 08/04/09 (Ref. NRC ADAMS ML092110537)	Chapter 8
FAQ 08-0044	Main Feedwater Pump Oil Spill Fires	NRC Closure Memo, 08/04/09 (Ref. NRC ADAMS ML092110516)	Chapter 9
FAQ 08-0048	Fire Ignition Frequency	NRC Closure Memo, 09/01/09, (Ref. NRC ADAMS ML092190457)	Chapter 10
FAQ 08-0049	Cable Tray Fire Propagation	NRC Closure Memo, 07/30/09 (Ref. NRC ADAMS ML092100274)	Chapter 11
FAQ 08-0043	Location of the Fire Within an Electrical Cabinet	NRC Closure Memo, 08/04/09 (Ref. NRC ADAMS ML092120448)	Chapter 12
FAQ 08-0046	Incipient Fire Detection Systems	NRC Closure Memo, 11/23/09 (Ref. NRC ADAMS ML093220426)	Chapter 13
FAQ 08-0050	Manual Nonsuppression Probability	NRC Closure Memo, 09/14/09 (Ref. NRC ADAMS ML092190555)	Chapter 14
FAQ 08-0052	Transient Fires – Growth Rates and Control Room Nonsuppression	NRC Closure Memo, 08-04/09 (Ref. NRC ADAMS ML092120501)	Chapter 15
FAQ 08-0047	Spurious Operation Probability	NRC Closure Memo, 12/4/08 (Ref. NRC ADAMS ML082950750 and ML082770662)	Chapter 16

The following FAQs related to fire PRA methods are not in this report but will be documented in a separate joint RES/EPRI report once they are completed:

FAQ No.	Title	Status (As of December 2009)
FAQ 08-0051	Electrical Hot Short Duration	NRC Draft Interim Position, 11/18/09 (Ref. NRC ADAMS ML092330663)
FAQ 08-0053	Kerite Cable Classification	Open

The remainder of this report is structured as follows:

- Chapter 2: Application of the Fire PRA Methods to NFPA 805 Change Evaluation
- Chapters 3 through 18: FAQ 06-0016 through FAQ 08-0052, excluding FAQ 08-0051

2 APPLICATION OF FIRE PRA METHODS TO NFPA 805 CHANGE EVALUATION

NFPA 805 allows for engineering analysis to be performed in support of plant changes. This engineering analysis includes the performance of Fire Modeling and Fire PRA (FPRA) calculations. The Fire Modeling portion of the NFPA 805[2] is applicable to risk-informed decision-making only as it supports the FPRA and therefore it is not covered in this chapter.

The risk analysis performed using FPRA can be addressed by the requirements in the ASME PRA Standard, Part 4, "Requirements for Fires At-Power PRA," henceforth referred to as the "FPRA Standard" [6]. The requirements that should be addressed are highly dependent on the analysis being performed for the change evaluation, and as such, may not involve the full FPRA. The degree to which a requirement must be met is dependent on its significance in determining the risk change; therefore, the needed capability category (i.e., the extent to which the level of detail, plant specificity, and realism of plant response are modeled) is dependent on the significance of the resulting risk for the change.

An FPRA prepared in support of transition to the NFPA 805 rule has as its primary objective the demonstration that the change in plant risk is acceptable to the Authority Having Jurisdiction (AHJ). Consequently, screening and conservative treatments that may not necessarily satisfy the requirements of the FPRA Standard may be fully adequate in the context of an NFPA 805 application. In addition, it should be noted that lower Capability Categories (CCs) in the Supporting Requirements (SRs) of the FPRA Standard [6] do not always result in conservative risk estimates (e.g., higher CDFs), while in some cases the higher CCs may yield the higher CDFs.[3] This issue needs to be considered when performing an analysis to ensure the risk is acceptable to the AHJ.

[2] Fire Modeling is described in NFPA 805 and the supporting NEI Implementation Guide NEI 04-02. NFPA 805 and NEI 04-02 require that all change analysis shall also include an assessment of risk. Fire Modeling is performed to identify and define fire scenarios that would require consideration in the risk assessment. This Fire Modeling option includes the comparison of the Limiting Fire Scenario (LFS) to the Maximum Expected Fire Scenario (MEFS), as described in NEI 04-02 Appendices D and J.

[3] Note that there may be offsetting factors. Increased rigor is likely to add more mitigation features as well, so credit is being given for more equipment to respond to the fire (rather than assuming the equipment is failed for every compartment). As the equipment selection process (overall) heads for Capability Category III, a more realistic assessment of the risk will occur, which may not necessarily lead to higher CDF and LERF. However, in some cases a higher CDF or LERF may result, and this may be the most realistic.

3 IGNITION SOURCE COUNTING GUIDANCE FOR ELECTRICAL CABINETS (FAQ 06-0016)

3.1 Background

FAQ 06-0016, Revision 0, was proposed to clarify the guidance from EPRI 1011989, NUREG/CR-6850, "EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities," on counting electrical cabinets and panels for NFPA (National Fire Protection Association) 805 transition applicants.

EPRI 1011989, NUREG/CR-6850 recommends cabinets to be counted by "visible" vertical sections assuming a "typical" electrical cabinet configuration. The available guidance, however, did not clarify how to count cabinets departing from this typical configuration that can be found in commercial nuclear plants. Consequently, further guidance was necessary to provide such clarifications. It should be noted that panel counting impacts only the fire frequency assigned to an individual panel or group of panels. Hence, the ultimate criterion for partitioning of the fire frequency is the relative number of ignition sources present. The counting guidance does not, in particular, have anything to do with the potential for fire spread between vertical sections or out of a panel.

The existing guidance in EPRI 1011989, NUREG/CR-6850 is based on industry data that has only been provided with fidelity adequate to support plant-level ignition frequencies for electrical cabinets. Although the guidance does address the broad applicability of the data, it leaves room for variability that can create issues with PRA quality. It is important that the ignition frequency results be of sufficient quality to support not only NFPA-805 transition but also the broader scope of regulatory inspection and enforcement issues related to FPRA. The guidance proposed will provide more consistency when determining plant-specific electrical cabinet ignition frequencies while working within the bounds of the existing data provided by EPRI 1011989, NUREG/CR-6850. This should facilitate the review and acceptability of the results.

The guidance provided in EPRI 1011989, NUREG/CR-6850 for Task 6, Fire Ignition Frequency (Section 6.5.6, Bin 15), states:

> Bin 15 – Electrical Cabinets (Plant-Wide Components): Electrical cabinets represent such items as switchgears, motor control centers, DC distribution panels, relay cabinets, control and switch panels (excluding panels that are part of machinery), fire protection panels, etc. Electrical cabinets in a nuclear power plant vary significantly in size, configuration, and voltage. Size variation range from small-wall mounted units to large

> walk-through vertical control cabinets, which can be 20' to 30' long. The configuration can vary based on number of components that contribute to ignition, such as relays and circuit cards, and combustible loading, which also affects the fire frequency. Voltages in electrical cabinets vary from low voltage (120 V) panels to 6.9 kV switchgears. Even though it is expected that these features affect the likelihood of fire ignition, from a simple analysis of the event data involving the electrical cabinets, it was determined that the variation by cabinet type did not warrant separate frequency evaluation. Therefore, one fire frequency was estimated for the electrical cabinets.

This issue affects only general electrical cabinets and panels. In the case of switchgears, load centers, unit substations, and motor control centers the term "segment" was uniformly interpreted to be equal to the individual vertical sections that define these types of components. As applied to general electrical cabinets and panels, the term "segments" could be interpreted to mean different metrics:

- A segment could be defined as an enclosed element that is generally independent of size or volume (also referred to as a vertical section).
- A segment could be defined as an individual section of an enclosure regardless of whether it was fully enclosed.
- A segment could be defined based on a "standard" or reference sample panel size.

Depending on the metric being used, the counting of electrical cabinets would result in varying results and consequently, different fire ignition frequency values. While EPRI 1011989, NUREG/CR-6850 allows the establishment of plant-specific criteria for counting of electrical cabinets, additional guidance is required to achieve a consistent basis for determining the ignition frequencies.

3.2 Resolution

The recommendations in EPRI 1011989, NUREG/CR-6850 consider it to be impractical to count ignition sources inside cabinets (e.g., circuit cards, relays, cable terminations and junctions, etc.) directly because (1) the number of ignition sources present in an entire plant is quite large and (2) in most cases the analyst will not be free to open multiple panels for routine inspection of contents. Hence, the guidance was written in such a way that the analyst is not expected to examine the contents of every panel in the plant as a part of the counting process. Examining a sample of representative panels will likely prove useful to the analyst, but the guidance presumes that this will be possible for, at most, a small sample of panels.

As an alternative, the guidance in EPRI 1011989, NUREG/CR-6850 is based on the counting of "vertical sections" as a surrogate for the counting of ignition sources. The overall objective is to strike a balance such that two banks of panels with a similar number of ignition sources would result in a similar panel count.

A generalized counting criterion for general electrical cabinets is discussed in the FAQ response [NRC ADAMS Accession No. ML072700475]. This proposed criterion would involve two elements. For switchgears, load centers, unit substations, and motor control centers the counting for the purposes of EPRI 1011989, NUREG/CR-6850, Task 6, Bin 15 would be based on vertical section. This counting is illustrated in the following examples.

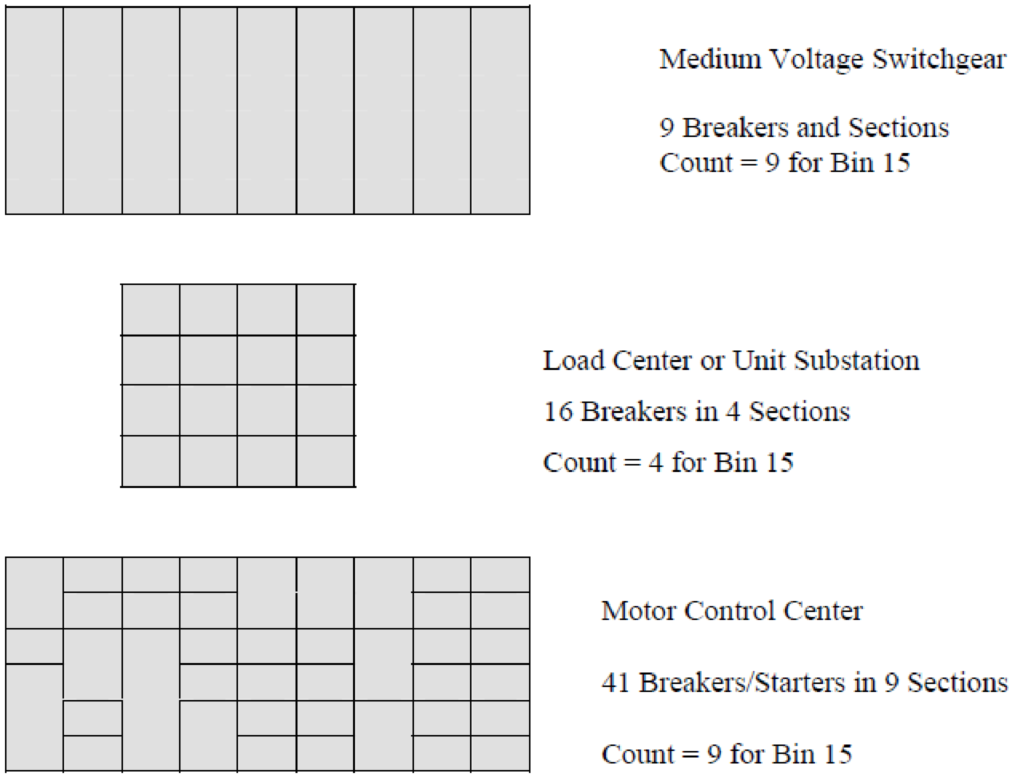

Figure 3-1
Counting of electrical cabinets

For general electrical cabinets and panels, counting is based on externally apparent vertical sections, regardless of the number of horizontal divisions within a vertical section (e.g., ignoring the three horizontal divisions in each of the four vertical sections of the second example above). No examination of the internal construction is required.

This proposed counting for electrical cabinets and panels is to be applied for a wide range of panel sizes. However, recognizing that the ignition frequency is more a function of the cabinet contents than the cabinet size, a basis is needed to address outlier conditions. It is proposed that each user be required to establish criteria for identifying the outliers and the basis for counting them. As an example, they can be counted by establishing a nominal “standard” or reference cabinet size. The count could also be based on evaluating the cabinet internals relative to a defined “standard” or reference configuration. For example, a particular user may define a cabinet with any horizontal dimension more than 8 feet as an outlier, and a “standard” cabinet as being nominally 4 feet in length x 3 feet deep. (Cabinet height is not generally an issue based on the use of vertical sections.) Using this example, the following cabinet and panel examples would be counted as follows:

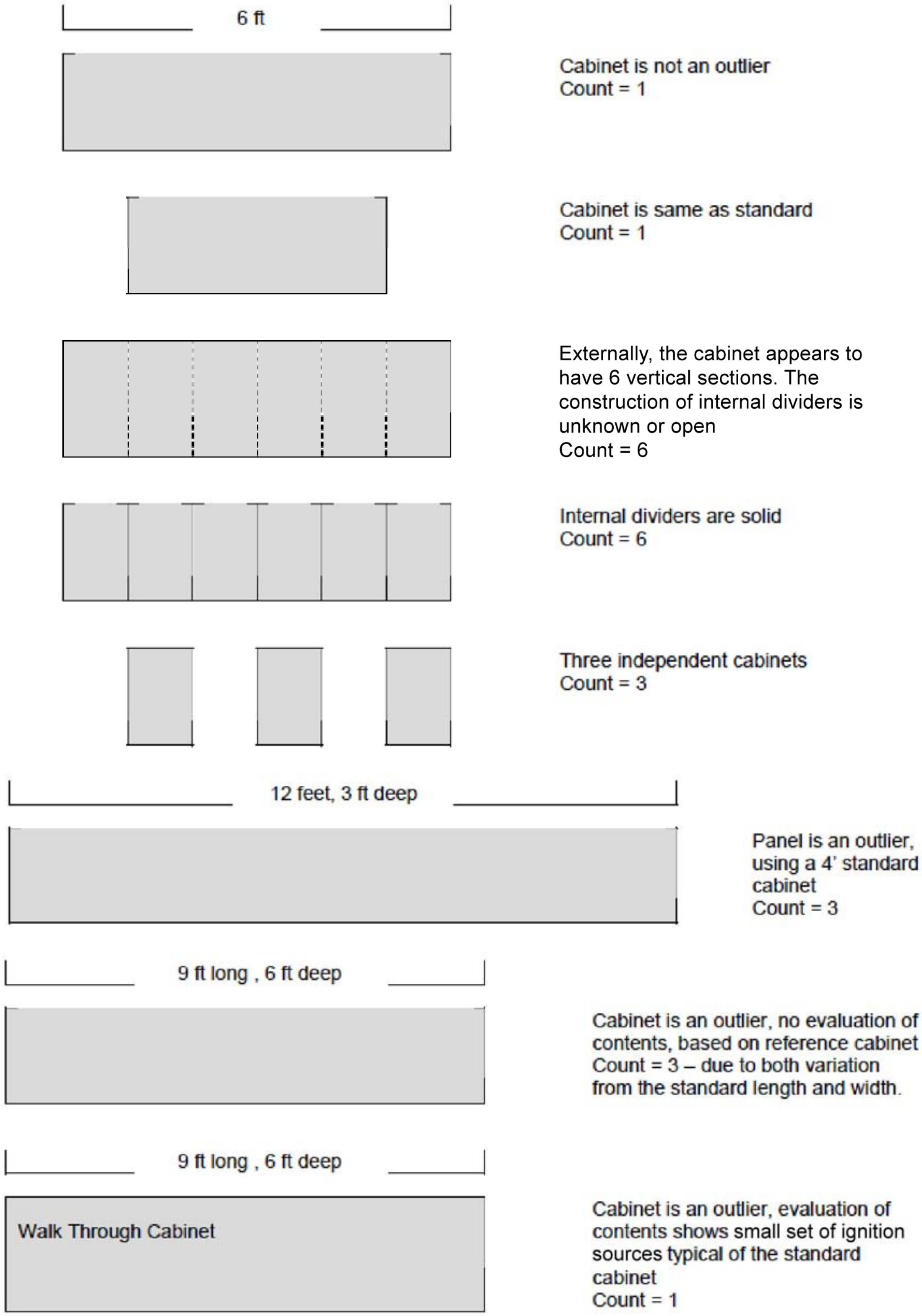

Figure 3-2
Counting of electrical cabinets

The intent is that a basis for the counting of outliers is required. A volumetric comparison is not required. Also, to prevent any appearance that this treatment is intended to be based on physical measurements, the proposed approach allows only integer counting. The assignment of fractional values would not be allowed. In addition, the proposed methodology retains the option for screening small cabinets resulting in a count of zero for them (as discussed in EPRI 1011989, NUREG/CR-6850). As applied in this case, the user would be allowed to screen cabinets or panels based on defined criteria and exclude them from the overall population count. When performing detailed fire modeling, the fire should be applied to the actual cabinet footprint by vertical section, including outliers.

4
IGNITION SOURCE COUNTING GUIDANCE FOR HIGH-ENERGY ARCING FAULTS (HEAFS) (FAQ 06-0017)

4.1 Background

The original Frequently Asked Question (FAQ) 06-0017, Revision 0, was proposed to clarify the guidance from EPRI 1011989, NUREG/CR-6850, "EPRI/NRC-RES Fire Probabilistic Risk Assessment Methodology for Nuclear Power Facilities," on counting high-energy arcing faults (HEAFs) for NFPA-805 transition applicants. Subsequently, this FAQ was split into two parts. Part one, labeled as Revision 1 to FAQ 06-0017 and the subject of this chapter, addresses the guidance for counting HEAFs associated with switchgear and load centers. Part two, the subject of FAQ 07-0035, addresses the guidance for counting HEAFs associated with bus ducts and junctions. This is treated separately in Chapter 7.

It is important that the ignition frequency results be of sufficient quality to support not only NFPA-805 transition but also the broader scope of regulatory inspection and enforcement issues related to FPRA. The guidance proposed will provide more consistency when determining plant-specific electrical cabinet ignition frequencies while working within the bounds of the existing data provided by EPRI 1011989, NUREG/CR-6850. This should facilitate the review and acceptability of the results.

The guidance provided in EPRI 1011989, NUREG/CR-6850 for Task 6, Fire Ignition Frequency (Section 6.5.6, Bin 16), states:

> Bin 16 – High-Energy Arcing Faults (Plant-Wide Components): High-energy arcing faults are associated with switchgear and load centers. Switchyard transformers and isolation phase buses are not part of this bin. For this bin, similar to electrical cabinets, the vertical segments of the switchgear and load centers should be counted. Additionally, to cover potential explosive failure of oil filled transformers (those transformers that are associated with 4.16 or 6.9kV switchgear and lower voltage load centers) may be included in vertical segment counts of the switchgear.

Pilot discussions and benchmarking of EPRI 1011989, NUREG/CR-6850 for Task 6, Fire Ignition Frequency, has shown inconsistency in the treatment of high-energy arcing faults (Bin 16). Strict interpretation of the guidance is that the HEAF count should mimic the electrical cabinet counts for switchgear and load centers. The industry experience and consequently the HEAF frequency are based on 3 events occurring on medium-voltage switchgears and ½ event occurring on a 480VAC load center. Because of the relative numbers of switchgears and load centers at an individual plant, it is expected that the resultant frequency may be inappropriately skewed.

4.2 Resolution

The state of knowledge regarding HEAF fires continues to evolve. New insights developed since publication of the EPRI 1011989, NUREG/CR-6850 do indicate that an adjustment of fire frequencies between low- and medium-voltage equipment is warranted.

The electrical power community has gained significant knowledge about HEAFs since publication of EPRI 1011989, NUREG/CR-6850. The increased awareness and knowledge base was driven by adoption of new arc flash protection requirements in NFPA 70E, *Standard for Electrical Safety Requirements for Employee Workplaces*. Discussions with experts close to the subject, including a member of the IEEE 1584 standards committee (*Guide for Performing Arc-Flash Hazards Calculations*), revealed that recorded events of HEAFs are actually dominated by incidents involving 480V gear. The experts confirm that the higher incidence of 480V events is partially attributable to the greater population of installed 480V equipment. However, other overlapping factors are also important:

- A majority of arc flash events are initiated by human error.
- Low-voltage equipment is worked on/operated more frequently than medium-voltage equipment.
- Workers have a more casual attitude when working on 480V gear, i.e., everyone knows that you will probably not get a second chance if you make a mistake working on medium-voltage equipment but they tend to perceive 480V gear as less threatening. Additionally, it is more probable that 480V equipment will be worked “hot”; that is, worked on while the equipment is energized.
- Basic design attributes of medium-voltage gear decrease the likelihood of initiating a sustained arcing fault. Key elements include insulated bus bars in lieu of open bus bar work, barrier protection, compartmentalization between phases, and increased creepage distances.
- Arcing faults do occur on 208V systems; however, sustained arcing faults at 208V are rare and difficult to reproduce.

With these observations in mind, the intent of the HEAF analysis (per Appendix M of EPRI 1011989, NUREG/CR-6850) is to capture “higher-consequence” events that may have a *substantive impact outside the cabinet of origin*. Other arc fault events (e.g., events that did not lead to an impact outside the originating panel) are already treated via the general electrical panel fire frequency, and this treatment need not be adjusted. Only the “higher-consequence” events are under question here.

Another observation that is evident from the event records amassed by the IEEE standard groups is that, even though the general incidence of arc faults in low-voltage equipment may actually be higher, the fraction of such events leading to substantive impacts outside the initiating cabinet (i.e., higher-consequence events) is actually lower than for similar incidents in medium-voltage equipment. In essence, if a sustained arc fault occurs in a 4.16 kV switchgear, the fault will very likely have an impact beyond the limits of the panel. In contrast, an arc fault in a low-voltage panel is more likely to remain confined to the panel and less likely to have impact beyond the panel. This rationale is supported by standardized arc flash calculations; equivalent stand off distances are typically greater for medium-voltage equipment, given normal and customary overcurrent protection.

This contention is consistent with both the broader industry experience and with the specific nuclear industry experience as cataloged in Appendix M of EPRI 1011989, NUREG/CR-6850. That is, the frequency analysis included three events in medium-voltage equipment, and only ½ of an event (i.e., one uncertain event) for low-voltage equipment. This assessment included consideration of whether each reported event actually had impact outside the panel of origin. There are many other low-voltage panel fire events that appear to have involved some degree of arc-flash, but that also remained confined to the panel of origin.

The proposed resolution to the underlying issue raised in the FAQ [NRC ADAMS Accession No. ML072500300] is to split fire ignition frequency Bin 16, HEAF, into two bins; namely, "16a – HEAF for low-voltage panels (480-1000V)" and "16b – HEAF for medium-voltage panels (greater than 1000V)." For each bin, the method of panel counting would then stand unchanged (i.e., count vertical sections). Given the split into two bins, the counting method—and hence the fire frequency apportioning process—need to be self-consistent within each of the two new bins, but there is no longer any cross-over between the low- and medium-voltage equipment. This also maintains consistency with the counting method for general thermal fires (i.e., the non-HEAF panel fires that must also be treated), which is also a highly desirable feature so that the analyst need not maintain two separate population counts for the same set of fire ignition sources. The net result is a repartitioning of the "higher-consequence" HEAF events between low-voltage and medium-to-high-voltage equipment in accordance with the event data. The revised annual fire frequencies for these two new bins are as follows:

16a: HEAF for Low-Voltage Panels (480–1000 V)		**16b: HEAF for Medium-Voltage Panels (above 1000 V)**	
Mean	4.8E-04	Mean	1.4E-03
Variance	1.4E-03	Variance	1.2E-02
5%	1.6E-05	5%	3.8E-05
50%	2.0E-04	50%	6.2E-04
95%	1.5E-03	95%	4.1E-03

In the course of providing the above response, the related issue of whether or not motor control centers (MCCs) should be included as potential sources of HEAFs along with the switchgear and load centers when counting sources was considered. While not explicitly mentioned in EPRI 1011989, NUREG/CR-6850, inclusion of MCCs when counting HEAF sources is explicit in the Fire Protection Significance Determination Process (Inspection Manual Chapter 609F). Consensus was reached regarding this, with the following guidance:

> Only MCCs with switchgear that is used to directly operate equipment such as load centers should be counted as HEAF sources.

5
IGNITION SOURCE COUNTING GUIDANCE FOR MAIN CONTROL BOARD (MCB) (FAQ 06-0018)

5.1 Background

Frequently Asked Question (FAQ) 06-0018 was proposed to clarify the guidance from EPRI 1011989, NUREG/CR-6850, "EPRI/NRC-RES Fire Probabilistic Risk Assessment Methodology for Nuclear Power Facilities," on counting "main control boards."

The scope of FAQ 06-0018 is the main control board, which is located in the main control room. The main control room contains electrical cabinets, identified as (Bin 15) plant-wide components in EPRI 1011989, NUREG/CR-6850 for the purposes of determining fire ignition frequency, in addition to the main control board. The recommendation in this FAQ is that the definition of the main control board provided in EPRI 1011989, NUREG/CR-6850, Appendix L, be accepted as also being applicable for Task 6, Bin 4 counting (i.e., main control board), given clarification regarding the relationship between Appendix L of EPRI 1011989, NUREG/CR-6850 and Task 6, Bin 4, as follows: There is a one-to-one correspondence between the main control board as discussed in Appendix L and Task 6, Bin 4, in EPRI 1011989, NUREG/CR-6850.

The guidance provided in EPRI 1011989, NUREG/CR-6850 for Task 6, Fire Ignition Frequency, is subject to application inconsistency in the treatment of the main control board (Bin 4). The guidance for Task 6 does not provide any specific definition or characterization of what constitutes a main control board (MCB) other than a reference to it being the central element of the room. A discussion among the NFPA-805 pilot plants that included consideration of other plants in their respective fleets found wide variability in the configuration of the main control room. There was a concern that inconsistent treatment of this bin would unnecessarily challenge the completion and review of the FPRA. This challenge would be manifested by a notable change in the fire frequency assigned to an individual panel, depending on whether it was counted as Bin 4 or Bin 15.

5.2 Resolution

As discussed in the resolution to this FAQ [NRC ADAMS Accession No. ML072500273], the intent of the guidance in EPRI 1011989, NUREG/CR-6850 was to *sharply limit* the scope of the panels to be included in the main control board ignition frequency bin. The main intent was to capture the main "horseshoe" and little else. For many plants, the main control board will be the main horseshoe and *nothing else*. This is important given that fires in the main control room that occur outside the main horseshoe were binned with the general electrical panel fires and not with the main control board. Changing the definition of a fire frequency bin (i.e., what goes into a particular bin) creates an inconsistency with the binning of events (in Chapter 6 of EPRI 1011989, NUREG/CR-6850) and the resulting fire frequency estimates.

The additional wording provided in Appendix L of EPRI 1011989, NUREG/CR-6850 (the bullet list on page L-2) was intended to allow for some flexibility given the wide variability among control rooms around the country. The guidance was not intended to open the door to inclusion of more than a small handful of other control room panels. Any panel that is detached from the main horseshoe would generally be excluded from this definition of the main control board with few exceptions.

An exception of the above described guidance may include “bench-board” panels that were detached from, but directly in front of, the main horseshoe (at some plants such panels are referred to as “consoles”). These bench-board-type cabinets, usually one or two per control room, may be counted as part of the main control board. These panels were (1) serving as an integral part of the main plant monitoring and control functions; (2) located in the center of the operators’ main work area; and (3) manned on a nearly continuous basis.[4]

Plants may have numerous smaller detached panels housing such equipment as computers and the event recording equipment and printers. These panels typically are in full view of the operators (generally behind or to the side of their main work area). Nonetheless, they should not be treated as a part of the main control board, because they are clearly and distinctly detached from the main control board and serve unique functions.

There may also be numerous “back panels” and other detached panels housing items such as balance-of-plant and off-site power controls and indicators. All of these panels should be excluded from the main control board and treated as general electrical panels. In general, the definition of the main control board is intended to *sharply limit* the scope of that bin to the main horseshoe and, under certain circumstances, a very small number of other detached panels. The intent is to treat the vast majority of the detached panels, and any “back” panels, as general electrical panels, not as a part of the main control board.

[4] Conditions specified in the example in the FAQ resolution

6
MISCELLANEOUS FIRE IGNITION FREQUENCY BINNING ISSUES (FAQ 07-0031)

6.1 Background

Frequently Asked Question (FAQ) 07-0031 was proposed to clarify the guidance found in EPRI 1011989, NUREG/CR-6850 [3] regarding counting for miscellaneous ignition source bins described in Chapter 6 of that reference. The relevant bins are (1) Bin 14 – Electric Motors, (2) Bin 21 – Pumps, (3) Bin 23 – Transformers, and (4) Bin 26 – Ventilation Subsystems. The general intent of the suggested changes was to ensure a higher level of consistency between four specific fire ignition source bins associated with electrical equipment (motors, pumps, ventilation subsystems, and transformers). The changes described in the chapter establish new criteria for eliminating certain motors and transformers from the counting process based on size (e.g., the associated component electrical power limits) or function.

6.2 Resolution

This section is divided into four subsections, one for each of the ignition frequency bins relevant to this chapter [NRC ADAMS Accession No. ML072840658].

6.2.1 Bin 14: Electric Motors

For Bin 14, Electric Motors (Plant-Wide Components), the intent was to exclude motors associated with equipment counted in other bins. Specifically, the response to this FAQ includes the following guidance:

Motors that are totally enclosed, including totally enclosed MOV drive motors, should be excluded from Bin 14 because the nature of the motor housing would prevent the extension of flames outside the motor casing. However, other motors (e.g., ventilated motors) do present the potential for fire spread outside the motor and should continue to be considered regardless of the motor application. Furthermore, the fire event database includes a small number of fire events involving MOV drive motors. Consequently, MOV drive motors that are not totally enclosed should be treated similarly to other general-use electric motors.

The original guidance provided in Section 6.5.6 of the methodology for Bin 14 (page 6-16) can be clarified as follows:

> Bin 14 – Electric Motors (Plant-Wide Components): Electric motors associated with various plant equipment such as elevators, valves, etc., with the following clarifications:
>
> - This bin includes any electric motor with a rating greater than 5 hp unless the motor meets one (or both) of the two exclusionary provisions immediately below. The bin excludes motors with a rating of 5 hp or less regardless of motor application.
> - This bin excludes electric motors that are attached to equipment already identified and counted in other bins (i.e., reactor coolant pumps, air compressors, dryers, pumps, RPS MG sets, and ventilation subsystems). That is, motors associated with a piece of equipment counted as a part of another ignition source bin are not counted separately as motors, but rather, are considered an integral part of the larger equipment item (the pump, the compressor, etc.).
> - This bin *excludes* any motors, including MOV drive motors, which are totally enclosed regardless of the motor size. A totally enclosed motor is defined by the National Electrical Manufacturers Association (NEMA) as “a motor designed without air openings so there is no free exchange of air between the inside and outside of the enclosure but not necessarily air or water tight” (Reference: NEMA MG 2-201, Rev. 1, 2007, “Safety Standard and Guide for Selection, Installation, and Use of Electric Motors and Generators”). Specifically, motors meeting the following NEMA classifications are *excluded* from the motor counting process and are not considered as ignition sources: totally enclosed machines; totally enclosed non-ventilated; totally enclosed fan-cooled; totally enclosed pipe-ventilated; totally enclosed water-cooled; and explosion-proof.”

6.2.2 Bin 21: Pumps

For Bin 21, Pumps (Plant-Wide Components), the clarification resulting from this FAQ indicates that excluding pumps associated with smaller (5 hp or less) hydraulic actuators is appropriate. The guidance relative to Bin 21 as provided in Section 6.5.6 is clarified as follows:

> Bin 21 – Pumps (Plant-Wide Components) and large hydraulic valves: For this methodology, it is assumed that above a certain size, fire ignition is the same for all pumps. Pumps with a rating of 5 hp or less are assumed to have little or no significant contribution to risk. The number of larger pumps (>5 hp) in all plant locations defined as “plant-wide” should be estimated.
>
> - This bin *excludes* small sampling pumps.
> - This bin *excludes* pumps with a rating of 5 hp or less. This bin *includes* pumps rated greater than 5 hp.
> - This bin *excludes* pumps associated with hydraulic actuators where the pump is rated 5 hp or less. The bin *includes* pumps associated with larger hydraulic actuators where the pump is rated above 5 hp.

6.2.3 Bin 23: Transformers

As originally written, Bin 23, Transformers (Plant-Wide Components), did not establish a lower limit for the inclusion/exclusion of transformers. The response to the FAQ suggests that this bin only include transformers with a power rating above 45 kVA for dry-type transformers. The FAQ response is based primarily on a review of the combustible content of smaller transformers. Dry transformers with a rating of 45 kVA or less are expected to have insufficient content of combustible material to produce a challenging fire as defined in Chapter 6 of EPRI 1011989, NUREG/CR-6850. In the event of an insulation breakdown, significant electrical energy could be released (i.e., arcing inside the transformer). However, given the small amount of combustible materials within the transformer (mainly the varnish used to coat the windings), it is expected that a significant fire escaping the transformer's housing is very unlikely. A potentially challenging fire is defined as one with the potential to spread beyond the bounds of the initiating component or to represent a direct threat to other plant equipment or cables. Small dry transformers would not appear to hold this potential.

Note that the original wording of the ignition source bin in Chapter 6 of EPRI 1011989, NUREG/CR-6850 had already excluded "small lighting transformers." The revision discussed immediately above will now exclude transformers with a rating of 45 kVA or less and will supersede the prior guidance. In order to avoid confusion and potential conflicts, the original wording associated with the exclusion of "small lighting transformers" has been deleted from the revised bin description provided below. The 45 kVA criterion applies to any dry-type transformers, including lighting transformers.

The FAQ, however, concludes that the same arguments would not apply to oil-filled transformers. These transformers should be included in the count regardless of the power rating. Any oil-filled transformer has a sufficient combustible content (i.e., the oil) to represent a potentially challenging fire in the event of transformer failure. In practice, smaller, indoor-type transformers are generally not of an oil-filled design. The guidance relative to Bin 23 as provided in Section 6.5.6 is modified and clarified as follows:

> Bin 23 – Transformers (Plant-Wide Components): This bin nominally includes any indoor transformer that is not an integral part of a larger component. In particular, all dry-type transformers with a rating greater than 45 kVA and all oil-filled transformers are included in this bin. Examples of transformers accounted for in this bin include: 4160V/480V station service transformers attached to AC load centers; low voltage regulators; and 480V/208-120V auxiliary service transformers. The large yard transformers are not part of this bin. The number of indoor transformers should be estimated with the following clarifications:
>
> - This bin *excludes* control power transformers and other small transformers, which are subcomponents in electrical equipment. These small transformers are assumed to be an integral part of the larger component.
> - This bin *includes* all indoor, oil-filled transformers regardless of size.

- This bin *excludes* dry-type transformers with a rating of 45 kVA or less. The bin *includes* all indoor dry-type transformers with a rating greater than 45 kVA.
- This bin *includes* wall-mounted transformers, unless they satisfy the 45 kVA exclusionary criteria immediately above.

6.2.4 Bin 26: Ventilation Subsystems

For Bin 26, Ventilation Subsystems (Plant-Wide Components), the FAQ response indicates that some clarification is appropriate. In particular, the original intent in EPRI 1011989, NUREG/CR-6850 was to exclude ventilation subsystems with very small motors consistent with Bin 14. In this case, the modification is simply a rewording of the existing guidance to make it more consistent with the other related bins. The guidance relative to Bin 26 as provided in Section 6.5.6 is clarified as follows:

> Bin 26 – Ventilation Subsystems (Plant-Wide Components): This bin includes components such as air conditioning units, chillers, fan motors, air filters, dampers, etc. A fan motor and compressor housed in the same component are counted as one component. The total number of ventilation subsystems should be estimated with the following clarification:
>
> - This bin excludes ventilation subsystems (e.g., fans, filter banks, or compressors) driven by an electric motor rated 5 hp or less. The bin *includes* any ventilation subsystem with an electric motor greater than 5 hp.

7
BUS DUCT (COUNTING) GUIDANCE FOR HIGH-ENERGY ARCING FAULTS (FAQ 07-0035)

7.1 Background

FAQ 07-0035 requests clarification regarding the treatment of high-energy arc faults (HEAFs) specific to bus duct failures. Appendix M of the consensus methodology document (EPRI 1011989, NUREG/CR-6850) provides guidance for the treatment of HEAFs in switchgear and load centers, but does not cover the treatment of bus duct fires. Further, while the document mentions bus ducts as a potential source of HEAF events, no fire event frequency or treatment guidance is provided. This FAQ is a split from FAQ 06-0017 (see Chapter 4).

7.2 Resolution

The resolution of FAQ 07-0035 [NRC ADAMS Accession No. ML091620572] states that review of the EPRI fire event database used in the development of EPRI 1011989, NUREG/CR-6850 identified several events involving bus duct arc fault failures. This event set was supplemented by additional nuclear power plant (NPP) fire events identified by the NRC staff as potentially relevant to the bus duct arc fault question. All of the identified events were reviewed for relevance to the topic of this FAQ, and a final set of fire events to be used in calculating fire frequency was identified (see further discussion below). In addition, a public meeting was held (August 2007, ADAMS ML072560081) to discuss the team's preliminary insights and to gain additional input from stakeholders. The proposed resolution is based on, and consistent with, all of the input received from these resources.

7.2.1 Summary

Intended scope of the bus duct analysis:

The guidance provided here applies to any electrical power distribution bus associated with the equipment already identified in Appendix M of EPRI 1011989, NUREG/CR-6850 as subject to HEAF failures and fires. That is, the guidance applies to power distribution buses associated with switchgear, load centers, and motor control centers of 440 V or greater. The guidance also applies to bus ducts associated with turbine generator output (the iso-phase bus), unit main, auxiliary and start-up transformers, and the unit emergency generators and their associated power transformers.

Classification of bus ducts by type:

A review of bus duct physical configurations as typically used in power plant applications has resulted in a recommended practice that would first classify each bus duct as falling into one (and only one) of the following four general categories:

Category 1: Nonsegmented or continuous bus ducts: A bus duct where the bus bar associated with each power phase is comprised of a single length of metal bar connecting two end-devices (e.g., terminating within a cabinet or at a specific piece of electrical equipment) with no intermediate junctions, transitions, or terminations along the length of the bus bars. Typically, the bus bars are wholly contained within a grounded metal enclosure that runs the full length of the distance between the termination points.

- Nonsegmented bus ducts tend to be comparatively short (on the order of no more than 12 feet in length) due to practical limits on the length of a single segment of bus bar. Examples:
  - A bus duct connecting a station service transformer to the associated switchgear cabinets where the transformer and switchgear are located in close proximity within a common fire area.
  - A bus duct connecting two separate banks of load cabinets located in close proximity (e.g., across an intermediate access walkway) and fed from a common power source.

Category 2: Segmented bus ducts: A bus duct where the bus bars are made up of multiple sections bolted together at regular intervals (transition points). Here, the bus bars are contained within open-ended sections of metal covers that are bolted together to form a continuous grounded enclosure running the full distance between termination points. Segmented bus ducts are able to accommodate tap connections to supply multiple equipment termination points.

- Segmented bus ducts tend to be longer in comparison to the nonsegmented bus ducts. Segmented bus ducts are used in cases where the required lengths and/or geometries make the use of nonsegmented bus ducts impractical.
- The length of each segment may vary depending on supplier and installation details.
- Segmented bus ducts tend to connect end devices that are remote from each other. Example: A segmented bus duct might be used to connect an oil-filled transformer located in an outdoor area to equipment (e.g., switchgear) located inside the plant buildings.

Category 3: Cable ducts: A power conductor configuration that provides a function like a bus duct but uses a length of insulated electrical cable in lieu of metal bus bars. Cable ducts may be routed in a variety of ways, not necessarily within continuous runs of metal enclosures.

- Cable ducts can be as long as, or longer than, a segmented bus duct because there is no practical limit to the length of cable that can be obtained and installed.
- Cable ducts may be used in application conditions similarly to either a segmented or nonsegmented bus duct.

Category 4: Iso-phase bus ducts: A bus duct where the bus bars for each phase are separately enclosed in their own protective housing. The use of iso-phase buses is generally limited to the bus work connecting the main generator to the main transformer.

7.2.1.1 Selection of Bus Duct Fire Scenarios

A review of the experience base for all types of bus ducts revealed one common characteristic; namely, that all of the identified bus duct arc fault events occurred either at the termination point of the duct or at a transition point along the length of a segmented bus duct. With the exception of the iso-phase bus ducts (category 4), in those events occurring at the termination point, all had been included in the “high energy arc fault (switchgear and load centers)” or “catastrophic failure (transformers)” event sets for the end devices as fire ignition sources in EPRI 1011989, NUREG/CR-6850. Hence, these events are already accounted for in the methodology and are treated as originating in the end device. Because nonsegmented bus ducts (category 1) and cable ducts (category 3) have no transition points other than the terminations at the end device, no treatment of bus duct faults/fires independent from the treatment of fires for the end devices is required. That is, arc faults for these two categories of bus ducts, 1 and 3, are inherently included in the treatment of the end device, and no further treatment is needed.

A review of available data indicates that events associated with iso-phase bus ducts (category 4) also manifest themselves at the termination points (i.e., the main generator or main transformer), but these events had not been included in the associated end device frequencies. The potential effects of the iso-phase faults also appear unique in comparison to the end device (transformer or exciter) fires as recommended in the existing guidance. Hence, some additional treatment for iso-phase bus duct faults occurring at the termination points is needed. For segmented bus ducts (category 2), a number of the identified fire events were manifested at bus transition points (a point where two segments of the bus duct are bolted together) rather than at the bus termination points. These events were generally attributed to loose bolted connections, to failed insulators, or to the accumulation of dirt/debris/contaminants in the bus duct. The key, however, is that the effects of the fault are manifested at transition points along the bus duct length. Fire scenarios for segmented bus ducts should, therefore, be postulated to occur at duct transition points (i.e., bolted connections). An alternate treatment is provided if the transition points cannot be easily identified based on external inspection.

7.2.1.2 Ignition Source Counting Guidance

Counting guidance: iso-phase bus ducts: For iso-phase bus ducts, there should generally be one iso-phase bus per unit (an iso-phase bus includes all three phases). If there is more than one iso-phase bus, simply count the total number of iso-phase buses per unit. For individual fire scenarios, the plant-wide frequency is applied (i.e., partitioned) equally to each end of each iso-phase duct counted. The plant-wide fire frequency and zone of influence are discussed below.

Counting guidance: segmented bus ducts: The analyst will need to choose between one of two recommended practices for counting segmented bus ducts as a fire ignition source. The choice will be dependent on whether or not the transition points can be identified based on an external visual inspection of the bus duct.

Counting approach 1: If the transition points along the length of the segmented bus duct can be identified by external visual inspection, or based on plant electrical construction drawings, then count the total number of transition points. Note that transition point counting *excludes* the bus end termination points, which are considered a part of the end device for fire frequency purposes. Transition points may be identifiable based on visual observation or review of design drawings. Transition points for the bus bars may, or may not, correspond to junctions in the outer ducting that surrounds the bus bars. It is not intended that the protective duct be removed to identify transition points.

However, industry feedback indicates that the joints or junctions in the outer ducting surrounding a bus duct cannot be assumed to correspond to junctions in the bus bars themselves without confirmation. A representative sample of plant applications should be inspected to ensure that the internal bus bar transition points and external duct junctions do in fact align with each other. Once the total count of transition points has been obtained, the plant-wide fire frequency is then partitioned to a specific location based on the number of transition points in the location of interest divided by the total number of transition points for the entire plant.

Counting approach 2: If the transition points cannot be identified based on external visual inspection, or by plant electrical construction drawings, then the partitioning of fire frequency to a specific fire scenario is based on apportioning of the fire frequency equally along the length of the bus duct. Hence, the analysis must estimate the total length of segmented bus duct present in the plant under analysis. A "per linear foot" fire frequency can then be estimated by dividing the plant-wide fire frequency by the total length of segmented bus duct in the plant.

That is, the fire frequency for a given fire scenario would be based on the ratio of the length of duct for which identified targets fall within the bus duct arc fault zone of influence (see discussion below for a definition of the zone of influence) to the total length of bus duct in the plant. A lower limit to the assumed fire frequency for any given fire scenario is also applied. That is, if the length of bus duct for which the identified target(s) fall within the zone of influence is less than 12 linear feet, then a minimum length of 12 feet should be assumed. This lower bound is based on the assumption that, lacking specific information on segment lengths, a nominal segment length of 12 feet should be assumed. Any single scenario is then assigned a fire frequency equivalent to that associated with one bus bar segment 12 feet in length (i.e., equivalent to one nominal transition point).

Once the count and partitioning values are known, the next step is to develop fire scenarios for analysis. The development of fire scenarios is again expected to follow one of two potential approaches as outlined in the following discussions. The analyst should be aware that the second of these two approaches introduces a degree of uncertainty into the analysis. As noted above, arc faults generally occur at the transition points. When the actual location of the transition points is not known, the approach assumes that a fault might occur at any point along the duct length.

Hence, fire scenarios might be developed for locations where there is, in actuality, no junction point. By the same token, the approach partitions fire frequency equally along the length of the bus duct, whereas in reality faults would be more frequent at the actual (but unknown) transition points. It is recommended that in assessing analysis results, these observations be treated as a part of the uncertainty and sensitivity analyses, and that the analysis be refined for cases where risk-significant fire scenarios develop (i.e., by examining the bus duct to determine if any transition points are actually present in the segment of bus duct associated with a significant scenario). This is discussed further below.

7.2.1.3 Anticipated Analysis Approach for Segmented Bus Ducts

Approach for known transition points: If the transition points for the bus ducts are known, then the approach to analysis would focus on the development of scenarios at those known locations. Note that even when transition points are not known generally, certain locations will represent known transition points based on geometric factors. For example, if a horizontal duct changes direction (i.e., makes a flat or vertical turn) or changes elevation (e.g., a step), that geometric transition would represent a transition point for that bus duct. For known transition points, the analysis should look for fire PRA targets (i.e., fire PRA equipment and cables) within the zone of influence (described below) and postulate scenarios accordingly.

Approach when transition points are not identifiable: In the case where transition points are not in known locations, the approach to analysis is similar but begins by assuming that a fault might occur at any point along the length of the bus duct. In this case, the analyst should trace the path of bus ducts through the plant and identify potential fire PRA targets within the bus-duct arc fault zone of influence (see definition below) at any point along the duct length. The development of fire scenarios would then depend on the relative length of bus duct for which an identified target set lies within the bus duct zone of influence.

- Analysis Approach 1: Potential fire PRA targets are located within the zone of influence for a significant length of duct (greater than the nominal assumed segment length of 12 feet): In this case, an estimate of the scenario fire frequency can be based on the plant-wide fire frequency times the ratio of the length of duct (e.g., linear feet) for which scenario targets lie within the zone of influence to the total length of segmented bus duct in the plant.
- Analysis Approach 2: A target set is identified but lies within the zone of influence for a limited portion of bus duct (i.e., less than the nominal assumed segment length of 12 feet): In this case, an initial analysis should assume that a fault occurs within that segment of the bus duct for which fire PRA targets might be impacted, however long it might be. The fire frequency assigned to the scenario is the minimum fire frequency value calculated based on a minimum 12 foot length of duct.

Note that in either approach, the analysis can always be refined by examining the bus duct to determine if one or more transition points actually lie within the applicable bus duct segment. If no transition points are identified within that particular duct section, then a fault scenario need not be postulated and the scenario “goes away.” If one or more transition points are identified within a particular duct section, then the analysis can be refined based on the known locations (i.e., both the fire frequency and the impacted target set may be refined once transition points are identified).

7.2.1.4 Fire Frequency and Frequency Partitioning

Based on the review of the fire events database, Tables 7-1 and 7-2 list all of the identified “candidate” fire events used to estimate the frequencies for segmented bus ducts and for iso-phase ducts, respectively. The events listed were identified based on a review of the events in EPRI’s Fire Event Data Base (FEDB) and on a similar review of events identified in various NRC documents (information notices, inspection reports, LERs, and staff reports) as provided by the NRC staff. Each event that included a bus duct was reviewed to determine (1) if the event meets the general criteria associated with a “potentially challenging event” consistent with the treatment of other fire ignition sources and (2) if the event was indeed uniquely associated with a bus duct arc fault and consequential fire rather than some other fire ignition source bin.

Table 7-1
Segmented Bus Duct Fire Events Used in Frequency Calculations

FEDB Incident No.	Event Date	Description
195	4/15/80	Fire involved a supply bus located in a switchgear room.
218	8/20/80	A short occurred on the bus work from the RAT to buses 1-1 and 1-2. This caused a reactor trip and turbine trip. Damage to equipment was limited to a 10 foot section of the bus bar. In addition, insulation between the insulated bus bar supports experienced some cracking due to the force of the fault. Several nonsafety-related cables located in a cable tray adjacent to the bus experienced insulation failure as a result of this event. (NOTE: Information in FEDB has been supplemented with information provided in LER 88-001-00.)
575	3/19/87	A fault in a 6.9 kV feeder line to the in-house buses of a unit auxiliary transformer resulted in a fire and explosion outside the building.
678	3/2/88	A section of the bus bar running from the mat to the bus switchgear was badly damaged due to insulation failure and a subsequent fault. During normal operations, a combination of insulation failure, debris accumulation, and possibly water resulted in an electrical fault in a main (4000 AMP) power bed bus bar. Degradation of the electric power feed resulted in a reactor trip. The fault was detected by a phase imbalance (differential current) alarm in the main control room and by reports of smoke in the turbine building basement. The fire brigade was called out. Deenergizing of the bus ended the fire. In addition to damage to the affected bus, several non-safety related cables located in a cable tray adjacent to the bus experienced insulation failure.

Table 7-1 (continued)
Segmented Bus Duct Fire Events Used in Frequency Calculations

FEDB Incident No.	Event Date	Description
922	7/10/87	Insulation on a 4160 V bus bar failed. This condition resulted in a phase to ground fault, which caused extensive damage to the bus bar and a fire. Upon investigation, the equipment operator noticed smoke and fire coming from the vicinity of the electrical bus bar located on the eastern end of the 606' elevation of the turbine building. The bus fire terminated once the transformer was deenergized. A smaller fire was extinguished by the equipment operator when rags and rubber goods on a maintenance cart were ignited by the falling aluminum slag.
2426	5/15/00	An electrical fault occurred on the 12 kV bus bars from UAT to non-vital switchgear, resulting in a fire in the non-vital switchgear room. The fault continued to be fed for 4-8 seconds by the decay of the main generator electrical field during generator coast-down, contributing to catastrophic failure of the bus bars. Security officers reported a fire at UAT 1-1, and operators notified the fire brigade. The fire brigade arrived at the switchgear room and determined that the fire was internal to the switchgear room and not associated with UAT 1-1. Given the large amount of smoke, the fire brigade captain requested off-site fire brigade support. The fire brigade extinguished a small fire in the 12 kV bus duct with a carbon dioxide extinguisher within 17 minutes of arriving at the switchgear room. Post-event inspection revealed that the center 12 kV bus bar was missing for approximately 1 yard, with the two exterior bus bars missing for approximately 6 and 9 inches. The bottom and top of the bus duct was melted for several feet, along with sections of the duct work on the perpendicular 12 kV bus sections at the tee connection. In addition, the fire had burned an approximately 1 foot square hole in the bottom of a second 4 kV bus duct 4 inches above the 12 kV bus duct. Although the 4 kV bus bars and duct were covered with black soot, the only conductor damage was a small piece of metal missing from the center bus bar and one outer bus bar, which the inspectors considered to be indicative of a single phase-to-phase fault. The floor beneath the fault contained a large slag pile, and a great deal of metal had splattered on the face of 12 kV non-vital Switchgear D and E. However, no missiles penetrated the switchgear, and they remained energized throughout the event. Later inspection revealed no internal damage. Smoke patterns on the cabinet doors indicate that plastic components on the cabinet faces (e.g., gauge faces, identifier tags, indicator lamp housings) ignited and burned during the event.
Not in FEDB	5/18/83	Startup bus failed because of a phase B to phase C fault, which propagated to ground. Further investigation revealed several degraded areas in the bus insulation at the support blocks. (See NRC Information Notice 89-64 for information on this event.)

Table 7-2
Iso-Phase Bus Duct Fire Events Used in Frequency Calculations

FEDB Incident No.	Event Date	Description
792	7/15/88	Arcing and fire were observed at a 22 kV iso-phase bus duct due to damaged ground straps and a deteriorated gasket between the cover and the duct.
929	10/9/89	Multiple ground faults caused by aluminum debris in an iso-phase bus duct started a chain of events that led to three separate fires: (1) an oil fire in the 'B' main power transformer, (2) a hydrogen fire under the main generator, and (3) a small oil fire in the generator housing. In addition to site fire brigade, off-site fire departments were contacted to assist.
Not in FEDB	6/18/04	An electrical fault in the one phase of the iso-phase bus lead to a fire near the main transformer at Vermont Yankee.[5] The fire also involved oil leaking from a flange on the main transformer itself and resulted in severe damage to the low-voltage bushing box on top of the main transformer, to the generator PT cabinet in the turbine building, and to the iso-phase bus duct itself.

The resulting set of relevant and potentially challenging events includes 7 events for segmented bus ducts and 3 events for iso-phase bus ducts. Note that, because of its significance, the June 18, 2004, Vermont Yankee iso-phase fire event is included in the frequency calculations. All other frequencies were based on events prior to December 31, 2000. The iso-phase event set, therefore, extends beyond the period covered by the FEDB; hence, the number of plant reactor years was adjusted to reflect plant operations through mid-June 2004 for the iso-phase bus duct case only. Also, it was verified that no other iso-phase bus fires have been reported between January 1, 2001, and mid-June 2004. The resulting plant-wide fire event frequency for segmented bus duct arc fault failures and iso-phase bus duct fires is characterized by the frequency distributions presented in Table 7-3. Note that in calculating fire frequencies, the number of plant reactor years is based on the entire U.S. fleet of light water reactors. That is, it has been assumed that all of the existing plants contribute to the bus duct fire frequency for both segmented and iso-phase events.

Table 7-3
Iso-Phase and Segmented Bus Duct Fire Frequency Distributions

Frequency Bin	Number of Events	Total Reactor Years	5th percentile	50th percentile	95th percentile	Mean	Variance
Segmented Bus Duct	7	2618	3.45E-05	8.51E-04	1.07E-02	3.27E-03	2.03E-02
Iso-Phase Bus Duct	3	2054	3.29E-05	6.79E-04	5.40E-03	1.85E-03	0.0801

[5] Reference: Licensee Event Report (LER) 50-064-2004-003-01, Revision 1, June 14, 2005.

Partitioning of these fire frequencies to specific locations for the segmented bus ducts should be performed in accordance with the counting guidance provided above. That is, each transition point will be assumed to have an equal fraction of the total plant-wide fire frequency.

For the iso-phase bus, partitioning should assume that the likelihood of a fire is equal for each end of the bus (i.e., half of the frequency goes to the transformer end and half to the generator end) and that the initial fault is equally likely to occur in any one of the three phases (i.e., the fault initiates in one of the three phases, not all three concurrently).

7.2.1.5 Estimating the Initial Fault Zone of Influence

Zone of influence for segmented (non-iso-phase) bus duct fires

The zone of influence for a segmented bus duct arc fault fire is considered unique from that assumed for electrical cabinets. The experience base illustrates that the bus duct events generally involved a pool of molten conductor and possibly burning insulation materials that forms within and then burns through the lower surface of the bus duct enclosure itself. This material spills out of the bus duct, may form a molten pool of metal on the floor or objects below, may splatter onto other nearby surfaces, and may ignite any combustible or flammable materials contacted. The recommended zone of influence is intended to reflect this experience base. For reference, one well-documented event considered prototypical of a bus duct fire occurred at Diablo Canyon on May 15, 2000.[6] Figures 7-1 and 7-2 provide photographs taken after this event (as provided in the cited inspection report—see footnote). Note the damage visible to the face panels on cabinets located below and to the side of the fault point. The photos show clear evidence (soot traces) that the surface-mounted components (e.g., the dial indicators, labels, switches, etc.) ignited and burned. Individual points of charring on the panel face are taken as indicative of impinging molten metal droplets. The exterior surfaces of cabinets on both sides of the access walkway directly below the primary faulting point were damaged. The fire did not extend to the interior of these cabinets. Surface damage occurred on cabinets on both sides of the aisle-way directly below the fault point, and extended to three adjacent panels on each side of the aisle. Based on the observed behavior, the recommended zone of influence for a segmented bus duct fire is as follows:

- Assume that the effects of the bus duct fault will be manifested at a transition point (the fault point). Recall that failures at end point terminations are captured under the end point equipment.
- The following zone of influence is assumed to originate from a point at the center of the bus duct at the assumed transition point location.
  - Assume that molten metal material will be ejected from the bottom of the bus duct below the fault point and will spread downward, encompassing the shape and volume of a right

[6] References: (1) U.S. NRC Information Notice 2000-14, "Non-Vital Bus Fault Leads to Fire and Loss of Offsite Power," 9/27/2000 and (2) U.S. NRC Diablo Canyon Inspection Report No. 50-275/00-09; 50-323/00-09, July 31, 2000.

circular cone whose sides are at an angle of 15° from the vertical axis (a total enclosed solid angle of 30°).

– Assume that molten metal material will also be ejected outwards and will spread within a sphere of 1.5-foot radius from the fault point. The fault point to be used when applying the 1.5-foot radial damage distance is the cross-sectional center of the bus duct.

– The cone will expand (height allowing) to a maximum diameter of 20 feet. Beyond this point, the burning materials will fall straight downward in a cylindrical shape. Note that the maximum expansion zone for the cone (20-foot diameter) corresponds to a distance 37 feet below the point of origin.

– Assume that any exposed combustible or flammable materials within this cone-shaped and spherical zone of influence will be ignited. Combustible/flammable materials will not be considered exposed if they are protected by a fire-rated raceway wrap, conduit, or solid steel panels. Specific examples of the recommended treatment of exposed versus non-exposed materials are as follows:

  - The solid metal side panels of a cabinet *will* prevent ignition of the combustible/flammable materials inside the cabinet.
  - For cabinets with a solid steel top where all cable or conduit penetrations are sealed (e.g., consistent with the guidance provided in EPRI 1011989, NUREG/CR-6850, Chapter 11, with respect to the propagation of fires out of an electrical panel), molten material deposited on top of the cabinet *will not* burn through the panel top.[7]
  - For cabinets with a ventilated top or unsealed cable or conduit penetrations, molten material deposited on top of the panel *will* penetrate into the panel and ignite the contents if the openings are within the zone of influence.
  - Open ventilation sections on cabinet side panels that are made up of an open mesh or screen section *will* allow the penetration of molten material into the cabinet if the openings are within the zone of influence.
  - For cabinet side panels or doors that include louvered ventilation openings where the louvers point downwards to the outside of the panel, molten material deposited on the surface of such panels *will not* penetrate into the cabinet. Cables in open-top cable trays *will* be ignited if they are within the zone of influence.
  - Cables in conduit *will not* be ignited by molten materials deposited on the outer conduit surface if the open ends of the conduit are located outside the zone of influence.
  - Cable in trays that are equipped with unventilated steel covers *will not* be ignited by molten metals falling from above.

[7] Note that, relative to this particular point of guidance, it is the judgment of the authors that even the minimum thickness of a typical steel cabinet top panel as employed in practice by manufacturers will be sufficient to prevent burn-through of the molten material ejected from a bus duct. The guidance specifically excludes credit for aluminum panels.

- Cables in trays that are equipped with aluminum covers of any kind, or with ventilated steel covers, will be ignited by molten metals falling from above.
- The first solid surface encountered by the material ejected from the bus duct will truncate the zone of influence along that line of travel. (Examples include: where the zone of influence intersects the floor, a sealed cabinet top, or a cable tray with a solid metal cover, it does not extend through that surface to other targets or flammable material beyond).

- Damage and ignition within the initial zone of influence occurs at time zero (concurrent with the initial fault), but the ensuing fire can be assumed to develop over time from a point ignition origin (e.g., a cable tray should be assumed to ignite at one point, not over its entire exposed length).
- Subsequent analysis of fire development, fire detection, and fire suppression response follow the same practices as applied to high-energy arc faults for switchgear and load centers. In particular, that manual fire brigade response curve applicable to high-energy arc faults for switchgear also applies to bus duct faults.

Figure 7-1
Photograph of the point on the bus duct.
The photograph shows where the arcing fault at Diablo Canyon was manifested (the fault point). Note that the tops of the cabinets to the left and right (the cabinets to the left are shown in Figure 7-2) are visible in the lower corners of this photograph.

Figure 7-2
Photograph of the surface damage and burning.
The photograph shows damage observed for the more heavily impacted cabinets on one side of the aisle-way below the fault point (the cabinet to the left as seen in Figure 7-1).

Zone of influence for iso-phase duct fires

For the iso-phase bus duct fires, it is recommended that the zone of influence should assume damage to any component or cable that would normally be considered vulnerable to fire damage (i.e., excluding items such as water-filled piping that would not normally be considered vulnerable to fire damage) located within a sphere centered on the fault point and measuring 5 feet in radius. Any flammable or combustible material within this same zone of influence should be assumed to ignite. The recommended zone of influence is intended to cover both the initial fault effect and the potential burning of hydrogen gas[8] that may be released at low pressure from the bus casing upon rupture. An enduring fire (i.e., lasting beyond the initial fault) should be assumed consistent with the nature of any flammable or combustible materials present within the zone of influence and potential fire spread beyond the zone of influence.

For the case of fires occurring at the main transformer termination points, the potential for involvement of the main transformer (and its oil) should be considered. In particular, the electrical lines will each penetrate the casing of the transformer, and this could allow the fire to spread to the transformer itself. Failure of the electrical penetration seals (e.g., melting of a rubber boot) could also create a path for oil leakage outside the transformer as was observed in the Vermont Yankee event.

[8] Iso-phase bus ducts are generally filled with hydrogen gas at low pressure to enhance both cooling and electrical isolation. Upon rupture the hydrogen gas will leak from the duct, but neither a jet fire nor an explosion are anticipated due to the initial rupture.

The analysis should also consider the potential for involvement of additional hydrogen gas beyond that which will leak from the casing as a result of the initial fault. That is, the configuration of, and potential failure in, the hydrogen purge/fill system should be evaluated to determine if additional leakage of hydrogen gas is plausible. This assessment will require consideration of case-specific storage, piping, and valve arrangements.

8
FIRE PROPAGATION FROM ELECTRICAL CABINETS (FAQ 08-0042)

8.1 Background

Text in Appendix G (Section G.3.3) of EPRI 1011989, NUREG/CR-6850 indicates that a fire in an unvented electrical cabinet does not propagate beyond the cabinet. More comprehensive language in Chapter 11 (Section 11.5.1.7.3) provides additional requirements on cabinet construction for those cabinets that do not propagate fires. In particular, Chapter 11 also requires that electrical cabinets have fire-sealed penetrations and be robustly secured for no propagation to occur beyond the cabinet. The bin 15 discussion in Chapter 6 provides information on definition of “robustly secured” as well. This clarification is not related to electrical cabinets for the purposes of high-energy arcing faults, as those faults counted in Appendix M for purposes of developing fire frequency are all assumed to breach the cabinet.

The guidance provided in Appendix G for the screening of fire propagation from “unvented” electrical cabinets appears to conflict with the guidance provided in Chapters 6 and 11 of the main body. Clarification is needed. Portions of the text in Appendix G, Section G.3.3, were an unintended carryover from the original *Fire PRA Implementation Guide* (EPRI TR-105928) and were not modified to reflect the EPRI/RES team’s consensus. The alternate discussion provided in Chapter 11 represents the consensus positions.

Appendix G (Section G.3.3) provides a general discussion of the effects of venting on fire development and fire propagation for electrical cabinets. In most regards, the discussions are correct. In particular, cabinet venting is important to the development of fires in an electrical cabinet. The point where the discussion deviates from the team consensus developed as a part of the methodology is where it discusses the potential for fire propagation outside the cabinet for a cabinet that is not vented.

In order to achieve closure of this FAQ in a timely manner, the NRC developed a draft interim staff position, as discussed below [NRC ADAMS Accession No. ML092110537]. This position was developed using currently existing information, databases, and experimental results, and should not be seen as prejudicing the NRC’s view of future developments in this area.

8.2 Resolution

The wording provided in Appendix G relative to the potential for fire spread beyond the boundaries of an unvented cabinet should be disregarded. The wording provided in Chapter 11 relative to fire propagation from electrical cabinets is the intended and correct guidance. (Specific citations are provided below.) Specifically, those portions of the second paragraph in Section G.3.3 that read as follows should be disregarded:

> Electrical cabinets that are not vented do not propagate a fire. … It is assumed that in the absence of other ventilation *(other than those listed in Table G.3)*, penetrations will not allow sufficient air exchange to replace oxygen consumed by the fire, and an incipient fire will self-extinguish when there is no longer enough oxygen to support combustion. [Italics added for clarity.]

Also, the final sentence of the third paragraph in Section G.3.3., which reads as follows, requires some clarification:

> … Therefore, air exchange through the top penetrations for typical NPP cabinet configurations listed above is not expected to be sufficient to support combustion.

This latter discussion is correct but incomplete. The fundamental factor not addressed by the wording in both of these citations is that, once a fire starts inside an electrical cabinet, uneven heating of the cabinet side/top panels and door(s) will take place. This uneven heating can cause these elements to warp unless they are "robustly secured" as discussed in Chapters 6 (under the Bin 15 discussion) and 11. Warping will in turn create new openings for the passage of air into and out of the cabinet. The observation of this behavior and its impact on fire growth behavior was a major finding of the Mangs/Keski-Rahkonan (VTT Finland) tests which are also discussed (and cited) in Appendix G.

In lieu of the wording from Appendix G, analysts should screen electrical cabinets for fire propagation potential based on the following guidance from Chapter 11 (Section 11.5.1.7.3, Step 7.a.3):

> In the case of electrical panels, the panel ventilation configuration and the latching configuration of the doors are important. If the panel contains open vents, either at the top or bottom of the pane, or if penetrations into the top or sides of the panel are not fire-sealed, fires can be assumed to be capable of spreading out of the panel to secondary combustibles. However, for un-vented cabinets, fire spread may be less likely. Fire spread out of the panel may still occur, unless the panel doors are attached and anchored at multiple points. Simple twist-handle style top-and-bottom door latches are not sufficient to contain a fire within a panel. Substantial warping of the door face may occur due to the heat of the fire. This can allow gaps to open in an otherwise un-vented panel. In contrast, fire spread is not considered likely given a weather-tight or waterproof cabinet construction where multiple mechanical fasteners secure panel access plates and where all penetrations into the panel are sealed.

As a point of clarification, it should be noted that in the above description on penetrations, the term “fire-sealed” was not intended to imply “fire-rated.” Rather, the intent was that penetrations into a cabinet would be sealed such that they would not readily allow for the passage of air.

This clarification has the potential to impact the preliminary fire modeling and screening analysis for fire propagation from electrical cabinets (fire ignition source Bin 15). If the potential for fire propagation outside any given cabinet was dismissed based on the guidance provided in Appendix G, then the screening results for these cabinets, and these cabinets only, should be reconsidered based on the guidance provided in Chapter 11.

This clarification should not require any reconsideration of the original fire ignition source counting results, provided the guidance in Chapter 6 was followed.

9
MAIN FEEDWATER PUMP OIL SPILL FIRES (FAQ-08-0044)

9.1 Background

FAQ 08-0044 was proposed by the Nuclear Energy Institute (NEI), through its NFPA 805 Task Force, to clarify the guidance from NEI 04-02, "Guidance for Implementing a Risk-Informed, Performance-Based Fire Protection Program under 10 CFR 50.48(c)," which in turn cited guidance on modeling oil spill fires as provided in EPRI 1011989, NUREG/CR-6850, "EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities," as appropriate for use in developing fire probabilistic risk assessments (PRAs). The authors believed that the guidance on oil spill fires cited in EPRI 1011989, NUREG/CR-6850 did not specifically address such fires from main feedwater (MFW) pumps and that, when applied to MFW pump oil spill fires, could lead to misrepresentative estimates for both the ignition frequency and severity factor (in terms of size of oil spill) that could subsequently yield overly conservative estimates of risk when used generically in fire PRAs. Initial analyses were performed under the Memorandum of Understanding (MOU) between the Electric Power Research Institute (EPRI) and Office of Nuclear Regulatory Research (NRC-RES), but were not concluded prior to EPRI publication of EPRI 1016735, "Fire PRA Methods Enhancements: Additions, Clarifications, and Refinements to EPRI 1011989," in December 2008 [7]. In order to achieve closure of this FAQ in a timely manner, the NRC developed a draft interim staff position, as discussed below [NRC ADAMS Accession No. ML092110516]. This position was developed using currently existing information, databases, and experimental results, and should not be seen as prejudicing the NRC's view of future developments in this area. The NRC concurs with use of this analytical approach as an interim method for assigning frequency and severity of MFW pump oil spill fires.

9.2 Resolution

Early applications of EPRI 1011989, NUREG/CR-6850 guidance to the specific case of MFW pumps have led to anomalous results. Given the large quantity (several hundred gallons) of oil found in a typical MFW pump, even assignment of the "small fire" severity level (i.e., 10% of the oil) in EPRI 1011989, NUREG/CR-6850 leads the analyst to postulate a fire that is actually very severe, with a frequency higher than indicated by industry experience. Depending on the fire PRA components and cables near a MFW pump, the postulated fire scenarios can be risk significant.

The guidance mentioned above was not developed with high-volume oil systems in mind, but rather, was aimed primarily at smaller-volume pump lubrication systems. Revised guidance has been developed specifically for MFW pump oil fires to more accurately represent industry experience regarding such fires.

Introduction and Problem Statement

Appendix E, Section E.3, of EPRI 1011989, NUREG/CR-6850 provides guidance for the treatment of oil spill fires as follows:

> The following steps are recommended for assigning the severity factor to scenarios involving oil spill fires:
>
> 1. Determine the amount of oil that can be spilled in the room.
> 2. Assign a severity factor of 0.02 to a scenario consisting of 98% or more of the amount of oil spilled and ignited.
> 3. Assign a severity factor of 0.98 to a scenario consisting of 10% of the amount of oil spilled and ignited.

Figure 9-1 provides a qualitative depiction of this guidance assuming that the amount of oil represents fire severity. The severity curve is divided into two parts: “small,” represented by 10% of the oil, and “large,” represented by 98% of the oil.

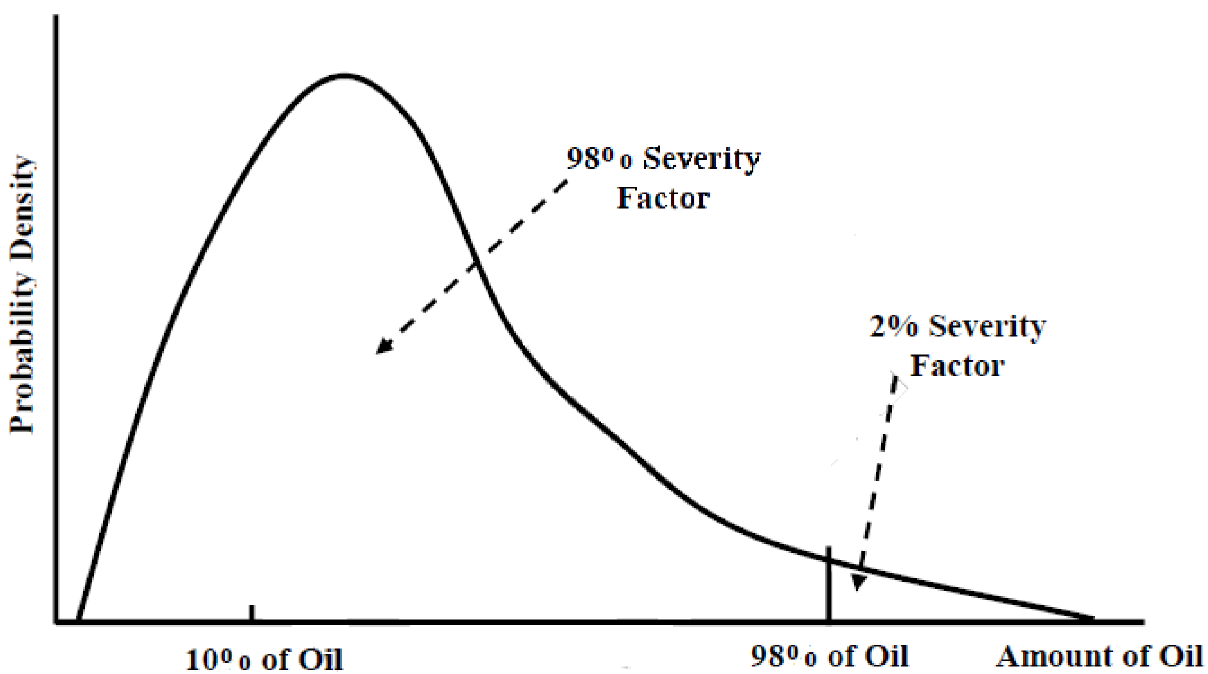

Figure 9-1
Oil fire severity factor guidance

Basis for the MFW Pump Oil Fire Revised Guidance

A similar partitioning approach toward fire severity is followed as documented in the original guidance, except that three severity levels are now defined instead of just two to reflect that (1) most MFW pump fire events had limited effect on the surrounding items and (2) none of them involved a large quantity of the pump lubricating oil. The three levels attempt to capture this experience and the potential for severe impact that can be experienced from an uncontrolled MFW pump oil spill. This is shown qualitatively in Figure 9-2 below.

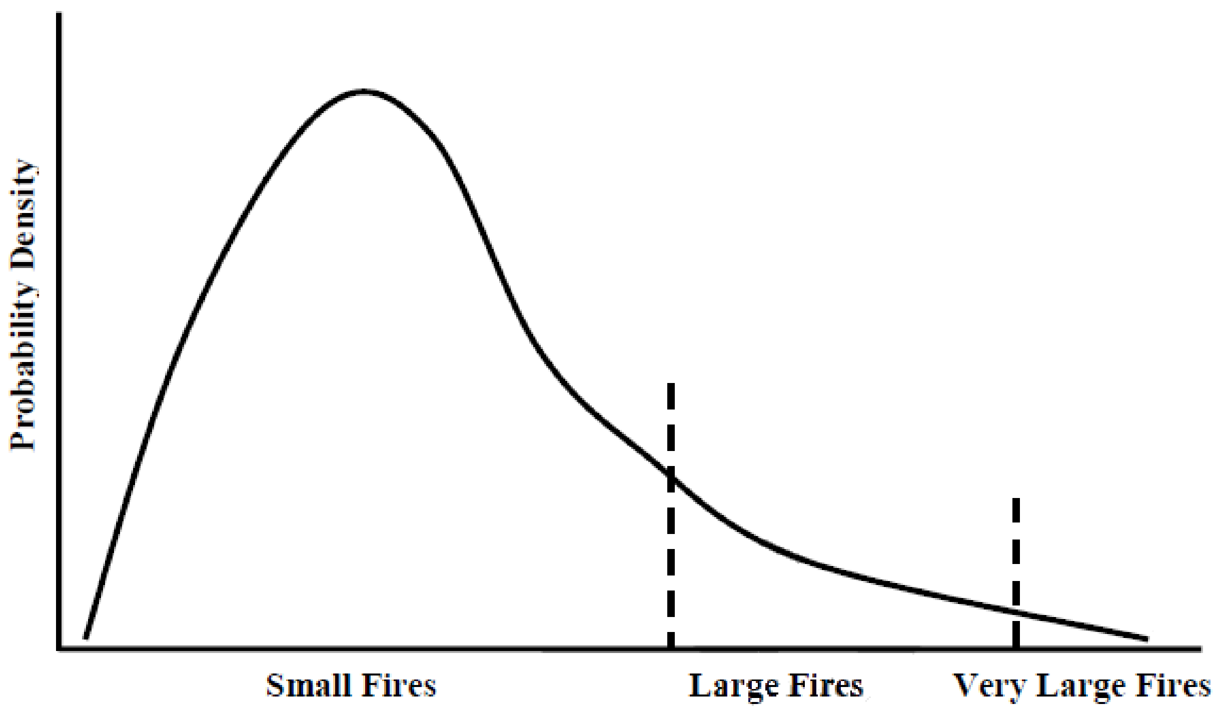

Figure 9-2
Main feedwater pump oil fire severity factors

The three severity levels are defined as follows:

- Small fires are defined as fires involving small oil leaks leading to the ignition of oil-soaked insulation on piping and equipment. These fires will involve a fraction of the oil inventory smaller than assumed in the following fire sizes. Fire damage is expected to be limited to the MFW pump.
- Large fires are defined as fire events involving a spill of 10% of the oil content (consistent with the small fire category in the original oil spill severity factor guidance as cited above).
- Very large fires are fire events that involve a spill of up to 100% of the oil inventory (again consistent with the large fire category in the original guidance as cited above).

Available fire modeling tools should be used to establish cable damage for large and very large fire sizes.

As described further below, all of the MFW pump fire events from the fire events database (FEDB), as referenced in EPRI 1011989, NUREG/CR-6850, fell into the category of small fires. None of these events included reports of damage to anything other than the burning insulation itself. However, some of the event reports state that open flaming was observed in the area of the burning insulation. These observations clearly indicate that some potential existed for fire spread to combustible materials or failure of fire PRA targets susceptible to fire damage had these been near the burning insulation.

The intent of the recommended approach is to ensure that the potential for fire spread or fire PRA target damage is considered based on scenario-specific conditions.

The next question that must be answered is the relative likelihood that, given a MFW pump oil leak/spill, the quantity of oil released would be equivalent to each of the three severity levels defined above (i.e., the severity factor or split fractions for small, large, and very large fires). This assessment is based on a review of the MFW pump oil fires identified in the FEDB. Table 9-1 provides the main feedwater pump-related fire events in the FEDB that involved oil. Fifteen fire events are presented in this table. Of these 15 events, 12 events were labeled as “challenging” and three as “undetermined” in the original fire frequency analysis.

Very large oil spills and fires have occurred, but only involving main turbine oil systems and not MFW pump oil systems. Given that larger oil spills have occurred in other plant lubrication systems, the possibility of such a spill from the MFW pump lubrication system cannot be entirely dismissed. Reviewing the event descriptions of all 15 MFW pump fire events, it was concluded that 10 events have sufficient information available to conclude that they were small fires that remained confined to the pump or nearby piping (e.g., oil-soaked insulation). In these 10 fire events, there was no reported damage to items above or adjacent to the location of the fire. Insufficient information is available to establish the severity of five of the events. However, it can be argued that if any of these five events were of the type classified here as either large or very large fires, then additional attention would have been expended in documenting the event (e.g., a more complete description would have been provided). Therefore, it can be inferred that these five events were also small fires.

Since EPRI 1011989, NUREG/CR-6850 uses only at-power operation fire events for estimating the frequency of MFW pump fires, one may conclude that no large or very large MFW oil fires have taken place during power operation. Using the counting approach of EPRI 1011989, NUREG/CR-6850, there were 12 challenging and three undetermined events (counted as 0.5 each) for a total of 13.5 fire events with no large or very large fires. From these statistics we can conclude that the conditional probability of a large or very large fire given a MFW pump oil fire is 0.5/14.5 = 0.034, or 3.4% (using Jeffreys’ approach).

Thus, one can conclude that 0.034 (3.4%) represents the fraction of MFW pump oil spills/fires that would be considered large or very large per the definitions given above. As noted above, none of the MFW pump fire events could be labeled as a very large spill/fire. The recommended estimate recognizes that very large spills would occur, but with a lower probability than large spills, and assumes that 10% of the large or very large spills/fires would actually be very large spills/fires. This yields a net severity factor of 0.0034 (0.34%) for the very large fire case.

Summary of Recommended MFW Pump Oil Fire Revised Guidance

The following steps are recommended for assigning the severity factor to scenarios involving MFW pump oil fires:

1. Determine the amount of oil available in the system for the large and very large oil spill fires.
2. The MFW pump oil fire plant-wide fire frequency remains unchanged.
3. Assign a severity factor of 0.0034 (0.34%) to *very large fires:* scenarios involving 100% of the total oil inventory spilled and ignited.
4. Assign a severity factor of 0.0306 (3.06%) to *large fires:* scenarios involving 10% of the total oil inventory spilled and ignited.
5. Assign a severity factor of 0.966 (96.6%) for *small fires:* scenarios involving a leak that leads to a fire that only impacts the MFW pump.

If either the very large or large fire scenario is found to be risk significant, the analyst may conduct a plant-specific analysis of the oil-containing devices/systems to identify various spill scenarios with the corresponding quantity of oil spilled and size of burning oil pool.

Table 9-1
FEDB Events Involving Main Feedwater Pump Oil

Incident No.	Date	Description	Challenging / Power	Leak / Spill
8	19-Aug-70	Fire resulted when oil leaking from a pump-motor reservoir, through a temporary insulation crack, contacted hot pipe (520°F) and vaporized. This caused flashing when contacting ventilation air.	Challenging / At Power	Leak
24	13-Sep-72	A leak in the oil supply line to the feedwater pump soaked insulation on the feedwater supply line, and ignition occurred when oil came in contact with a hot pipe. Fire was quickly extinguished with dry chemical. As piping insulation was removed after fire (30 min), several flare-ups occurred, which again were quickly extinguished. Fire brigade response was prompt (< 5 min).	Challenging / At Power	Leak
201	22-Apr-80	A smoldering fire resulted from lube oil that leaked from a main turbine shaft-driven feedwater pump onto piping insulation.	Challenging / At Power	Leak

Table 9-1 (continued)
FEDB Events Involving Main Feedwater Pump Oil

Incident No.	Date	Description	Challenging / Power	Leak / Spill
476	26-Jun-85	At 2126 hours on June 26, 1985, Waterford 3 Steam Electric Station was at 91 percent reactor power when operations personnel received information of a fire in feedwater pump A. At 2131 hours the control room was informed by personnel on the scene that the B feedwater pump, rather than the A pump, was on fire. Since the A pump was already secured, and since the steam generator water levels were decreasing, operation personnel tripped the main turbine and reactor. The fire was extinguished by plant personnel at 2136 hours. The fire was started by a small oil leak, and it was limited to a small portion of the outer wrapping of insulation on the feedwater piping.	Challenging / At Power	Unknown
477	29-Jun-85	On June 29, 1985 at 0957 the reactor was manually scrammed and the main turbine manually tripped due to a fire in the reactor feedwater pump 1B, while the remaining reactor feedwater pump was secured for maintenance. The fire was extinguished and the plant shut down in an orderly fashion.	Challenging / At Power	Unknown
662	08-Jan-88	While performing routine rounds, an equipment operator observed smoke being emitted from the 2C Reactor Feed Pump (RFP) discharge piping. As it was initially suspected, an oil leak was causing the smoke. The fire was extinguished using fire extinguishers and fire water.	Challenging / At Power	Leak
737	29-Jul-88	As a result of maintenance activities, oil-soaked lagging and paper was ignited by the hot surface of Feedwater Pump A suction pipe.	Challenging / At Power	Leak
739	30-Jul-88	Walking by Steam Generator Feedwater Pump A, plant personnel noticed smoke rising from the outboard pump bearing area, and immediately contacted the control room. The fire brigade commenced attack from the feedpump platform, but were unable to determine the effectiveness of the attack due to the steam rising from the pump casing. They redirected their attack from the bottom of the feed pump, putting the fire out in its incipient stage.	Challenging / At Power	Leak
824	13-Jul-92	A fire was reported at the "B" reactor feed pump; the cause may have been due to oil-soaked insulation; the fire was extinguished in about 15 minutes.	Challenging / At Power	Leak

Table 9-1 (continued)
FEDB Events Involving Main Feedwater Pump Oil

Incident No.	Date	Description	Challenging / Power	Leak / Spill
961	11-Aug-91	Event occurred on August 11, 1991. At approximately 08:55 a fire was reported in the turbine building. The plant was at power operation. The fire was reported to be approximately 18 minutes in duration. The fire was detected and extinguished by the fire brigade. This fire was extinguished by using water and carbon dioxide. The fire apparently originated from oil-soaked insulation resulting from a lubrication oil leak. The root cause of this event was turbine bearing lube oil leaking from the flange gasket of the ground brush assembly. This saturated the surrounding insulation with oil, which fueled the fire once ignited. A ground wire was pinched between the gasket and the flange, creating a leak path.	Challenging / At Power	Leak
1110	02-Feb-90	–	Undetermined / At Power	Unknown
1240	11-Sep-76	Oil-soaked insulation was smoldering. An air hose was being used to remove smoke from room to find its source. The air caused the insulation to flame.	Undetermined / At Power	Leak
2183	13-Sep-76	–	Undetermined / At Power	Unknown
2388	16-Dec-93	Ref. SOS 93-2116	Challenging / At Power	Unknown
2422	24-Aug-00	Residual lubrication oil caught fire on the B reactor feed pump. The fire was in the area of the outboard pump bearing. The fire was controlled with portable extinguishers and completely extinguished using less than 200 gallons of water from a hose line.	Challenging / At Power	Leak

10
FIRE IGNITION FREQUENCY (FAQ 08-0048)

10.1 Background

FAQ 08-0048 was proposed by the Nuclear Energy Institute (NEI), through its NFPA 805 Task Force, to clarify the guidance from NEI 04-02, "Guidance for Implementing a Risk-Informed, Performance-Based Fire Protection Program under Title 10 of the Code of Federal Regulations Part 50 (10 CFR 50.48(c))," which cited the fire ignition frequencies as provided in EPRI 1011989, NUREG/CR-6850, "EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities," as appropriate for use in developing Fire Probabilistic Risk Assessments (PRAs). NEI believed that the fire events data cited in EPRI 1011989, NUREG/CR-6850 could be reinterpreted as supporting reduced frequencies, for the most part, for various fire bin ignition categories subsequent to approximately 1990. Initial analyses were performed under the memorandum of understanding (MOU) between the Electric Power Research Institute (EPRI) and Office of Nuclear Regulatory Research (NRC-RES), but were not concluded prior to EPRI publication of EPRI 1016735, "Fire PRA Methods Enhancements: Additions, Clarifications, and Refinements to EPRI 1011989," in December 2008 [7].

10.2 Resolution

EPRI 1016735 included the analysis completed to date for FAQ 08-0048, considered by the NRC as necessary but not yet sufficient to formally close out this FAQ. In order to achieve closure of this FAQ in a timely manner, the NRC has incorporated the EPRI-1016735 analysis into a draft interim NRC position, as discussed below [NRC ADAMS Accession No. ML92190457]. This draft interim position should not be seen as prejudicing the NRC's view of future developments in this area. NRC-RES and EPRI, under the MOU, are updating the fire events database from EPRI 1011989, NUREG/CR-6850 to be inclusive through the year 2008, and establishing a process for subsequent periodic updating. Subsequently, NRC-RES and EPRI will be in a position to complete confirmatory analysis to update the fire bin ignition frequencies in EPRI 1011989, NUREG/CR-6850.[9]

Chapter 2, "Fire Ignition Frequency," and Appendices A and B, "Statistical Methods" and "Fire Ignition Data and Results Details," of EPRI 1016735, "Fire PRA Methods Enhancements: Additions, Clarifications, and Refinements to EPRI 1011989," document the analysis performed by EPRI to revise, for the most part, the fire bin ignition frequencies cited in EPRI 1011989,

[9] Upon successful completion, NRC-RES and EPRI will issue a joint report and eventually revise NUREG-CR-6850, EPRI 1011989 to establish new frequencies for the fire bin ignition categories.

NUREG/CR-6850, for subsequent use in performing fire PRAs for NFPA-805 transitions, as per guidance in NEI 04-02, "Guidance for Implementing a Risk-Informed, Performance-Based Fire Protection Program under 10 CFR 50.48(c)." At the time of publication of EPRI 1016735 (December 2008), NRC-RES, through the MOU with EPRI, was awaiting confirmatory analysis by EPRI that the revised fire bin ignition frequencies cited in EPRI 1016735 using the existing fire events data through year 2000 from EPRI 1011989, NUREG/CR-6850 could be considered applicable today. This confirmation would consist of analysis of more recent fire events data (i.e., subsequent to year 2000) to statistically verify that the revised frequencies subsequent to approximately 1990 could still be considered valid once data beyond year 2000 were incorporated. Since EPRI 1016735 was published prior to completion of this confirmatory analysis, the NRC was unable to reach closure of this FAQ through the formal process.

Nonetheless, to achieve closure of this FAQ in a timely manner, the NRC establishes the following interim position with regard to the use of the new fire bin ignition frequencies in EPRI 1016735, Chapter 2, Table 2-2, "Updated Bin Frequencies and Statistical Parameters (Individual Bins)." The NRC accepts use of these revised fire bin ignition frequencies for fire PRAs conducted for NFPA-805 transition for best-/point-estimate calculations of fire risk (core damage frequency [CDF] and large early release frequency [LERF]), including delta-risk values from plant change evaluations, with the following provision. The fire PRA, including plant change evaluations, must also evaluate the sensitivity of the risk and delta-risk results to evaluations performed using the current fire bin ignition frequencies[10] in EPRI 1011989, NUREG/CR-6850, Chapter 6, "Fire Ignition Frequencies," Table 6-1, "Fire Frequency Bins and Generic Frequencies," and Appendix C, "Determination of Generic Fire Frequencies," Table C-3, "Generic Fire Ignition Frequency Model for U.S. Nuclear Power Plants."[11] For those cases where the results from this sensitivity analysis indicate a change in the potential risk significance associated with elements of the fire PRA or plant change evaluations that affects the decisions[12] being made (e.g., what is acceptable with the new frequencies from EPRI 1016735 might not be

[10] The sensitivity analyses should be performed for a fire ignition frequency bin using the mean of the fire ignition frequency bins contained in NUREG/CR-6850. Furthermore, sensitivity analyses only need to be performed for those bins characterized by an alpha from the EPRI 1016735 analysis that is less than or equal to 1. Note that an alpha value less than or equal to 1 is characteristic of a reverse-J shaped probability density function, i.e., the same shape as the non-informative prior distributions used in EPRI 1016735. This reverse-J shape is indicative of the large uncertainty in the bin fire frequency due to the sparsity of data for that bin, and therefore, the potential for significant changes should the post-2000 fire event data differ significantly from the 1991-2000 data. The required sensitivity analysis is, for the purpose of this interim solution, judged to provide an adequate indication of the effects on risk and delta-risk in such a case. Note also that a sensitivity analysis need not be performed for Bin 9 (Air Compressors); the alpha value in Table 2-2 of EPRI 1016735 appears to be in error.

[11] As modified to address any FAQs related to fire ignition frequencies that were closed out prior to issuance of EPRI 1016735, (e.g., FAQ 06-0017, "Guidance for Counting High-Energy Arcing Faults [HEAFs]" [ADAMS Accession No. ML072500300]), and any similarly related FAQs that may subsequently be closed out (e.g., FAQ 07-0035, "Bus Duct Counting Guidance for High Energy Arcing Faults" [ADAMS Accession No. ML091620572]).

[12] The portion of the fire PRA supporting the decisions may be very focused for analyses associated with many fire protection features and systems. For example, a fire barrier may be subject to failure by a single type of fire ignition source or a fixed suppression system may be protecting a single type of ignition source. As a result, sensitivity analyses of all relevant ignition source bins may only require examination of a single (or few) ignition source bin(s) for a particular decision.

acceptable with the current applicable set from EPRI 1011989, NUREG/CR-6850), the licensee must address this situation by considering fire protection, or related, measures that can be taken to provide additional defense in-depth.[13]

Under the MOU, NRC-RES and EPRI are updating the fire events database from EPRI 1011989, NUREG/CR-6850 to be inclusive through the year 2008, as well as establishing a process for subsequent periodic updating. Therefore, NRC-RES and EPRI will be in a position to complete the confirmatory analysis for the new fire bin ignition frequencies in EPRI 1016735. Upon successful completion, NRC-RES and EPRI should jointly revise EPRI 1011989, NUREG/CR-6850, to establish new frequencies for the fire bin ignition categories, eliminating the need for the specific sensitivity analysis cited here.

10.2.1 Impact on Current Fire PRA and FAQ Implementation Plan

1. The current PRA analysis should replace the frequency values used with the following for best-/point-estimate calculations of fire risk (core damage frequency [CDF] and large early release frequency [LERF]), including delta-risk values from plant change evaluations, with provision (2) below:

Bin #	Mean Frequencies	5% Bound	95% Bound	Alpha	Beta
1	3.26E-04	1.28E-06	1.25E-03	0.5	1534
2	2.35E-03	2.75E-04	6.11E-03	1.5	639
3	2.34E-03	3.20E-04	5.89E-03	1.655	708.4
4	8.24E-04	4.23E-05	2.47E-03	1	1212.9
5	1.25E-03	2.64E-04	2.83E-03	2.32	1856.4
6	2.46E-03	5.00E-04	5.65E-03	2.235	906.73
7	4.81E-03	1.90E-03	8.80E-03	5.03	1045.1
8	5.04E-03	2.10E-03	9.02E-03	5.5	1091.1
9	4.65E-03	1.83E-03	8.51E-03	0.5	1075.3
10	1.18E-03	1.38E-04	3.07E-03	1.5	1271.9
11	9.43E-04	4.84E-05	2.82E-03	1	1060.5
12	1.32E-03	1.55E-04	3.43E-03	1.5	1137.8
13	4.20E-04	1.65E-06	1.61E-03	0.5	1189.9
14	3.41E-03	1.16E-03	6.61E-03	4	1173.6
15.1	2.36E-02	5.36E-03	9.40E-02	0.453	19.16
15.2	1.06E-03	1.24E-04	2.75E-03	1.5	1419.3

[13] It is recognized that there is some degree of subjectivity in this determination, which may require consensus between the licensee and NRC on a plant-specific basis. Such a change need not necessarily result in a risk increase; A change in the risk profile (e.g., dominant fire scenarios, etc.) could also affect the decisions being made. Also, defense-in-depth measures should be commensurate with any potential increase in risk significance (e.g., as per RIS 2005-07, “Compensatory Measures to Satisfy the Fire Protection Program Requirements” (ADAMS Accession No. ML042360547)).

Bin #	Mean Frequencies	5% Bound	95% Bound	Alpha	Beta
16.1	1.27E-03	1.49E-04	3.31E-03	1.5	1200.4
16.2	8.24E-04	9.66E-05	2.15E-03	1.5	1820.0
17	1.18E-03	1.38E-04	3.07E-03	1.5	1271.9
18	1.11E-03	1.30E-04	2.89E-03	1.5	1350.5
19	1.24E-03	1.45E-04	3.22E-03	1.5	1212.9
20	8.83E-03	2.02E-03	1.95E-02	2.5	283.19
21	1.42E-02	8.81E-03	2.06E-02	15.5	1094.
22	9.33E-04	3.85E-05	2.88E-03	0.92	985.87
23	8.02E-03	4.18E-03	1.29E-02	9	1122.7
24	3.65E-03	1.11E-03	7.38E-03	3.425	938.34
25	8.28E-03	4.08E-03	1.37E-02	7.815	944.14
26	6.12E-03	2.87E-03	1.04E-02	7	1144.1
27	1.62E-03	1.90E-04	4.21E-03	1.5	927.84
28	8.38E-03	4.06E-04	1.40E-02	7.5	894.67
29	1.89E-03	5.84E-04	3.79E-03	3.5	1856.4
30	9.78E-04	1.15E-04	2.55E-03	1.5	1534
31	4.50E-04	1.77E-06	1.73E-03	0.5	1110.2
32	5.44E-03	2.12E-03	1.00E-02	4.901	901.31
33	2.10E-03	3.73-04	4.98E-03	2	951.96
34	3.23E-03	8.81E-04	6.79E-03	3	927.84
35	3.89E-03	1.20E-03	7.82E-03	3.5	899.78
36	7.55E-03	3.52E-03	1.28E-02	6.91	915.35
37	3.41E-03	9.71E-04	7.07E-03	3.15	922.51

2. Note that sensitivities must be performed on the above frequencies for those cases pointed out in the earlier FAQ discussion (refer to second footnote in Section 11.2).

11
CABLE TRAY FIRE PROPAGATION (FAQ 08-0049)

11.1 Background

FAQ 08-0049 was proposed by the Nuclear Energy Institute (NEI), through its NFPA 805 Task Force, to clarify the guidance on cable fire propagation provided in EPRI 1011989, NUREG/CR-6850, for use in developing fire PRAs. The FAQ authors believed that the empirical cable tray fire propagation model in EPRI 1011989, NUREG/CR-6850 has led to conservative estimates of cable fire growth rates and unrealistically short room burnout times when used outside the Zone of Influence (ZOI)—i.e., outside the fire plume that extends above the ignition source. The purpose of this FAQ is to clarify (or emphasize) the limits of this model.

In order to achieve closure of this FAQ in a timely manner, the U.S. NRC developed an interim NRC staff position, as discussed below [NRC ADAMS Accession No. ML092100274]. This position was developed using currently existing information, databases, and experimental results, and should not be seen as prejudicing the NRC's view of future developments in this area. The staff's interim position clarifies the limits of the cable tray fire propagation model provided in EPRI 1011989, NUREG/CR-6850.

11.2 Resolution

Predicting cable tray ignition, fire propagation (flame spread), and heat release rate is a complex endeavor due to the multiple phenomena that are involved. The NRC's interim position is as follows:

> The empirical cable tray fire propagation model, as specified in EPRI 1011989, NUREG/CR-6850, when applied within the zone of influence above the burning fuel, provides times to ignition of horizontal cable trays, and angles of flame spread, immediately above the ignition source that are representative of the test results from Section 3.4 of NUREG/CR-5384, "A Summary of Nuclear Power Plant Fire Safety Research at Sandia National Laboratories, 1975-1987," for use in fire PRAs when applied within the limits of those tests' validity. The NRC recommends that the tray-to-tray fire spread rates and angles be used only in cases that are similar in nature to these tests upon which they are based, i.e., within the configurations specified in NUREG/CR-5384. Care must be exercised whenever applying this model. The experiment upon which this rule set in NUREG/CR-5384 is based included only cross-linked polyethylene (XPE) cables, which were constructed using thermoset materials that were not protected in any way. Therefore, if the configuration in question includes other than XPE cables, especially thermoplastic cables, that are not protected, a different rule set would be appropriate. Tests have shown that thermoplastic cables have higher heat release rates and lower

> damage thresholds than XPE. However, if the configuration includes cables with flammability and electrical performance characteristics that are more robust than XPE cables, or cables that are protected in some way, this rule set may be conservative, also depending on the ignition source heat release rate, etc.
>
> An additional important aspect that needs to be considered to evaluate the application of the rule set is the separation distance between cable trays. The testing used separation distances of 8 inches of horizontal separation and 10.5 inches of vertical separation between cable trays. If the configuration in question has separation distances greater than these, the rule set may be conservative.

The following discussion provides a means to understand the analysis of cable tray fires. In a very basic, first-order analysis, one can assume thermal damage occurs the instant the target reaches its minimum failure temperature. For example, if the target is an electrical cable and it is known that the cable (thermoplastic) fails at 400°F (204°C), the analyst can assume failure as soon as the cable is exposed to a 400°F (218°C) hot gas layer (the corresponding threshold for a thermoset cable is 625°F [329°C]). For ignition to occur, the cable insulation must be heated sufficiently to vaporize and form a flammable premixed system. We know, from thermal detector and sprinkler response, that all materials have a mass that must be heated before they can reach a target temperature. This thermal inertia is quantified as the response time index for detection and suppression devices. The same principle applies to electrical cables, however with a number of complications. For example, where is the cable located in the tray: top, bottom, against a side rail, or in the center of the cable mass? Does the cable have any fire retardant coating? If so, which brand? Cables that are thermally stable are difficult to ignite and exhibit higher ignition temperature. A cable or coated cable can ignite when its surface is hot enough to generate flammable gas, unless the level of oxygen available is insufficient for ignition. Then the gas can often accumulate elsewhere and burn later.

These are just a sampling of the possible variables that complicate the thermal impact on cable tray fire propagation. Many of these factors are unknown, and could affect the time to the onset of ignition/gasification and flame spread of cable tray insulation, especially when considering locations elsewhere in the room (i.e., not immediately above the ignition source). These factors would tend to complicate the analysis and are not generally amenable to inclusion in a generic treatment. A detailed analysis would likely capture some of these aspects of the cable tray fire scenario. For example, EPRI 1011989, NUREG/CR-6850, Section H.1.5.2 (Tables H-5 and H-6), provides time to failure of thermoplastic and thermoset cable insulation when exposed to hot gas layer temperature. Beyond the configurations identified above, the NRC recommends that detailed fire modeling be performed. Zone fire models and computational fluid dynamics (CFD) codes are known to provide target thermal response modeling capabilities within or outside of the fire plume (zone of influence). A combination of engineering correlations and computer fire modeling can also apply to these types of scenarios.

The empirical tray-to-tray fire spread rule set is intended for use only in cases that are similar in nature to the test upon which it is based. The NRC recommends that the empirical cable tray fire propagation model, as specified in EPRI 1011989, NUREG/CR-6850, only be used to predict cable tray fire propagation within the following two configurations:

> Configuration 1: a single vertical stack of horizontal cable trays separated nominally in accordance with Regulatory Guide 1.75 [8] where the tray stack is located directly above a fire source.
>
> Configuration 2: two adjacent vertical stacks of horizontal cable tray separated nominally in accordance with Regulatory Guide 1.75 where both of the tray stacks being modeled are located directly above a fire ignition source such that both trays would be either fully or at least partially immersed in the fire plume.

NRC recommends that these spread rate models, as applicable to the two configurations above, not be used outside the original zone of influence for the reasons previously cited. For NFPA 805 applications, the licensee will need to develop and justify plant-specific, configuration-specific models if they are to be used outside the original zone of influence. These models will be an area of detailed staff review.

12
LOCATION OF FIRES WITHIN ELECTRICAL CABINETS (FAQ 08-0043)

12.1 Background

Lessons from National Fire Protection Association (NFPA) 805 pilot plants and review of the Fire Probabilistic Risk Assessment (PRA) Standard indicate that the assumed locations for fires within electrical cabinets, as specified in NUREG/CR-6850, may be conservative. Conservative assumptions of cabinet fire locations can greatly affect the end results.

NUREG/CR-6850, "EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities, Volume 2: Detailed Methodology," Section G.3.2, provides two possible approaches to the location for a fire within an electrical cabinet that is used for fire modeling calculations. In the introductory paragraph, the method suggests opening the cabinet to determine the location of the fire based on the location of the cable bundles. In the itemized bullets, the method suggests locating the fire at the top of the cabinet.

In practical applications, the fire is always assumed to start at the top of the cabinet. This assumption is applied even for cabinets that are sealed on the top (without horizontal top vents or openings). However, the Fire Protection Significance Determination Process (SDP) (NRC Inspection Manual Chapter 0609, Appendix F), Page F-21, recommends assuming that the location of an electrical cabinet fire is one foot below the top of the cabinet. The basis for this guidance was derived from experimental observations, as discussed below.

The NRC developed the interim position discussed below in order to achieve closure of this FAQ in a timely manner. This interim position was developed using currently existing information, databases, and experimental results, and should not be seen as prejudicing the NRC's view of future developments in this area. Final endorsement of this position will be addressed through the next revision of either Regulatory Guide 1.205 or NUREG/CR-6850.

12.2 Resolution

Testing[14] has shown that early fire development begins heating the cables and other combustible materials within the cabinet. Once those internal combustibles get hot enough to generate significant pyrolyzates (combustion products), the fire will transition to oxygen-limited behavior ("oxygen-limited fire") within the cabinet. Under these conditions, burning continues within the cabinet (cables develop deep-seated fire), but is limited by the availability of oxygen (i.e., air that flows into the lower sections of the cabinet through ventilation grills, gaps between cabinet panels, gaps around the cabinet doors, or gaps opened by warping of the cabinet panels and doors). Significant unburned pyrolyzates are also generated, which are then vented from the upper portion of the cabinet.

As these unburned pyrolyzates leave the cabinet, they come into contact with ambient air (oxygen) and burn at or near the exit point (e.g., the upper ventilation grills or other openings). Hence, assuming that the fire origin is near the base of the upper vertical ventilation openings in an electrical cabinet is a reasonable predictor of typical cabinet fire location under large-scale burning conditions. In general, such vertical grills will typically be located within one foot of the electrical cabinet top so that the general application of the proposed "one-foot rule" from the Fire Protection SDP will be representative of the anticipated behavior for the vast majority of closed-top electrical cabinets.

It is recommended that the assumed fire location used for screening and detailed fire modeling calculations *for electrical cabinets sealed on the top* (without horizontal top vents or openings) be one foot below the top of the cabinet. This assumption should be applied until detailed review of the cabinet contents can be performed for additional location determination, per Section G.3.2 of NUREG/CR-6850.

The assumed fire location *for a fire within a cabinet that is not sealed at the top* should be the top of the cabinet (see additional guidance below). As a point of clarification, it should be noted that in the above description on penetrations, "sealed at the top of the cabinet" was not intended to imply "fire-rated." Rather, the intent was that penetrations into a cabinet would be sealed such that they would not readily allow for the passage of air.

For vented cabinets, where the vent is either located on the side of the cabinet (vertical) or top of the cabinet (horizontal), the analysis can (as an alternative to the above assumed location) locate the fire at the uppermost vent. For example, if a cabinet includes two vertical vents on the side, the fire should be assumed to be located at the elevation of the upper vertical vent. Similarly, if there is a vent in the top corner of the cabinet, the fire should be assumed to be in the center of the corner vent. When two or more vents are located at the same height, then the analysis should conservatively assume the fire is located at the vent closest to any targets. If this last assumption

[14] Note that these insights are based on the same cabinet fire test programs referenced in NUREG/CR-6850, EPRI 1011989; namely, those from Sandia National Laboratory/NRC, IRSN (Institut de Radioprotection et de Sûreté Nucléaire [Institute for Radioprotection and Nuclear Safety (France)]) and VTT (Valtion Teknillinen Tutkimuskeskus [Technical Research Centre of Finland]).

greatly affects the results, additional refinement may be needed either by more accurate modeling of the fire size expected to occur at each vent or by using the general guidance discussed above from NUREG/CR-6850.

For cabinets that are neither vented nor considered sealed per FAQ 08-0042, the fire location would be assumed at the top of the door or opening that is expected to fail when fire damage occurs. If multiple doors or openings could possibly fail, the analysis should conservatively assume the fire is located at the uppermost door or opening. Additional refinement may be needed if this last assumption greatly affects the results.

NUREG/CR-6850 should be revised to reflect the guidance provided above for the assumed fire location to be used for screening and detailed fire modeling for electrical cabinets.

12.3 References

1. Revision 0 to FAQ 08-0043, March 13, 2008, Accession No. ML081500507
2. Revision 1 to FAQ 08-0043, December 4, 2008, Accession No. ML083540152
3. NEI 04-02, Guidance for Implementing a Risk-Informed, Performance-Based Fire Protection Program Under 10 CFR 50.48(c), Revision 1, Accession No. ML052590476
4. NFPA 805, Performance-Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants, 2001 Edition (available through the Public Document Room or NFPA)
5. Regulatory Guide 1.205, Risk-Informed, Performance-Based Fire Protection for Existing Light-Water Nuclear Power Plants, Accession No. ML061100174
6. NRC Regulatory Information Summary 2007-19, Process for Communicating Clarifications of Staff Positions Provided in Regulatory Guide 1.205 Concerning Issues Identified During The Pilot Application of National Fire Protection Association Standard 805, Accession No. ML071590227
7. NUREG/CR-6850 (EPRI 1011989), Accession Nos. ML050940183 (Vol. 1) and ML050940189 (Vol. 2)

13
INCIPIENT FIRE DETECTION SYSTEMS (08-0046)

13.1 Background

The purpose of this interim position is to provide the current staff position for determining the probability of nonsuppression in fire areas that have installed incipient fire detection systems. FAQ 08-0046 was proposed by the Nuclear Energy Institute (NEI), through its National Fire Protection Association (NFPA) 805 Task Force, to seek additional guidance on modeling the use of incipient fire detection systems in fire probabilistic risk assessment (PRA) applications. The authors believed that insufficient guidance existed on modeling these systems in NUREG/CR-6850 (EPRI 1011989), “EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities.” Initial development of the additional guidance was performed under the memorandum of understanding (MOU) between the Electric Power Research Institute (EPRI) and the Office of Nuclear Regulatory Research (RES). These efforts were not concluded prior to EPRI publication of EPRI 1016735, “Fire PRA Methods Enhancements: Additions, Clarifications, and Refinements to EPRI 1011989,” in December 2008.

Incipient fire detection systems have been used extensively in the telecommunications industry to minimize fire damage and limit interruption of service. A national consensus standard has been developed, NFPA 76, “Fire Protection of Telecommunications Facilities,” to address fire events in these high-value facilities. NFPA 76 classifies incipient fire detection systems as very early warning fire detection systems (VEWFDS)—systems that detect low-energy fires before the fire conditions threaten telecommunications service.

In telecommunications service, VEWFDS have proven to be very effective in detecting fires in the incipient stage that originated in electrical and electronic cabinets and low-voltage electrical circuits (cable runs, junction boxes, termination cabinets, etc.). In fact, NFPA 76 essentially requires VEWFDS use in high-value areas such as main distribution frame equipment and other signal processing areas.

In order to achieve closure of this FAQ in a timely manner, the NRC has developed an interim position, as discussed below. This position was developed based on the staff’s understanding of the VEWFDS detection equipment as well as how electrical and electronic equipment in nuclear power plants fail, and should not be seen as prejudicing the NRC’s view of future developments in this area. Final endorsement of this position will be addressed through the next revision of either Regulatory Guide 1.205 or NUREG/CR-6850.

13.2 Resolution

Applicability: This interim position applies to aspirating smoke detectors (ASD) installed as very early warning fire detectors as defined by NFPA 76 (2009 version), installed to monitor incipient degradation in electrical cabinets as discussed below. The position is based on the information on ASD VEWFDS available to the NRC staff. NFPA 76 requires that in order for a fire detection system to be considered a VEWFDS, it must meet two sensitivity criteria: It must be set up to provide Alert thresholds of at least 0.2 percent per foot obscuration (effective sensitivity at each port) and Alarm thresholds of at least 1 percent per foot of obscuration (effective sensitivity at each port). Licensees are free to propose the use of other technologies that meet these sensitivity requirements, but additional information/justification will be required.

Spot-type detectors installed to meet the requirements of NFPA 72 may have been described as being capable of detecting fires in the incipient stage. In many cases the description of fire detection systems in licensee’s design and licensing basis documentation claims that the detection system can detect fires in the incipient stage. While this may be true to some extent, in order to obtain the credit described in this interim position, the detection system must be capable of meeting the more stringent requirements described in NFPA 76.

Discussion: The current state of the art with respect to fire detection systems includes very highly sensitive detection systems designed to sense very slowly progressing degradation of electrical components before the flaming stage of fire occurs (incipient stage). There are numerous types of electrical components that exhibit this type of failure mode, many of which are used extensively in commercial nuclear power plants. Most low-voltage (~250 volts or less) electric and electronic components will degrade over a long period of time, with observable telltales that can be sensed by these sensitive detection systems.

Examples of these include terminal strips, cables, interpanel wiring, electromechanical relays, transformers, switches, power supplies, amplifiers, bistables, controllers, manual-automatic control stations, indicators, gauges, and computers. In fact, a very high percentage of the electrical and electronic components inside cabinets in nuclear plants would be expected to exhibit this type of degradation.

Industry Proposal: EPRI has developed a methodology to credit VEWFDS in Fire PRA quantification. EPRI Technical Report 1016735, “Fire PRA Methods Enhancements, Additions, Clarifications and Refinements to 1011989,” includes a discussion on crediting VEWFDS in Chapter 3, “Crediting Incipient Fire Detection Systems in FPRA Quantification.” There is also information on incipient fire detection systems in Appendix C, “Supplement for Crediting Incipient Fire Detection in FPRA Quantification.”

The EPRI report provides a good general overview of the concept of VEWFDS fire detection, as well as a good description of the types of fires that exhibit gradual degradation that is detectable using VEWFDS.

The EPRI report proposes to apply this methodology to all electrical/electronic components with a voltage of equal to or less than 250VDC or 480VAC.

The EPRI report also proposes to apply this methodology to various rotating equipment categories. Due to the variety of failure mechanisms related to mechanical/rotating equipment, the staff does not feel that application of the full risk reduction factors being considered for VEWFDS are appropriate for these components. Licensees that wish to credit risk reduction (beyond defense-in-depth) for VEWFDS that monitor rotating equipment must provide justification in the NFPA 805 License Amendment Request. The staff will consider each on a case-by-case basis.

The EPRI approach utilizes an event tree to model the factors that could impact the effectiveness of the VEWFDS in preventing/mitigating a postulated event. The event tree provided by EPRI includes split fractions for: 1) the percentage of components that would be covered by VEWFDS, 2) the reliability/availability of the VEWFDS and 3) the percentage of time the pre-emptive actions of the first responders are successful.

The NRC staff has reviewed the EPRI approach, and the NRC interim staff position represents changes to that approach.

NRC Interim Staff Position: While the approach proposed by EPRI in report 1016735 provides a high-level approach to modeling a VEWFDS, there are several other issues that should be addressed and conditions applied to improve accuracy/realism.

The first relates to the population of components that would exhibit incipient degradation. An additional factor should be added to the event tree to address the fact that a given electrical cabinet may have some percentage of components that may fail quickly and therefore not allow credit for incipient detection. Examples include electrical/electronic circuit boards that contain electrolytic capacitors, chart recorder drives, cooling fan motors, and mechanical timers driven by electric motors.

The second relates to the rate of component degradation. The failure mechanisms that provide indication in the incipient phase may occur over extended time periods. This time period has a direct correlation to the effectiveness of the process since a longer degradation time would imply that the time period between detection of the degrading condition and a transition to a flaming fire would be longer, resulting in a higher probability of success that a fire will be prevented or, if not prevented, mitigated. However, although there is significant operating experience with VEWFDS, there is limited useful data documenting the duration of the incipient degradation time. As a result of the limited data, there is uncertainty related to the incipient degradation time. This uncertainty should be factored into the assessment of VEWFDS effectiveness.

The third relates to the response to a VEWFDS alert/alarm. Since the proposed approach uses human intervention as the primary means of mitigating an impending fire, a factor should be inserted that allows this important part of the process to be accurately modeled.

In order to <u>prevent</u> a fire, the response activity must also include actions to remove power from the failing component/subcomponent. As the event tree is currently constructed in the EPRI report, the actions to respond to the location and find the component/subcomponent have been addressed (essentially the “Operator Response”). The skill set needed to accomplish this is similar to that for responding to any other fire: the skill set corresponding to that of an operator or trained fire brigade member. However, once the component/subcomponent has been located and identified, another skill set will be required. This task (call it the "Technician Response") requires someone knowledgeable in electrical/electronic circuits who can locate and read the appropriate drawings to determine how to remove power from the degrading device. In many cases, this activity is not a trivial exercise. It may involve researching numerous drawings (elementary, connection, interconnection, etc.) to properly locate the appropriate fuse, circuit breaker, or switch. In some cases, the required isolation device may not be in the same cabinet, the same row, or possibly even in the same room.

If the actions to locate the device and remove power are not taken at an early stage, the effectiveness of the incipient process to prevent a fire is reduced. Note that this factor can be influenced by the rate of component degradation. If the degradation process occurs over a long time period, and is detected early in the process, the available time to prevent/mitigate a potential fire is much greater, allowing a higher probability of success.

Based on these considerations, the event tree shown in Figure 13-1 is proposed for more accurately assessing the risk of fire assuming that a VEWFDS is installed. There is limited data from which the various factors can be derived. The EPRI report has cited a small number of tests that demonstrate the sensitivity of VEWFDS. The tests, however, do not address the duration or probability of the incipient degradation process that is a key factor in the true benefit of these systems. The NRC approach to dealing with this lack of data is addressed in the following.

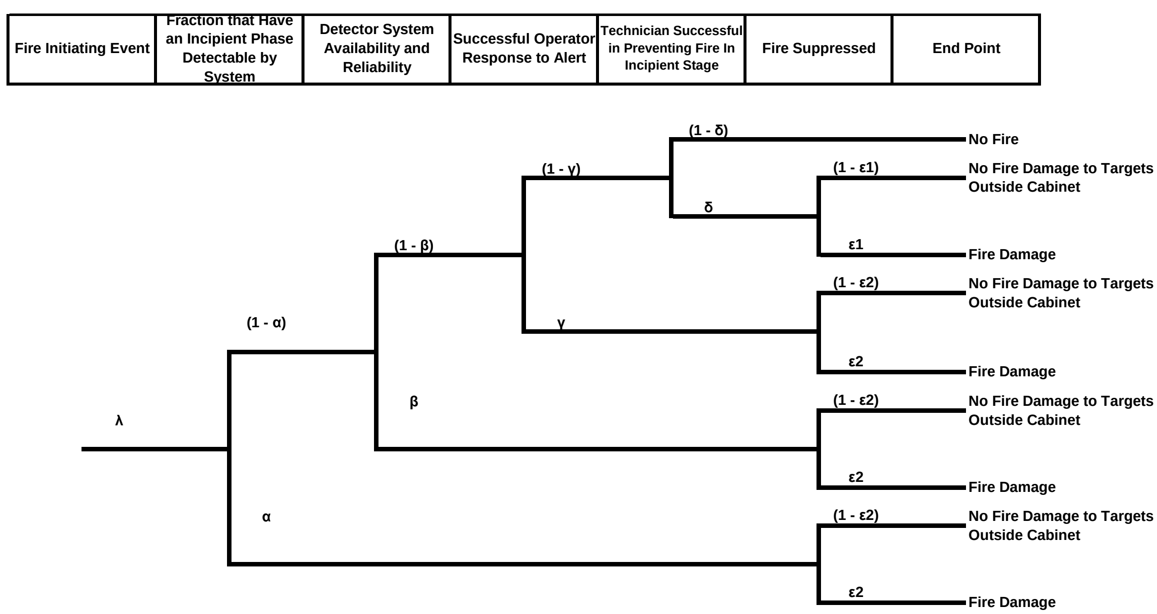

Figure 13-1
Proposed event tree for assessing fire risk, assuming VEWFDS is installed

Discussion of Branches of NRC Event Tree: At this time, this interim staff position, and the corresponding event tree, only apply to VEWFDS installed to monitor incipient fire conditions inside low-voltage (less than or equal to 250V) electrical cabinets. The branch points of the event tree are discussed in turn below. Each branch includes conditions that should be in place to obtain the credit listed.

Fraction That Has an Incipient Phase Detectable by the System: For VEWFDS monitoring equipment inside electrical cabinets with a voltage of 250V or less, α, the factor for that percentage of components that do not exhibit incipient degradation, may be set to 0.

To take credit for this value, only low-voltage (less than or equal to 250V) electrical cabinets may be included. In order to set this number to 0, the analyst must verify that the cabinet does not contain fast-acting components (such as electrical/electronic circuit boards that contain electrolytic capacitors, chart recorder drives, cooling fan motors, mechanical timers driven by electric motors, etc.) This assumption should be confirmed by inspection of the cabinet and adjusted if necessary based on the results of the inspection if there are components that would be fast acting. If fast-acting components are present, the event tree should include the branches addressing the Fraction that Has an Incipient Phase Detectable by System (α). For instance, if a cabinet contains 25 relays that would not be fast acting, along with a cooling fan and a motor-operated timer relay, the licensee could ratio the number of fast-acting components (2) to the total number in the cabinet (27) and come up with a value for α ($\alpha = 2/27 = 0.074$).

Where aspirated VEWFDS systems are used, the characteristics of the cabinet to be monitored must allow the use of an aspirated VEWFDS (aspirated systems would not function properly in a tightly sealed cabinet).

In addition, in contrast to the EPRI position, 480 VAC cabinets and rotating equipment are also excluded. If licensees desire to credit VEWFDS on components with fast-acting, higher-voltage systems or components, or rotating equipment, additional factors should be included to address their higher probability of not exhibiting incipient behavior.

Detection System Availability and Reliability: Success for this branch in the event tree means that the VEWFDS has issued an alert. β, the failure probability for this branch, can be determined using the process provided by EPRI in report 1016735 or set equal to 1E-02.

The licensee should justify that their system is sufficiently similar to the systems evaluated in EPRI 1016735 when using this value for reliability. For example, EPRI 1016735 primarily has information on cloud chamber and laser aspirating detector systems. The use of other technologies should be justified to use the proposed value above.

The system should be designed and installed by trained and qualified technicians to NFPA 76 following appropriate vendor guidance, tested in accordance with an appropriate standard including appropriate vendor requirements, and maintained in accordance with manufacturer and code requirements.

The system should pass the full vendor's acceptance test and associated sensitivity testing, including any extended period of commissioning, prior to being placed in service.

In addition to the regular functional testing required by NFPA 76 and any required preventive maintenance required by the vendor, the system should be tested and maintained in accordance with NFPA 72 and all vendor requirements (calibrated as required by the manufacturer).

Most VEWFDS have the capability to provide two or more alarm levels. Alarms that are set to occur prior to the flaming stage are typically referred to as "Alerts," and alarms that are set to occur when the device has entered the flaming or true fire stage are called "Alarms." VEWFDS alert and alarm levels should be controlled through the licensee's setpoint control program. Calibrations, such as rebaselining the alert and alarm levels, that reduce the sensitivity of the system should be evaluated to assure that the early detection function of the system is not compromised. Reductions in sensitivity should be considered in the fire PRA as a reduction in the system's effectiveness.

Testing and calibrations should be documented, and documentation should be maintained for the life of the plant.

Successful Operator Responses to Alert: Success of this event implies that plant personnel have identified the cabinet that contains the source of the alert and have staged appropriately trained personnel (a qualified fire watch as is used for hot work or a "flash watch") at that location, who are prepared to initiate fire suppression if an actual fire (e.g., open flaming) were to break out. γ reflects the likelihood that plant personnel fail to respond to an alert signal in a timely manner (i.e., prior to outbreak of open flaming within the source). γ, the probability of failure of the operator/fire brigade to respond to the alert and find the component, can be determined based on a human reliability analysis (HRA) or conservatively set to 1E-02 if the VEWFDS is addressable to multiple cabinets or to 5E-03 if the VEWFDS is addressable to an individual cabinet. The lower value recognizes that the cabinet affected is known and does not require additional investigation by the responders to identify the affected cabinet.

The recommended value assumes that the VEWFDS provides at least one hour of warning prior to the actual outbreak of an open flaming fire. This value is considered conservative for an annunciator response when there is nothing else going on—since the alert occurs prior to any damage, it can be assumed there is no fire and no transient at this time.

This number assumes that the operator response procedure directs the area and/or cabinet (if the VEWFDS is addressable to individual cabinets) to be investigated upon an alert from the VEWFDS.

This number assumes that procedures would be in place to require establishment upon the annunciation of an alert of a qualified continuous "flash watch" (similar to that used to monitor hot work) until the potential for fire has been removed or until there has been a formal, documented evaluation of the event. (Note: One acceptable means of meeting this qualification requirement is to provide training in accordance with the requirements in NFPA 1081, "Standard for Industrial Fire Brigade Member Professional Qualifications," Section 5.2.1, "Manual Fire Suppression.")

Effective methods must be established for locating the source of the incipient detection (portable VEWFDS, thermography, etc.) and the associated equipment must be dedicated for use, maintained in an operable condition, available on site at all times and appropriately staged to be rapidly accessed by first responders when needed.

First responders are properly trained to respond to the incipient condition, identify the faulted cabinet, and suppress potential fires. Personnel using portable equipment to locate incipient degradation must be trained in its use, including on-the-job training such that they are familiar with the equipment, procedures for its use, and any limitations and/or precautions required. Also, adequate procedures exist, and the response process has been included within the scope of the fire brigade training and periodic drill process.

Technician Successful in Preventing Fire in Incipient Stage: To simplify the analysis, δ, the factor for the probability of failure to remove power from the device once it has been located, is set to 1. This is done because of the difficulty in assessing the likelihood of successful prevention.

This approach is taking credit for the fire watch only, as a surrogate for prevention. To be effective, the licensee must commit to procedures that require an appropriately trained fire watch to be in place until the problem has been resolved. Success in this approach is ultimately judged based on the ability to control the fire rather than suppress it. So long as the fire is prevented from growing significantly, the adverse consequences related to a large cabinet fire, and the associated fire growth due to secondary combustibles, are prevented. This is conservative, since in reality there would not be a fire contribution at all if the fire was prevented. In the case of fire prevention, the only impact on plant operation would be the unavailability of the component(s) in the cabinet for the duration of the repair.

If a licensee desires to obtain more credit in this process, the more detailed NRC event tree may be used, including the branches with δ (with adequate and appropriate justification in the form of a detailed human reliability analysis). One way a licensee could achieve significant fire prevention credit would be to "prelocate" the isolation devices for all ignition sources within each cabinet in an effort to speed up the process. If such an effort was taken, additional credit for preventing fires could be allowed. This would need to include predetermining the isolation devices, conveniently displaying that information for use in response to VEWFDS alerts, training responders so that they could rapidly locate and operate the isolation device(s), and conducting drills to periodically demonstrate this ability.

Fire Suppressed: There are two cases for this branch point.

Success in the event following success in successful operator response to alert or alarm is that the "flash watch" stationed at the cabinet has successfully controlled the fire before it affects the target. $\varepsilon 1$ represents the probability that, given success of event γ, the personnel staged at the cabinet responsible for the VEWFDS alert fails to promptly suppress the fire (i.e., quickly enough to prevent damage to PRA targets outside the cabinet) once open flaming does break out. ε1, the probability of "enhanced" nonsuppression, may be set to 1E-03. This is considered to be reasonable given the nature of the response required by a trained responder who is stationed at the location with the correct equipment.

Success for the branches following failure in the successful operator response or detector unavailability is prevention of damage to the targets by the fire brigade. ε2, the probability of "normal" nonsuppression, should be taken from the Detection Suppression Event Tree in NUREG/CR-6850, Appendix P, using the electrical fire suppression curve for manual suppression as appropriate. Credit should be given as described in Appendix P for automatic detection and suppression (normal spot detectors and automatic suppression in the area) as well as delayed manual detection, manual actuation of fixed suppression, and manual suppression via the fire brigade.

With the above simplifications, the event tree simplifies to the following:

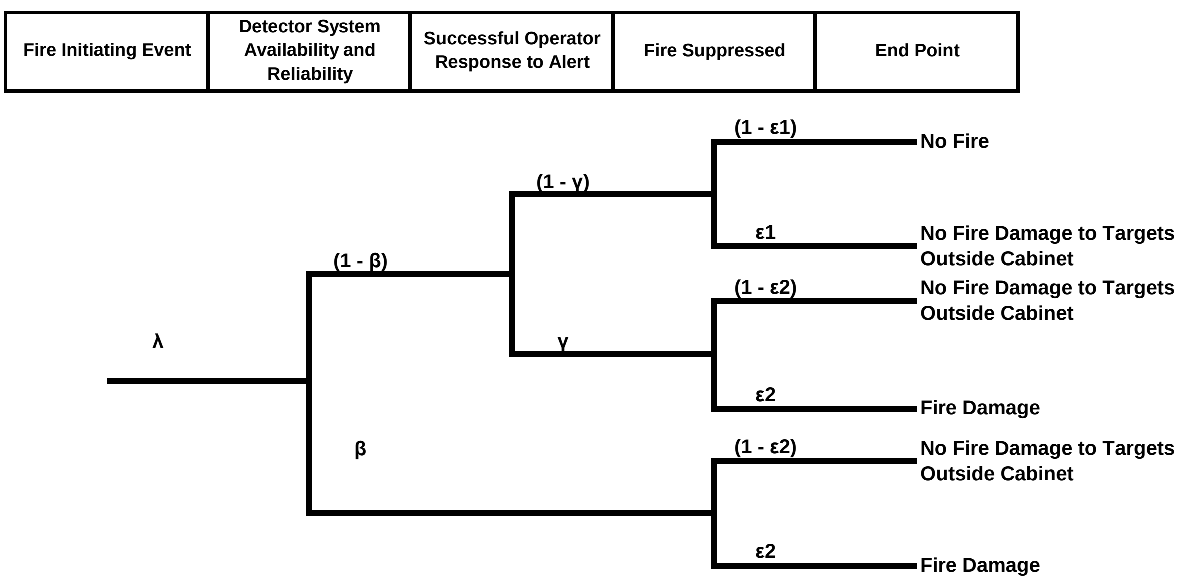

Figure 13-2
Simplified event tree

Other General Considerations: Note that the staff plans to document the licensee commitments associated with the VEWFDS design, installation, testing, compensatory measures, and procedures for responding to the VEWFDS alert/alarms in each licensee's license amendment request and reviewed and approved in the associated NRC Safety Evaluation, as applicable.

Licensees that employ VEWFDS and model them in their fire PRA models that do not use the proposed values provided in this position should justify the various split fractions used in the plant-specific application and provide a characterization of the uncertainty on each of the split fractions and perform a sensitivity analysis to demonstrate robustness of the proposed position on acceptability of the plant change. The licensee should describe the operator response in sufficient detail for the NRC staff to understand how the human error probability (HEP) was determined. Regardless of how VEWFDS are modeled, licensees should provide a description of alarm response procedures, troubleshooting methods, and training of operators, maintenance personnel, fire watch standers, and fire brigade members.

Based on the possible significant risk reduction being credited for VEWFDS installation, licensees should include in their fire protection program appropriate compensatory measures to address the unavailability/inoperability of the VEWFDS. These compensatory measures should be controlled through the use of a licensee-controlled process such as a Technical Requirements Manual or other defined process used to address fire protection program impairments that will ensure that the compensatory measures will be carried out. For licensees that plan to install VEWFDS as part of the NFPA 805 transition, the process for defining and controlling the compensatory measures should be described in the NFPA 805 License Amendment Request. Unless compensatory measures are evaluated to be equivalent to VEWFDS, such as continuous hot-work-type fire watch or use of a portable VEWFDS, an extended period of unavailability/inoperability may have a significant impact on overall plant fire risk. For example, an out-of-service period of four days would decrease the effectiveness of the system by an order of magnitude, based on the assumed availability factor. Even a day of unavailability would reduce effectiveness by a factor of about 3.

Two additional factors in a performance-based approach are the implementation of the NFPA 805 monitoring program and the fire PRA maintenance and update process. The staff expects licensees that implement VEWFDS to monitor the availability, reliability, and effectiveness of the VEWFDS so that, over time, more accurate and representative data may be used in the risk model. As required by NFPA 805, licensees are expected to set availability, reliability, and effectiveness targets and to take appropriate corrective actions when system performance does not meet the targets. Licensees are also expected to maintain their risk analysis current with the latest information. This includes consideration of new information from nuclear industry operating experience and external sources such as industry testing, research, data from other industries (such as the telecommunications industry), etc. While implementing the fire PRA maintenance and update process, if operating experience indicates that VEWFDS availability, reliability and effectiveness are not as high as currently modeled in the fire PRA, actions must be taken to update the analysis to reflect the new information.

Licensees are cautioned that while the installation of VEWFDS to monitor critical control cabinets may significantly decrease fire risk and positively impact several of the fire protection defense-in-depth attributes (preventing fires from occurring, and rapidly detecting and suppressing those fires that do occur), consideration of defense-in-depth is a requirement of NFPA 805. Licensees are still required to demonstrate the ability to achieve the nuclear safety performance criteria assuming that a challenging fire impacts safe shutdown equipment. Depending upon the other defense-in-depth attributes for a given fire area, recovery actions and/or physical plant modifications may still be required to demonstrate the ability to meet the nuclear safety performance criteria.

Deviations from the information provided in this position should be justified and, prior to credit in NRC regulatory activities, should be submitted to the NRC for review and approval.

13.3 References

1. Revision 0 to FAQ 08-0046, March 31, 2008, Accession No. ML081200120
2. NRC Draft Interim Position on FAQ 08-0046, Accession No. ML091750338
3. Resolution of stakeholder comments on the NRC Draft Interim Position, Accession No. ML093220197
4. EPRI 1016735, Fire PRA Methods Enhancements, December 2008, Accession No. ML090290195
5. NEI 04-02, Guidance for Implementing a Risk-Informed, Performance-Based Fire Protection Program Under 10 CFR 50.48(c), Revision 1, Accession No. ML052590476
6. NFPA 805, Performance-Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants, 2001 Edition (available through the Public Document Room or NFPA)
7. Regulatory Guide 1.205, Risk-Informed, Performance-Based Fire Protection for Existing Light-Water Nuclear Power Plants, Accession No. ML061100174
8. NRC Regulatory Information Summary 2007-19, Process for Communicating Clarifications of Staff Positions Provided in Regulatory Guide 1.205 Concerning Issues Identified During The Pilot Application of National Fire Protection Association Standard 805, Accession No. ML071590227
9. NUREG/CR-6850 (EPRI 1011989), EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities, Accession Nos. ML050940183 (Vol. 1) and ML050940189 (Vol. 2)

14
MANUAL NONSUPPRESSION PROBABILITY (FAQ 08-0050)

14.1 Background

FAQ 08-0050 was proposed to clarify the guidance on manual nonsuppression probability provided in NUREG/CR-6850. This guidance required the separate consideration of fire brigade response time in manual nonsuppression analysis, despite its inclusion in much of the analysis. The purpose of this FAQ is to update guidance provided in NUREG/CR-6850, Appendix P, for the treatment of manual suppression and the fire brigade response. As a part of this update, a process has also been developed to adjust the nonsuppression analysis for scenario-specific fire brigade responses.

The NRC developed the interim position discussed below in order to achieve closure of this FAQ in a timely manner. This interim position was developed using currently existing information, databases, and experimental results, and should not be seen as prejudicing the NRC's view of future developments in this area. Final endorsement of this position will be addressed through the next revision of either Regulatory Guide 1.205 or NUREG/CR-6850.

14.2 Resolution

14.2.1 Introduction

The suppression time of a fire is an important factor in the determination of the likelihood of fire-induced damage to a component. This time, labeled as T_{supp} in this FAQ, is the time interval between when the fire is detected and when it is suppressed. Note that, depending upon the severity of the fire, the plant's fire brigade may be called to respond. Figure 14-1 shows the conceptual relationship between T_{det} (the time interval between the start of the fire and when the fire is initially detected), T_{supp}, and T_{fb}, the time from fire detection until the fire brigade begins to apply suppressant agents.[15]

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[15] Note that T_{det}, T_{supp} and T_{fb} vary from fire to fire, and are treated statistically in the fire PRA.

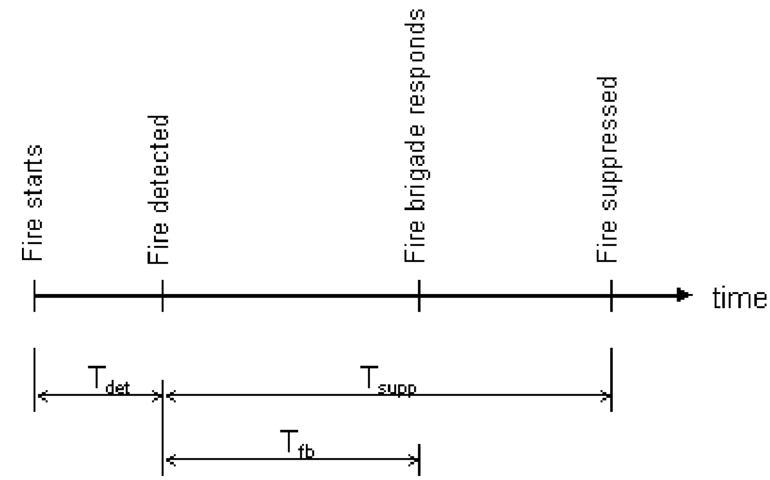

Figure 14-1
Conceptual relationship between fire detection time, suppression time, and fire brigade response time

As discussed in NUREG/CR-6850, EPRI 1011989 (referred to elsewhere in this FAQ as NUREG/CR-6850 for brevity), the probability of nonsuppression by time t, $P_{ns}(t)$, is given by

$$P_{ns}(t) = Pr(T_{supp} \geq t)$$

When used in computing the probability of fire-induced damage, t refers to the time available before damage to fire PRA targets occurs. Thus, in this application, t is replaced by the estimated time to damage minus the estimated time to detect the fire, i.e., $\langle T_{damage} \rangle - \langle T_{det} \rangle$. This difference represents the estimated time available to suppress the fire. Methods to compute $\langle T_{damage} \rangle$ and $\langle T_{det} \rangle$ are described in NUREG/CR-6850.

Note also that this definition of time available to suppress the fire differs from NUREG/CR-6850 in that it does not require an adjustment for T_{fb} (the fire brigade response time). That is, NUREG/CR-6850 defines the time available for manual suppression as the time to damage minus the time to detection minus the fire brigade response time, i.e., $\langle T_{damage} \rangle - \langle T_{det} \rangle - \langle T_{fb} \rangle$. Under the revised approach, the fire brigade response time is already included in the distribution for T_{supp}, as discussed below.

Thus, the probability of fire-induced damage is given by:

$$P_{damage} = P_{ns}(\langle T_{damage} \rangle - \langle T_{det} \rangle) = Pr(T_{supp} \geq [\langle T_{damage} \rangle - \langle T_{det} \rangle])$$

Two complications in the development of $P_{ns}(t)$ are the following:

- Available data records for actual fire events are often incomplete or ambiguous regarding the detection time, suppression time, and brigade role and response time.
- NUREG/CR-6850 does not provide guidance as to how generic nonsuppression probability distributions can be revised to reflect scenario-specific considerations (e.g., difficult-to-access fire locations) that can affect the fire brigade response time.

This FAQ resolution provides clarifying and revised guidance for the estimation of $P_{ns}(t)$.

14.2.2 Solution

This solution addresses the probability of nonsuppression for scenarios involving manual fire suppression (i.e., sequences D, E, H, I, L, and M in Figure P-1 of NUREG/CR-6850). In particular, this approach recognizes that manual suppression in these particular scenarios includes suppression activities by non-fire brigade personnel. Hence, there is some probability of manual suppression prior to arrival of the fire brigade. The solution is provided in two parts. The first part addresses cases where the fire brigade response time for the scenario being analyzed is judged to be comparable to the industry average. The second part addresses the process for making adjustments for cases where it is judged that the fire brigade response time distribution is significantly different from that underlying the events reported in the EPRI Fire Events Database.

As a result of this FAQ, the two branch points in Figure P-1 that represent manual actuation of a fixed suppression system (MF) and the fire brigade response (FB) should be replaced by a single new branch point, manual fire suppression (MS). The manual nonsuppression curves and adjustment factor developed as a part of this FAQ can be used if no explicit credit is being taken for manual actuation of a fixed suppression system. In cases where this credit is being taken, a plant-specific analysis must be done. This plant-specific analysis must address the procedures and training for manually actuating a fixed suppression system, and explain how dependencies between manual actuation of a fixed suppression system and other manual suppression activities (e.g., manual suppression by portable extinguishers and hose stream) are addressed.

The preceding discussion of MS replaces the NUREG/CR-6850 discussions of the MF and FB branch points from Figure P-1.

(1) Industry-average response

Figures 14-2 and 14-3 provide revised nonsuppression probability curves to be used when there are no scenario-specific factors that would tend to make the fire brigade response significantly different from the population of responses included in available data. Furthermore, the nonsuppression curves are used when the fire is not suppressed by prompt suppression, if applicable[16] (i.e., "PS" fails), and not suppressed by automatic fixed suppression systems[17] (i.e., "AS" fails). These nonsuppression curves apply specifically to the new branch point MS, "manual suppression."

(2) Scenario-specific adjustments

For cases where it is judged that the fire scenario being analyzed involves factors that will significantly affect fire brigade response (i.e., lead to a scenario-specific fire brigade response time more than 5 minutes different than the nominal fire brigade response time), the following approach may be used to estimate the impact of these factors on the probability of nonsuppression.

Identify the scenario-specific factors expected to significantly affect T_{fb}, which is composed of the time for the fire brigade to reach the fire (after the fire is initially detected) and the time for the brigade to begin applying suppressants to the fire. Consider the location, accessibility, and type of fire; the location and condition of necessary equipment (e.g., hose stations) and material; and any special features of the fire location (e.g., proximity to sensitive equipment) that could affect the fire brigade's decisions and actions.

Document those factors judged to make the scenario unusual in comparison with fire scenarios more typical for the plant being analyzed.

Estimate $\langle T_{fb-t} \rangle$ and $\langle T_{fb-s} \rangle$, the mean typical and scenario-specific fire brigade response times,[18] respectively, and document the basis (e.g., fire brigade response exercise results) for these estimates.

Compute the probability of nonsuppression as follows:

$$P_{ns}(t) = F_{ns,i}(t \cdot C_s) = \exp[-\lambda(t \cdot C_s)]$$

where $F_{ns,i}(\bullet)$ is the exponential function for the appropriate nonsuppression curve from Figures 14-2 and 14-3, λ is the corresponding mean suppression rate (1/time) from Table 14-2 below, and C_s is a scenario-specific adjustment factor:

$$C_s = 1 - \left[\frac{\langle T_{fb-s} \rangle - \langle T_{fb-t} \rangle}{\langle T_{fb-s} \rangle + \langle T_{fb-t} \rangle} \right]$$

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[16] For example, a continuous fire watch during hot work activities.

[17] Automatic systems are unavailable, fail, or are assessed as not effective against the fire scenario.

[18] Recall that T_{fb}, even for a well-specified fire scenario, is a statistical variable.

Basis

(1) Industry-average response

The adjustment to Figure P-1 to combine MF and FB into MS has been done to make the fire PRA treatment more consistent with the data. Since the manual nonsuppression curves generated with this FAQ credit both non-fire brigade and fire brigade suppression activities, the order of the top events in the event tree could be misleading. For example, non-fire brigade suppression activities, and even fire brigade suppression activities themselves, could very well come before manual actuation of a fixed suppression system. Therefore, there are potentially important dependencies between manual actuation of a fixed suppression system and the fire brigade that would have an impact on the available time that a fire brigade has to fight the fire, or the size of the fire that the brigade has to fight.

The nonsuppression curves in Figures 14-2 and 14-3, and associated tabulated values in Table 14-1, are based on a reanalysis of the 250 manual suppression fire events addressed in NUREG/CR-6850. Suppression rates for this reanalysis are provided in Table 14-2. This reanalysis provides a treatment of available data for fire duration and fire suppression times that is more consistent with the conceptual framework shown in Figure 14-1. It recognizes that manual suppression is a continuous activity that can begin once the fire is detected, rather than rely primarily on fire brigade suppression efforts.

The nonsuppression curves from NUREG/CR-6850 and from this FAQ are each based on data provided in the EPRI Fire Events Database. This data is contained in Table 14-3. However, NUREG/CR-6850 uses, when possible, data entered in the “suppression time” field of the database. (For those events where suppression times are not provided, NUREG/CR-6850 uses the fire duration data[19] entered in the EPRI Fire Events Database.) In this FAQ, the nonsuppression curves are based on data provided in the “fire duration” field of the database.[20] The recorded fire duration is the time from fire detection to extinguishment, and generally corresponds to T_{supp} in Figure 14-1.

As discussed earlier, the treatment in this reanalysis avoids the need to subtract the fire brigade response time from the available time to suppress the fire when estimating the damage probability. Thus, this treatment eliminates a conservatism inherent in NUREG/CR-6850 with respect to fire brigade response times.

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[19] Fire duration and suppression time have specific database fields, and the times were taken from these fields.

[20] In a few exceptions, the duration times in the description of the event contradict the field. For those cases, the duration extracted from the event description is used in the analysis.

The nonsuppression curves respond to the uncertainty in the fire duration data in a manner consistent with that used in NUREG/CR-6850. Approximately 70 manually suppressed fire events in the EPRI Fire Events Database have duration data entered as a range (e.g., “16 to 30 minutes” or “less than 5 minutes”). For such events, all points in the range are treated as being equally likely and the midpoint of the range is used in the numerical analysis, i.e., 23 min and 2 min, respectively, for the examples.

It should be noted that the analysis underlying Figures 14-2 and 14-3 has removed four fire events treated in NUREG/CR-6850. Three incidents (1176, 1345, and 2469 impacting the transient and welding nonsuppression curves) occurred in outside areas (2 events in a service building and 1 event in a steam generator construction area) and are outside the scope of this reanalysis. Incident 914 appears to be a duplicate of incident 495 based on similar event descriptions (with the exception that incident 914 is listed as an electrical fire in the suppression curve field and incident 495 is listed as an oil fire). Since the descriptions in the text clarify that the fire was an electrical fire, incident 495 was also removed. In addition to these four removals, one event, incident 821, was transferred from the analysis of electrical fires to that of oil fires. The associated description and data are more consistent with an oil fire.

(2) Scenario-specific response

The nonsuppression distributions shown in Figures 14-2 and 14-3 are derived from an analysis of events in which the fires were manually suppressed. Some (but not all) of these events were suppressed by the plant fire brigade, and so the nonsuppression distributions implicitly include the fire brigade response. The purpose of the adjustment described in the Solution portion of this FAQ is to address scenarios where the fire brigade response is expected to be very different from that included in the Figure 14-2 and Figure 14-3 curves.

Although methods are available for estimating the contribution of the fire brigade response time to the overall fire duration (taking account of the uncertainties in the available data), such methods have not yet been fully tested with current data and incorporated into software tools for fire PRA practitioners. The FAQ solution uses a simple adjustment factor, labeled C_s above, that exhibits the following, appropriate trends as $<T_{fb-s}>$ and $<T_{fb-t}>$ change.

If the scenario-specific fire brigade response is quicker than a typical response (i.e., $<T_{fb-s}>$ is less than $<T_{fb-t}>$) then $C_s > 1$ (i.e., the effective time available for manual suppression is increased).

If the scenario-specific fire brigade response is slower than a typical response (i.e., $<T_{fb-s}>$ is greater than $<T_{fb-t}>$), then $C_s < 1$ (i.e., the effective time available for manual suppression is decreased).

If the scenario-specific fire brigade response is the same as a typical response (i.e., $<T_{fb-s}>$ equals $<T_{fb-t}>$), then $C_s = 1$ (i.e., there is no adjustment).

(3) Correction factor

The correction factor (C_s) is not based on a first-principles analysis. Rather, the factor was derived largely on an empirical basis in order to achieve the desired behavior. The objective was to create a relatively straightforward correction factor that adjusted the available time to reflect fire brigade responses that were either faster or slower than the typical case. Additional desirable characteristics of the adjustment include the following items.

The magnitude of the adjustment should not be excessive for any cases. The objective for the interim position (e.g., pending additional validating research) was to allow for modest changes from generic values to reflect case-specific conditions.

The adjustment factor should reflect that small differences in response time are generally more significant if the typical response time is small than if the typical response time is large. For example, a 5-minute difference in brigade response time is more significant to the overall fire behavior when the brigade response occurs within a 10–15 minute time frame than it is if the brigade response occurs within a 30–35 minute time frame.

The adjustment factor should never be less than or equal to zero (that is, $C_s>0$ for all cases). If $C_s \leq 0$ for a given case, then no credit whatsoever would be given to manual fire suppression regardless of the time available before fire damage occurs.

Even if the fire brigade response time exceeds the time available for suppression, the probability of nonsuppression should still reflect the potential that other plant personnel may intervene and suppress the fire. This characteristic is consistent with the intent of the original FAQ.

The correction factor should work for all practical cases without the need for additional rule sets to limit application or to correct anomalous results.

The form of the adjustment factor used derives from common temperature normalization forms used in heat transfer, especially when dealing with various conduction and convection problems where temperature differences tend to dominate the solution. This form does provide all of the desired characteristics listed above.

Recall that the correction factor is defined as follows:

$$C_s = 1 - \left[\frac{\langle T_{fb-s} \rangle - \langle T_{fb-t} \rangle}{\langle T_{fb-s} \rangle + \langle T_{fb-t} \rangle} \right]$$

The summation in the denominator may appear arbitrary, but is important because it acts to de-emphasize small changes in larger numbers and prevents the correction factor from going to zero, at least for practical applications. Other potential formulations not utilizing the summation in the denominator (e.g., normalizing using just $<T_{fb-s}>$ or $<T_{fb-t}>$) were generally found to be too volatile (yielding excessively large corrections) and tended to yield anomalous or unreasonable results for certain types of cases (e.g., yielding $C_s \leq 0$ for some cases). Other forms, such as a simple linear shift in the time available, also tended to yield anomalous results for certain types of cases, requiring the application of additional rule sets to correct such cases.

The analyst may also note that the following is an equivalent numerical form for the correction factor:

$$C_s = \left[\frac{\langle T_{fb-t} \rangle}{(1/2)\left(\langle T_{fb-s} \rangle + \langle T_{fb-t} \rangle\right)} \right]$$

This alternate form illustrates that the correction factor can also be seen as the ratio of the typical response time to the average of the typical and case-specific response times.

Insights from results

Figures 14-4 through 14-15 provide comparisons of the suppression curves from this analysis and from NUREG/CR-6850. First of all, the FAQ 50 curves typically provide comparable to slightly higher nonsuppression probabilities than NUREG/CR-6850. These curves are very similar since approximately one-half of the 250 suppression data entries in the database contain no entry for suppression time. Secondly, a “6850+10” curve was generated with the assumption of a 10-minute full fire brigade response. The results of this second comparison between the FAQ 50 curves and the “6850 + 10” curves demonstrate the potential degree of conservatism with the NUREG/CR-6850 approach of adding the fire brigade time to the suppression time.

Insights from database review

The reanalysis of the manual fire suppression events in the database highlighted that manual fire suppression is a more continuous process than the original NUREG/CR-6850 treatment provided. Unlike the NUREG/CR-6850 analysis, which assumed that manual fire fighting was largely a function of the fire brigade, manual fire suppression activities effectively begin as soon as a fire has been detected, and if needed, confirmed. Many of the fire events are suppressed before the fire brigade arrives in full. The revised analysis treats the overall process of manual fire suppression in a more continuous manner consistent with the actual response to a fire.

Furthermore, for those cases where the database explicitly indicates that the fire brigade applied a hose stream, this database review confirmed that the duration data do not contain the time for detection. Approximately one-third of these events include information in the event description that allowed an independent confirmation for when the recorded duration began and ended. In those cases, the recorded duration began when the fire was detected by plant personnel or upon indications provided by alarms or failure of equipment.

Finally, the time needed for confirmation of the fire after detection is rarely identified in fire events. A plant will generally confirm a detector actuation prior to sending out a full fire brigade to apply a hose stream. For those fires detected by fire watches or by plant personnel, confirmation may not be necessary. Note that nearly one-half of the entire 250 events in the set of suppression data identify plant personnel as the means of detection.

14.3 References

1. Revision 0 to FAQ 08-0050, May 13, 2008, Accession No. ML081200318
2. NRC Draft Interim Position on FAQ 08-0050, Accession No. ML091660045
3. Resolution of stakeholder comments on the NRC Draft Interim Position, Accession No. ML092180533
4. NEI 04-02, Guidance for Implementing a Risk-Informed, Performance-Based Fire Protection Program Under 10 CFR 50.48(c), Revision 1, Accession No. ML052590476
5. NFPA 805, Performance-Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants, 2001 Edition (available through the Public Document Room or NFPA)
6. Regulatory Guide 1.205, Risk-Informed, Performance-Based Fire Protection for Existing Light-Water Nuclear Power Plants, Accession No. ML061100174
7. NRC Regulatory Information Summary 2007-19, Process for Communicating Clarifications of Staff Positions Provided in Regulatory Guide 1.205 Concerning Issues Identified During The Pilot Application of National Fire Protection Association Standard 805, Accession No. ML071590227
8. NUREG/CR-6850 (EPRI 1011989), Accession Nos. ML050940183 (Vol. 1) and ML050940189 (Vol. 2)

Table 14-1
Updated Numerical Results for Suppression Curves

Time (min)	T/G fires	High-energy arcing faults	Outdoor transformers	Flammable gas	Oil fires	Electrical fires	Transient fires	PWR containment	Welding	Control room	Cable fires	All fires
0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
5	0.883	0.947	0.836	0.881	0.684	0.602	0.531	0.687	0.392	0.189	0.446	0.714
10	0.780	0.897	0.698	0.776	0.468	0.362	0.282	0.472	0.153	0.036	0.199	0.510
15	0.689	0.850	0.584	0.683	0.320	0.218	0.150	0.325	0.060	0.007	0.089	0.364
20	0.609	0.805	0.488	0.602	0.219	0.131	0.080	0.223	0.024	0.001	0.040	0.260
25	0.538	0.762	0.408	0.530	0.150	0.079	0.042	0.153	0.009	*	0.018	0.186
30	0.475	0.722	0.341	0.467	0.102	0.048	0.023	0.105	0.004	*	0.008	0.133
35	0.419	0.684	0.285	0.411	0.070	0.029	0.012	0.072	0.001	*	0.004	0.095
40	0.370	0.647	0.238	0.362	0.048	0.017	0.006	0.050	*	*	0.002	0.068
45	0.327	0.613	0.199	0.319	0.033	0.010	0.003	0.034	*	*	*	0.048
50	0.289	0.581	0.166	0.281	0.022	0.006	0.002	0.024	*	*	*	0.035
55	0.255	0.550	0.139	0.248	0.015	0.004	*	0.016	*	*	*	0.025
60	0.226	0.521	0.116	0.218	0.010	0.002	*	0.011	*	*	*	0.018
65	0.199	0.493	0.097	0.192	0.007	0.001	*	0.008	*	*	*	0.013
70	0.176	0.467	0.081	0.169	0.005	*	*	0.005	*	*	*	0.009
75	0.155	0.443	0.068	0.149	0.003	*	*	0.004	*	*	*	0.006
80	0.137	0.419	0.057	0.131	0.002	*	*	0.002	*	*	*	0.005
85	0.121	0.397	0.047	0.116	0.002	*	*	0.002	*	*	*	0.003
90	0.107	0.376	0.040	0.102	0.001	*	*	0.001	*	*	*	0.002
95	0.095	0.356	0.033	0.090	*	*	*	*	*	*	*	0.002
100	0.084	0.337	0.028	0.079	*	*	*	*	*	*	*	0.001

* A value of 1E-3 should be used

Table 14-2
Original and Updated Mean Suppression Rates (λ)

		Original NUREG/CR-6850		Revised Analysis	
Suppression Curve	**No. of original events/revised events**	**Original Total Suppression Time**	**Original Mean Suppression Rate [/min]**	**Revised Total Duration**	**Revised Mean Suppression Rate [/min]**
T/G fires	21/21	749	0.03	846	0.025
Control room	6/6	18	0.33	18	0.33
PWR containment	3/3	23	0.13	40	0.075
Outdoor transformers	14/14	373	0.04	390	0.036
Flammable gas	5/5	195	0.03	197	0.025
Oil fires	36/36	404	0.09	474	0.076
Cable fires	5/5	21	0.24	31	0.161
Electrical fires	114/113	942	0.12	1113	0.102
Welding fires	19/18	99	0.19	106	0.188
Transient fires	24/22	199	0.12	174	0.126
High-energy arcing faults	3/3	239	0.01	276	0.011
All fires	245[21] /246	3113	0.08	3655	0.067

[21] The "All Fires" nonsuppression analysis in the original NUREG/CR-6850 excluded events from the cable fire bin. Thus, the total number of events taken from the individual suppression analyses in the original NUREG/CR-6850 is 250; however, the number of events used in the "All Fires" curve is only 245.

Table 14-3
List of Fire Events for Original and Revised Suppression Curves[22]

Incident No.	Date	Year	Mode of Operation	Suppression Curve	Fire Suppression Time (T_{supp})	
					Original NUREG/ CR-6850 Value [min]	Revised FAQ 50 Value [min]
398	9/7/1983	1983	Low Power Operation	Cable	2	2
510	2/1/1986	1986	Power Operation	Cable	10	10
681	3/9/1988	1988	Low Power Operation	Cable	5	15
2361	3/10/1986	1986	Power Operation	Cable	2	2
2425	3/1/2000	2000	Power Operation	Cable	2	2
485	8/24/1985	1985	Power Operation	Containment (PWR)	15	24
1041	7/11/1994	1994	Power Operation	Containment (PWR)	6	14
1488	10/21/1987	1987	Power Operation	Containment (PWR)	2	2
537	9/4/1986	1986	Low Power Operation	Control Room	1	1
659	12/30/1987	1987	Power Operation	Control Room	1	2
756	10/14/1988	1988	Low Power Operation	Control Room	1	1
928	3/1/1989	1989	Power Operation	Control Room	1	2
980	3/23/1990	1990	Undetermined	Control Room	2	2
2160	4/4/1996	1996	Low Power Operation	Control Room	10	10
238	1/24/1981	1981	Power Operation	Electrical	5	30
269	8/10/1981	1981	Power Operation	Electrical	1	1
352	11/3/1982	1982	Power Operation	Electrical	5	5
357	11/27/1982	1982	Power Operation	Electrical	2	4
388	6/19/1983	1983	Power Operation	Electrical	4	4
418	4/28/1984	1984	Low Power Operation	Electrical	10	60
469	5/2/1985	1985	Low Power Operation	Electrical	1	11
484	8/14/1985	1985	Power Operation	Electrical	15	15
490	10/11/1985	1985	Undetermined	Electrical	11	11
493	10/31/1985	1985	Power Operation	Electrical	1	1
498	12/3/1985	1985	Power Operation	Electrical	10	10
505	1/8/1986	1986	Low Power Operation	Electrical	36	36
513	2/19/1986	1986	Low Power Operation	Electrical	6	6
516	3/8/1986	1986	Low Power Operation	Electrical	6	8
518	3/22/1986	1986	Low Power Operation	Electrical	1	1
522	4/17/1986	1986	Low Power Operation	Electrical	10	10
529	6/22/1986	1986	Power Operation	Electrical	1	1
541	9/19/1986	1986	Power Operation	Electrical	5	10

[22] Date, year, and mode of operation for each event are draft and have not been confirmed. This information is not relevant to the analysis, but provided as a modifier to the incident number.

Table 14-3 (continued)
List of Fire Events for Original and Revised Suppression Curves

Incident No.	Date	Year	Mode of Operation	Suppression Curve	Fire Suppression Time (T_{supp})	
					Original NUREG/ CR-6850 Value [min]	Revised FAQ 50 Value [min]
544	10/14/1986	1986	Undetermined	Electrical	12	12
551	12/16/1986	1986	Power Operation	Electrical	1	1
557	1/31/1987	1987	Low Power Operation	Electrical	10	30
572	3/14/1987	1987	Power Operation	Electrical	3	8
608	6/17/1987	1987	Low Power Operation	Electrical	1	1
611	7/2/1987	1987	Low Power Operation	Electrical	12	12
614	7/10/1987	1987	Power Operation	Electrical	3	3
625	9/17/1987	1987	Power Operation	Electrical	1	14
642	11/4/1987	1987	Power Operation	Electrical	45	50
644	11/10/1987	1987	Undetermined	Electrical	10	10
654	12/11/1987	1987	Power Operation	Electrical	1	1
656	12/17/1987	1987	Power Operation	Electrical	25	30
665	1/19/1988	1988	Low Power Operation	Electrical	10	10
667	1/28/1988	1988	Low Power Operation	Electrical	7	7
673	2/8/1988	1988	Low Power Operation	Electrical	2	2
708	5/10/1988	1988	Low Power Operation	Electrical	3	8
726	6/11/1988	1988	Low Power Operation	Electrical	3	17
735	7/21/1988	1988	Power Operation	Electrical	2	13
745	8/17/1988	1988	Power Operation	Electrical	5	10
755	10/5/1988	1988	Power Operation	Electrical	2	3
792	7/15/1988	1988	Power Operation	Electrical	10	5
821	12/22/1990	1990	Power Operation	Electrical (to oil)	20	20
876	3/8/1992	1992	Low Power Operation	Electrical	6	6
914	11/20/1985	1985	Low Power Operation	Electrical	20	23
922	7/10/1987	1987	Power Operation	Electrical	3	3
942	3/5/1989	1989	Power Operation	Electrical	6	15
977	1/19/1990	1990	Low Power Operation	Electrical	9	9
978	1/22/1990	1990	Low Power Operation	Electrical	2	2
1034	10/15/1996	1996	Power Operation	Electrical	10	10
1053	8/19/1989	1989	Power Operation	Electrical	7	7
1097	11/15/1986	1986	Low Power Operation	Electrical	95	95
1100	4/18/1989	1989	Power Operation	Electrical	5	5
1124	10/7/1986	1986	Undetermined	Electrical	4	4
1129	2/15/1989	1989	Low Power Operation	Electrical	1	1
1133	11/7/1989	1989	Undetermined	Electrical	5	5
1135	4/6/1990	1990	Low Power Operation	Electrical	24	24

Table 14-3 (continued)
List of Fire Events for Original and Revised Suppression Curves

Incident No.	Date	Year	Mode of Operation	Suppression Curve	Fire Suppression Time (T_{supp})	
					Original NUREG/ CR-6850 Value [min]	Revised FAQ 50 Value [min]
1137	6/7/1990	1990	Low Power Operation	Electrical	1	1
1139	7/9/1990	1990	Power Operation	Electrical	3	3
1141	9/10/1990	1990	Undetermined	Electrical	5	5
1142	12/19/1994	1994	Power Operation	Electrical	10	10
1160	9/27/1991	1991	Undetermined	Electrical	5	5
1163	2/29/1992	1992	Undetermined	Electrical	5	5
1173	2/20/1994	1994	Low Power Operation	Electrical	12	12
1213	2/9/1995	1995	Power Operation	Electrical	5	5
1262	11/2/1990	1990	Low Power Operation	Electrical	3	3
1264	10/3/1991	1991	Power Operation	Electrical	1	1
1270	10/12/1992	1992	Power Operation	Electrical	1	1
1276	7/25/1993	1993	Power Operation	Electrical	35	35
1335	3/3/1992	1992	Power Operation	Electrical	7	7
1337	3/31/1989	1989	Low Power Operation	Electrical	9	9
1339	6/28/1990	1990	Low Power Operation	Electrical	29	29
1487	4/17/1987	1987	Power Operation	Electrical	2	2
1489	10/26/1987	1987	Low Power Operation	Electrical	2	2
1491	6/11/1990	1990	Low Power Operation	Electrical	2	2
1501	10/11/1994	1994	Low Power Operation	Electrical	2	2
1504	8/15/1995	1995	Low Power Operation	Electrical	10	10
1509	11/23/1998	1998	Low Power Operation	Electrical	1	1
1511	3/19/1999	1999	Power Operation	Electrical	2	2
2127	5/25/1996	1996	Undetermined	Electrical	2	2
2161	7/10/1996	1996	Low Power Operation	Electrical	2	2
2179	1/12/1994	1994	Undetermined	Electrical	22	22
2190	1/8/1997	1997	Undetermined	Electrical	45	45
2191	3/7/1994	1994	Undetermined	Electrical	2	2
2211	2/13/1997	1997	Power Operation	Electrical	10	10
2219	3/21/1996	1996	Undetermined	Electrical	2	2
2227	3/2/1997	1997	Power Operation	Electrical	2	2
2236	10/22/1997	1997	Power Operation	Electrical	10	10
2251	1/16/1998	1998	Power Operation	Electrical	10	10
2255	1/11/1993	1993	Undetermined	Electrical	2	2
2269	10/31/1994	1994	Power Operation	Electrical	2	2
2272	11/19/1995	1995	Undetermined	Electrical	10	10
2273	9/25/1995	1995	Undetermined	Electrical	2	2

Table 14-3 (continued)
List of Fire Events for Original and Revised Suppression Curves

Incident No.	Date	Year	Mode of Operation	Suppression Curve	Fire Suppression Time (T_{supp})	
					Original NUREG/ CR-6850 Value [min]	Revised FAQ 50 Value [min]
2276	7/6/1995	1995	Power Operation	Electrical	10	10
2281	5/14/1998	1998	Power Operation	Electrical	10	14
2305	6/7/1998	1998	Undetermined	Electrical	2	2
2311	9/1/1999	1999	Power Operation	Electrical	2	2
2313	8/16/1999	1999	Power Operation	Electrical	2	2
2314	8/24/1999	1999	Power Operation	Electrical	10	10
2319	5/6/1999	1999	Undetermined	Electrical	2	2
2329	11/29/1992	1992	Power Operation	Electrical	2	2
2336	8/22/1990	1990	Power Operation	Electrical	2	2
2339	10/14/2000	2000	Power Operation	Electrical	10	10
2349	7/1/1998	1998	Power Operation	Electrical	10	10
2351	8/12/1997	1997	Power Operation	Electrical	2	2
2353	10/14/1996	1996	Power Operation	Electrical	2	2
2375	2/19/1999	1999	Power Operation	Electrical	2	2
2377	10/23/2000	2000	Low Power Operation	Electrical	2	2
2378	2/25/2000	2000	Power Operation	Electrical	10	12
2387	11/18/1993	1993	Power Operation	Electrical	2	2
2416	11/5/2000	2000	Low Power Operation	Electrical	10	10
2426	5/15/2000	2000	Power Operation	Electrical	22	22
2428	8/16/2000	2000	Power Operation	Electrical	22	22
2441	12/27/2000	2000	Power Operation	Electrical	2	2
2445	10/5/1987	1987	Undetermined	Electrical	2	2
2447	8/1/1987	1987	Undetermined	Electrical	2	2
2476	1/23/1989	1989	Undetermined	Electrical	10	10
433	7/20/1984	1984	Power Operation	Flammable Gas	46	46
512	2/17/1986	1986	Power Operation	Flammable Gas	9	9
528	6/19/1986	1986	Low Power Operation	Flammable Gas	60	72
1516	1/13/1998	1998	Power Operation	Flammable Gas	20	10
2356	8/31/1992	1992	Power Operation	Flammable Gas	60[23]	60
947	1/3/1989	1989	Power Operation	High-Energy Arcing Faults	46	59
2175	6/10/1995	1995	Power Operation	High-Energy Arcing Faults	57	76
2424	2/3/2001	2001	Power Operation	High-Energy Arcing Faults	136	141
260	6/30/1981	1981	Low Power Operation	Oil	1	5

[23] Cited duration is 60+ minutes.

Table 14-3 (continued)
List of Fire Events for Original and Revised Suppression Curves

Incident No.	Date	Year	Mode of Operation	Suppression Curve	Fire Suppression Time (T_{supp})	
					Original NUREG/ CR-6850 Value [min]	Revised FAQ 50 Value [min]
262	7/14/1981	1981	Power Operation	Oil	8	8
263	7/16/1981	1981	Power Operation	Oil	1	1
266	7/24/1981	1981	Power Operation	Oil	15	15
296	1/9/1982	1982	Low Power Operation	Oil	40	45
476	6/26/1985	1985	Power Operation	Oil	10	10
477	6/29/1985	1985	Power Operation	Oil	3	10
495	11/2/1985	1985	Low Power Operation	Oil (Deleted)	20	23
508	1/25/1986	1986	Low Power Operation	Oil	1	1
524	5/10/1986	1986	Power Operation	Oil	9	34
535	8/13/1986	1986	Low Power Operation	Oil	3	11
559	2/8/1987	1987	Low Power Operation	Oil	4	21
566	3/1/1987	1987	Low Power Operation	Oil	25	30
662	1/8/1988	1988	Power Operation	Oil	60	60
710	5/10/1988	1988	Low Power Operation	Oil	27	27
736	7/24/1988	1988	Power Operation	Oil	15	23
737	7/29/1988	1988	Power Operation	Oil	3	7
765	11/27/1988	1988	Low Power Operation	Oil	3	3
811	4/17/1992	1992	Undetermined	Oil	1	1
824	7/13/1992	1992	Power Operation	Oil	15	15
875	5/27/1990	1990	Low Power Operation	Oil	1	1
961	8/11/1991	1991	Power Operation	Oil	11	18
1023	8/16/1993	1993	Power Operation	Oil	10	5
1108	6/6/1989	1989	Power Operation	Oil	4	4
1110	2/2/1990	1990	Power Operation	Oil	5	5
1263	3/8/1991	1991	Low Power Operation	Oil	6	6
1482	1/22/1986	1986	Power Operation	Oil	10	5
1483	3/13/1986	1986	Power Operation	Oil	10	5
1485	7/20/1986	1986	Low Power Operation	Oil	10	5
1506	2/24/1998	1998	Power Operation	Oil	2	2
1507	5/11/1998	1998	Power Operation	Oil	2	2
1514	10/9/1997	1997	Power Operation	Oil	2	2
2183	9/13/1996	1996	Undetermined	Oil	45	45
2345	11/3/2000	2000	Power Operation	Oil	2	2
2388	12/16/1993	1993	Power Operation	Oil	10	10
2422	8/24/2000	2000	Power Operation	Oil	10	10
368	2/16/1983	1983	Power Operation	Outdoor Transformers	1	12

Table 14-3 (continued)
List of Fire Events for Original and Revised Suppression Curves

Incident No.	Date	Year	Mode of Operation	Suppression Curve	Fire Suppression Time (T_{supp}) Original NUREG/ CR-6850 Value [min]	Fire Suppression Time (T_{supp}) Revised FAQ 50 Value [min]
405	11/14/1983	1983	Power Operation	Outdoor Transformers	40	40
407	12/23/1983	1983	Power Operation	Outdoor Transformers	120	120
734	7/17/1988	1988	Power Operation	Outdoor Transformers	2	2
860	9/4/1992	1992	Power Operation	Outdoor Transformers	27	27
934	4/13/1986	1986	Power Operation	Outdoor Transformers	120	120
1033	6/23/1996	1996	Power Operation	Outdoor Transformers	20	20
1035	1/5/1999	1999	Power Operation	Outdoor Transformers	15	15
2283	6/23/1994	1994	Power Operation	Outdoor Transformers	2	2
2285	10/25/1994	1994	Power Operation	Outdoor Transformers	10	10
2331	7/19/1994	1994	Power Operation	Outdoor Transformers	2	2
2341	8/21/2000	2000	Power Operation	Outdoor Transformers	2	2
2407	10/18/2000	2000	Power Operation	Outdoor Transformers	2	2
2427	9/22/2000	2000	Power Operation	Outdoor Transformers	10	16
323	5/27/1982	1982	Power Operation	Transient	20	20
464	3/29/1985	1985	Undetermined	Transient	5	5
567	3/2/1987	1987	Power Operation	Transient	4	4
577	3/27/1987	1987	Power Operation	Transient	5	5
650	11/30/1987	1987	Power Operation	Transient	1	1
653	12/10/1987	1987	Power Operation	Transient	10	15
704	4/20/1988	1988	Power Operation	Transient	8	10
968	4/3/1989	1989	Undetermined	Transient	8	8
997	2/11/1992	1992	Undetermined	Transient	5	5
1050	1/1/1989	1989	Power Operation	Transient	5	5
1119	2/23/1989	1989	Power Operation	Transient	1	1
1128	3/10/1988	1988	Power Operation	Transient	10	10
1164	3/16/1992	1992	Undetermined	Transient	10	10
1171	4/13/1993	1993	Power Operation	Transient	1	1
1176	9/29/1994	1994	Power Operation	Transient (Removed)	25	25
1195	8/8/1990	1990	Power Operation	Transient	1	1
1345	2/6/1990	1990	Undetermined	Transient (Removed)	7	7
2253	4/1/1993	1993	Power Operation	Transient	2	2
2257	1/12/1994	1994	Undetermined	Transient	2	2
2262	7/2/1994	1994	Power Operation	Transient	45	45
2291	1/6/1993	1993	Undetermined	Transient	2	2
2386	11/13/1993	1993	Power Operation	Transient	10	10
2393	8/9/1995	1995	Power Operation	Transient	2	2

Table 14-3 (continued)
List of Fire Events for Original and Revised Suppression Curves

Incident No.	Date	Year	Mode of Operation	Suppression Curve	Fire Suppression Time (T_{supp})	
					Original NUREG/ CR-6850 Value [min]	Revised FAQ 50 Value [min]
2501	12/1/1999	1999	Power Operation	Transient	10	10
304	2/4/1982	1982	Power Operation	Turbine Generator	10	20
326	6/11/1982	1982	Power Operation	Turbine Generator	30	45
384	5/20/1983	1983	Power Operation	Turbine Generator	18	20
401	9/19/1983	1983	Power Operation	Turbine Generator	2	5
402	9/25/1983	1983	Power Operation	Turbine Generator	1	1
487	9/12/1985	1985	Power Operation	Turbine Generator	30	35
531	7/23/1986	1986	Power Operation	Turbine Generator	3	8
554	1/2/1987	1987	Power Operation	Turbine Generator	95	95
562	2/16/1987	1987	Power Operation	Turbine Generator	45	45
636	10/16/1987	1987	Power Operation	Turbine Generator	6	8
668	1/28/1988	1988	Power Operation	Turbine Generator	217	217
809	12/23/1989	1989	Power Operation	Turbine Generator	4	44
851	11/9/1991	1991	Power Operation	Turbine Generator	15	15
926	1/20/1989	1989	Power Operation	Turbine Generator	14	20
929	10/9/1989	1989	Power Operation	Turbine Generator	160	160
940	10/2/1987	1987	Power Operation	Turbine Generator	16	25
1024	12/25/1993	1993	Power Operation	Turbine Generator	2	2
1042	7/29/1994	1994	Power Operation	Turbine Generator	9	9
2124	6/15/1994	1994	Power Operation	Turbine Generator	60[24]	60
2229	8/1/1997	1997	Power Operation	Turbine Generator	10	10
2337	9/12/1991	1991	Power Operation	Turbine Generator	2	2
242	2/24/1981	1981	Power Operation	Welding	2	2
257	6/3/1981	1981	Power Operation	Welding	3	3
294	12/17/1981	1981	Undetermined	Welding	0	0
319	4/14/1982	1982	Power Operation	Welding	2	2
413	2/13/1984	1984	Power Operation	Welding	0	0
474	6/14/1985	1985	Power Operation	Welding	3	5
700	4/15/1988	1988	Power Operation	Welding	10	15
751	9/27/1988	1988	Undetermined	Welding	10	10
1095	9/8/1986	1986	Power Operation	Welding	2	2
1200	9/1/1992	1992	Power Operation	Welding	1	1
1201	10/5/1992	1992	Power Operation	Welding	0	0

[24] Cited duration is 60+ minutes.

Table 14-3 (continued)
List of Fire Events for Original and Revised Suppression Curves

Incident No.	Date	Year	Mode of Operation	Suppression Curve	Fire Suppression Time (T_{supp}) Original NUREG/ CR-6850 Value [min]	Fire Suppression Time (T_{supp}) Revised FAQ 50 Value [min]
1231	3/9/1993	1993	Undetermined	Welding	1	1
1232	1/25/1994	1994	Power Operation	Welding	0	0
1275	7/14/1993	1993	Undetermined	Welding	27	27
2126	7/22/1996	1996	Undetermined	Welding	2	2
2143	8/13/1993	1993	Undetermined	Welding	2	2
2188	3/5/1994	1994	Undetermined	Welding	2	2
2237	10/28/1997	1997	Power Operation	Welding	22	22
2469	7/14/1988	1988	Undetermined	Welding (Removed)	10	10

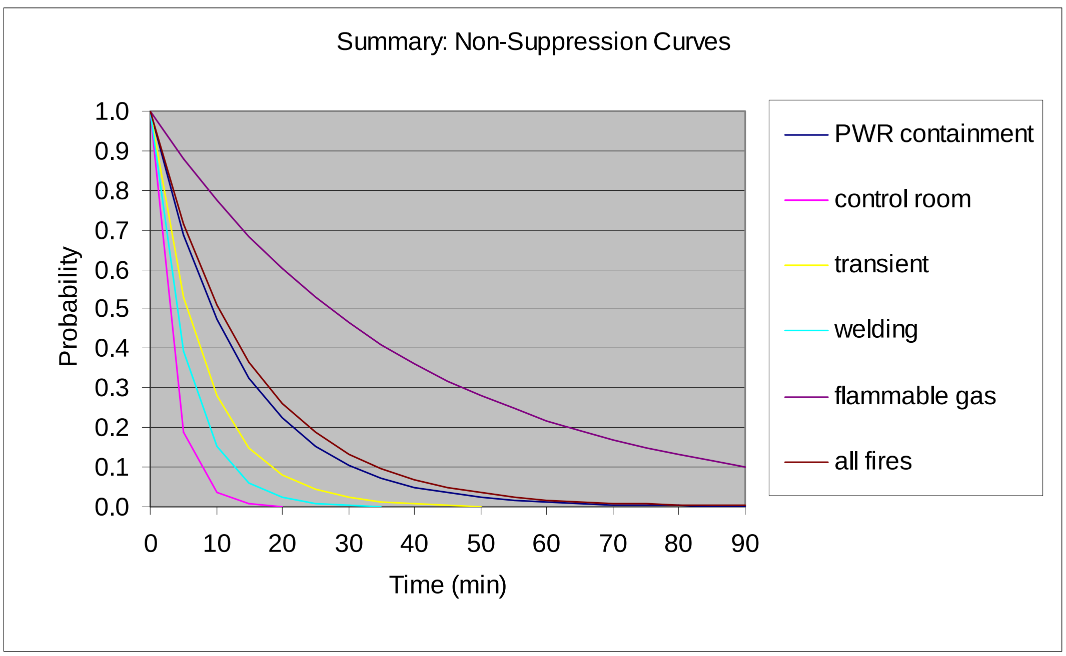

Figure 14-2
Revised nonsuppression curves Part A

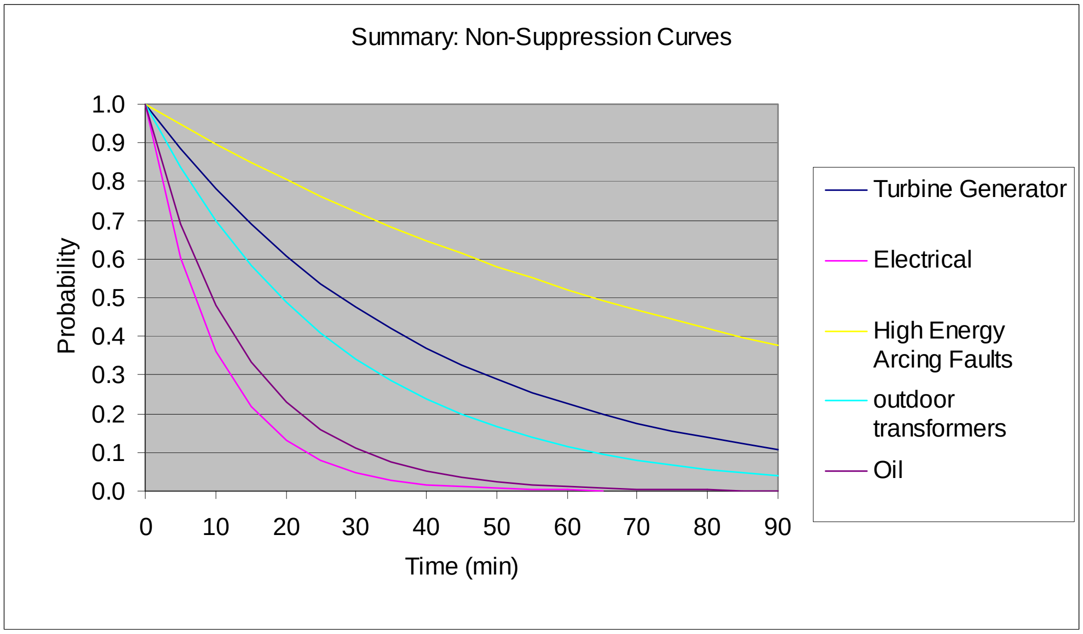

Figure 14-3
Revised nonsuppression curves Part B

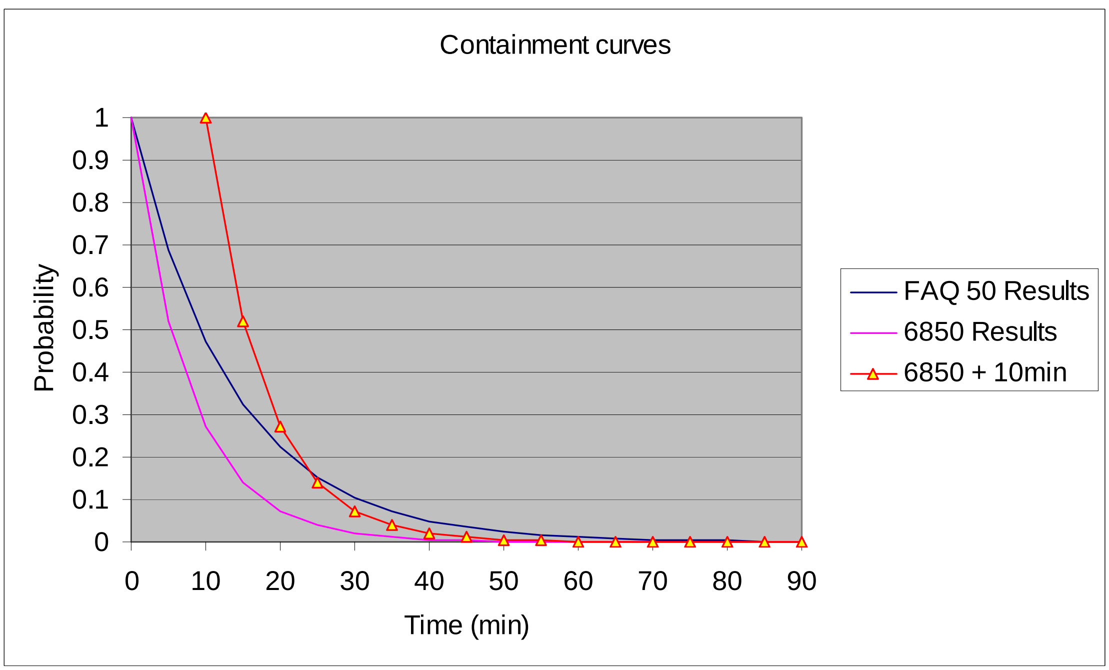

Figure 14-4
Revised nonsuppression curves for individual groupings

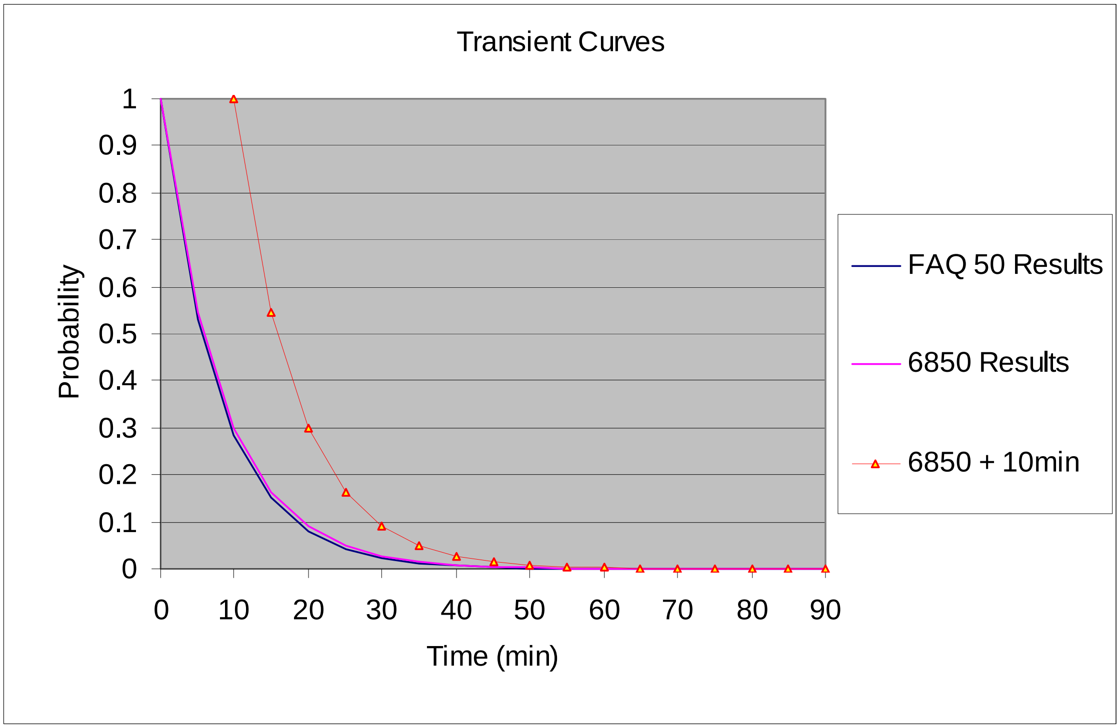

Figure 14-5
Revised nonsuppression curves for individual groupings

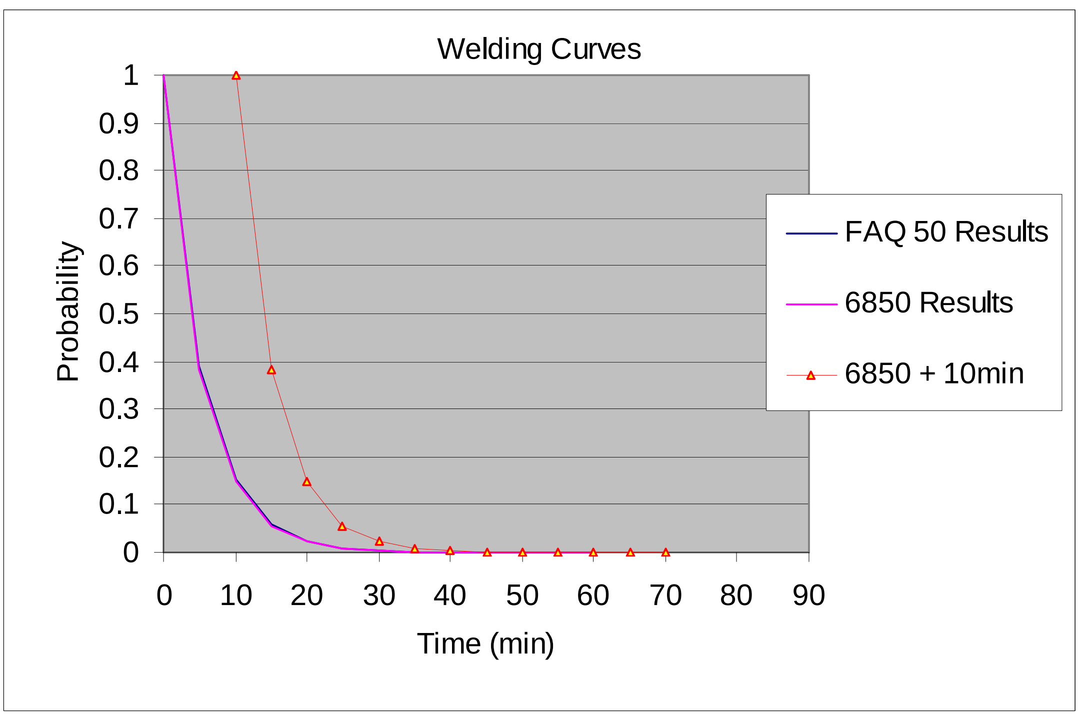

Figure 14-6
Revised nonsuppression curves for individual groupings

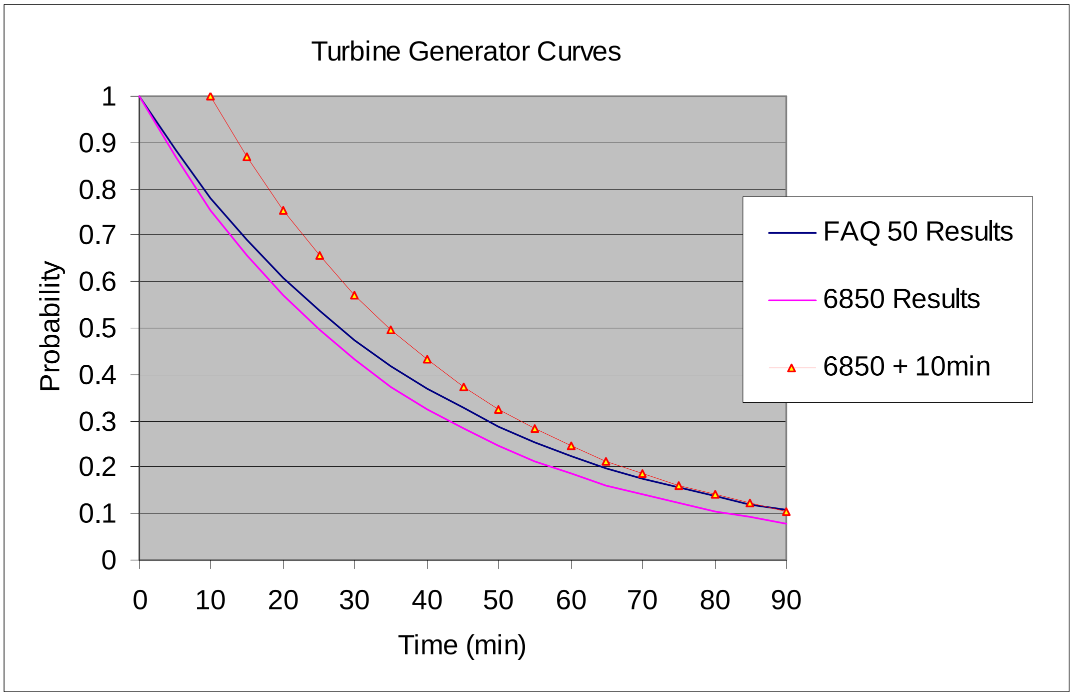

Figure 14-7
Revised nonsuppression curves for individual groupings

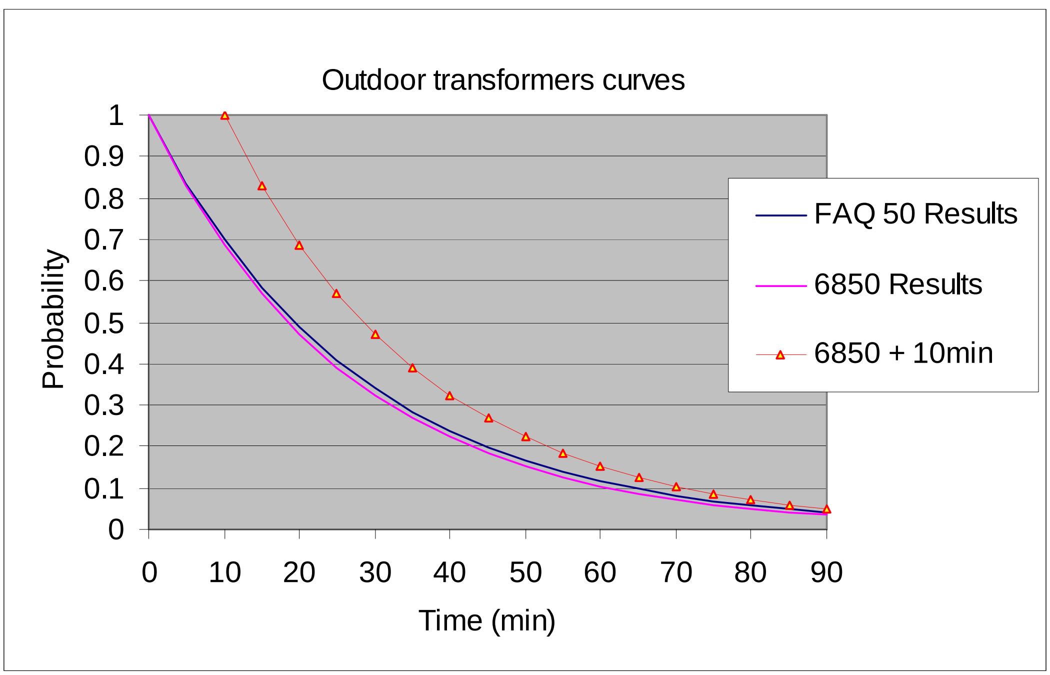

Figure 14-8
Revised nonsuppression curves for individual groupings

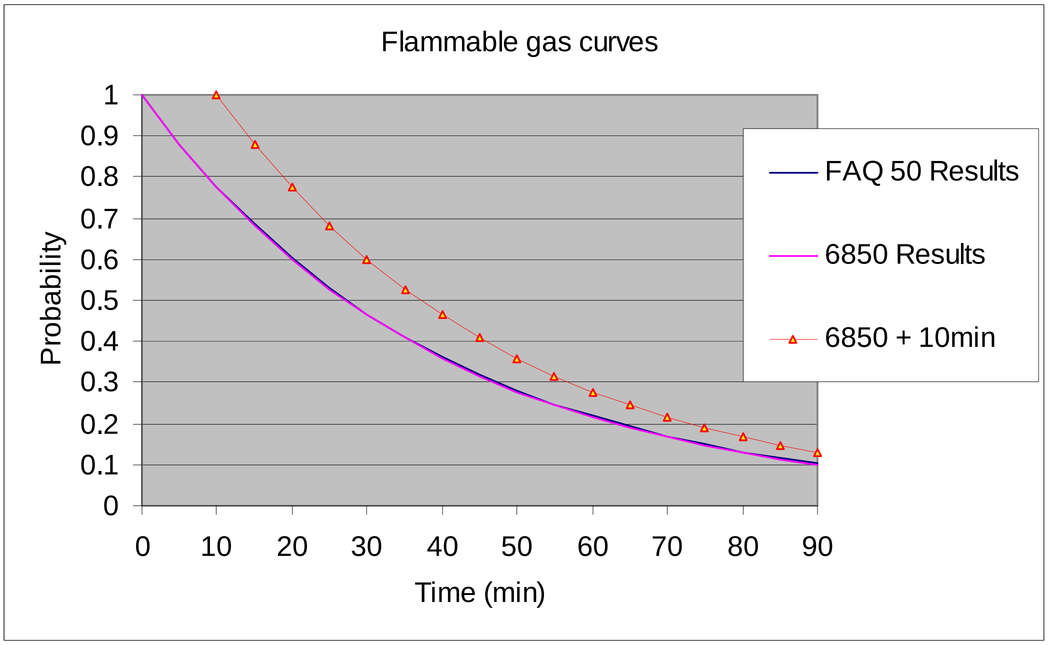

Figure 14-9
Revised nonsuppression curves for individual groupings

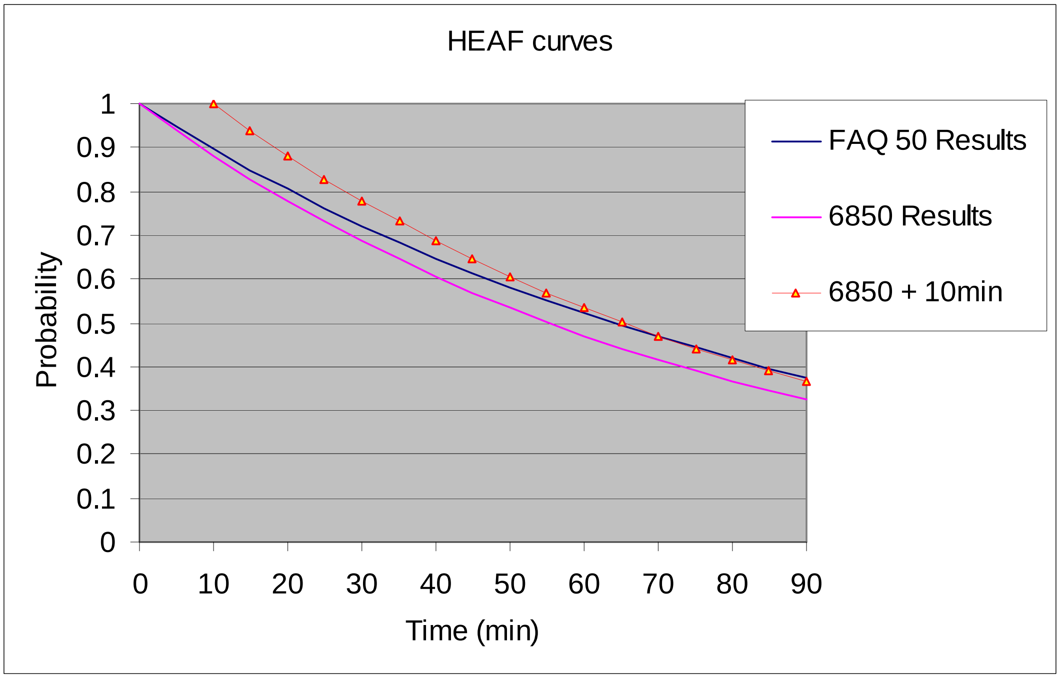

Figure 14-10
Revised nonsuppression curves for individual groupings

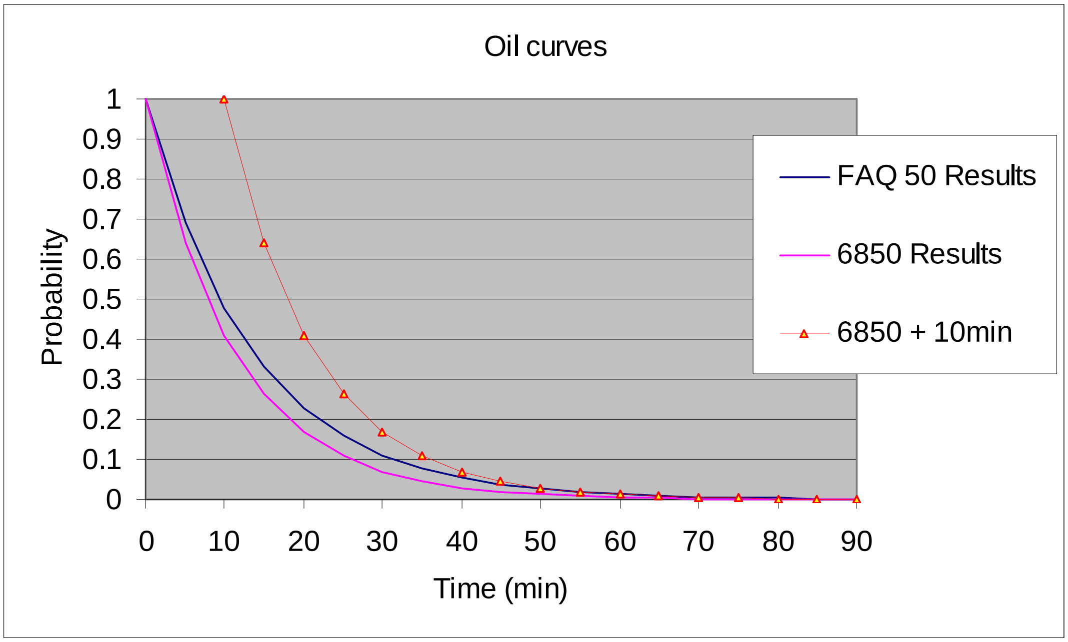

Figure 14-11
Revised nonsuppression curves for individual groupings

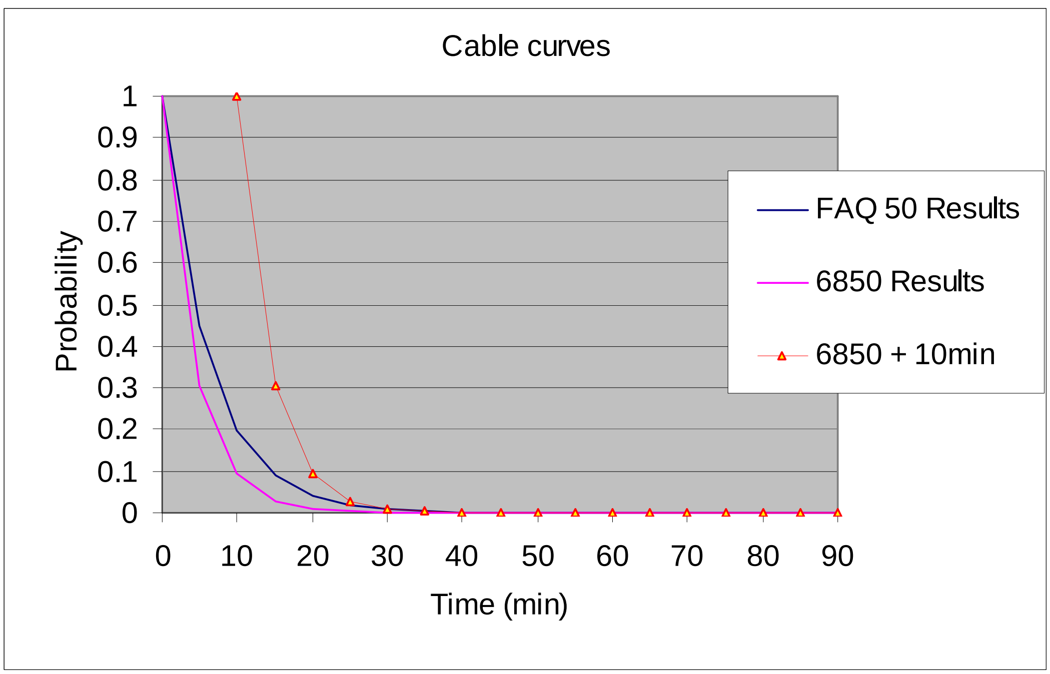

Figure 14-12
Revised nonsuppression curves for individual groupings

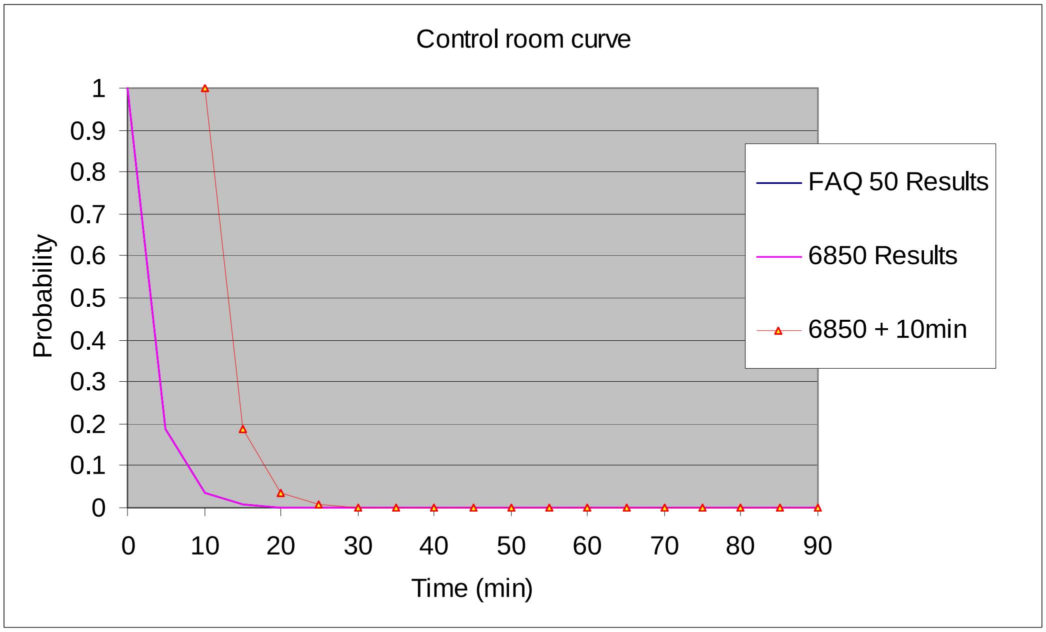

Figure 14-13
Revised nonsuppression curves for individual groupings

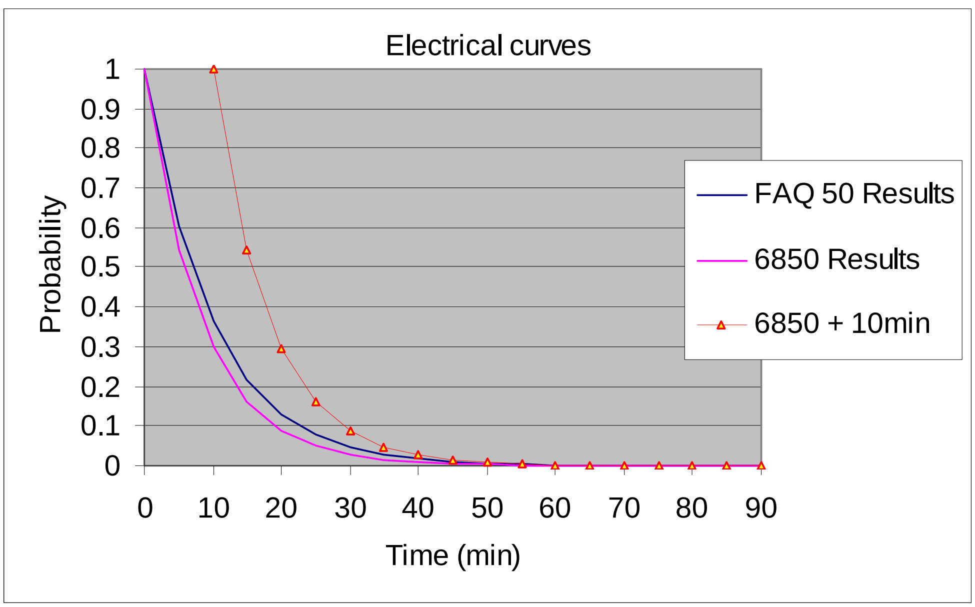

Figure 14-14
Revised nonsuppression curves for individual groupings

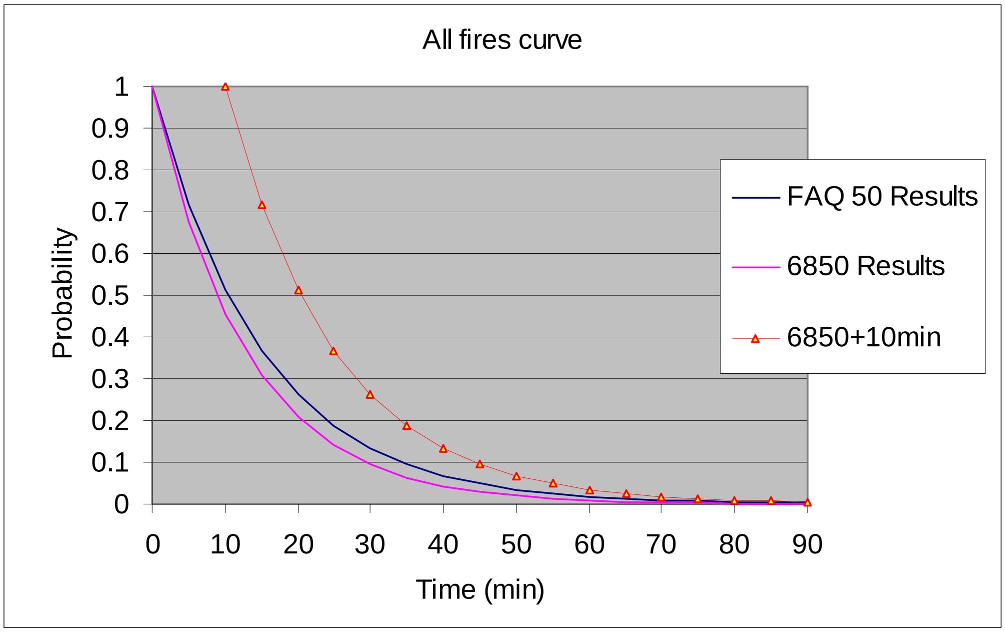

Figure 14-15
Revised nonsuppression curves for individual groupings

15
SPURIOUS OPERATION PROBABILITY (FAQ 08-0047)

15.1 Background

15.1.1 Purpose of FAQ 08-0047

FAQ 08-0047 was proposed to clarify guidance on quantification of spurious actuation probabilities for independent vs. dependent combinations. NUREG/CR-6850 (EPRI 1011989) provided a calculational scheme for multiple spurious actuation probabilities that implicitly assumed independence. As such, it would overestimate the joint probability in cases where the spurious actuations exhibited dependence. Subsequently, technical exchange took place between the Task Force and NRC staff, documented in Revision 1 to FAQ 08-0047 (ADAMS Accession No. ML082770662).

The NRC staff has reviewed the proposal to add this clarifying guidance on the discussion in NUREG/CR-6850 to NEI 04-02 as presented in FAQ 08-0047, Revision 1, and finds that nothing in this FAQ would prevent continued endorsement of NEI 04-02. Circumstances requiring guidance interpretation or new guidance are as follows.

Lessons learned from pilot review of the Fire PRA Standard indicate confusing guidance within NUREG/CR-6850 on the determination of circuit failure probabilities (spurious operation probabilities) for components with multiple cables within a fire area.

During the pilots, it was noticed that circuit analysts were basically assuming that many cables within a fire area could cause a spurious operation independently of the other cables affected by the same fire. However, under certain conditions, when the first cable is damaged (either from spurious operation or blowing the fuse in the circuit), the damage to the other cables does not affect the outcome, i.e., the likelihood of a spurious actuation of the component is not increased.

Particularly, spurious actuation from the second cable contributes to increased spurious actuation probability of the component when the second cable has a separate power supply. NUREG/CR-6850 doesn’t provide guidance for looking at the independence or dependence of cable failures, and the FAQ information below has been developed to provide this guidance.

15.2 Resolution

A potential issue has been identified that could lead to the development of highly conservative estimates of the conditional probability of spurious actuations in cases where a given fire scenario may lead to the failure of more than one cable capable of inducing the spurious actuation. In particular, NUREG/CR-6850, EPRI TR 1011989, contains a specific statement as follows:

> When more than one cable can cause the component failure mode of concern, and those cables are within the boundary of influence for the scenario under investigation, the probability estimates associated with all affected cables should be considered when deriving a failure estimate for the component. In general, the probabilities should be combined as an "Exclusive Or" function, as shown: (with corresponding equation).

This statement appears twice in Chapter 10; namely in Section 10.5.3.1, page 10-9, bullet list item #3 (top of page) and in Section 10.5.3.1, page 10-11, bullet list item #4.

This treatment assumes that the cable failures and corresponding circuit responses are independent. However, in various cases, the cable failures and the potential for specific circuit effects will not, in fact, be independent. In such cases, use of the "exclusive or" combinatorial approach would overestimate the overall spurious actuation likelihood. Clarification of this guidance is needed.

15.2.1 Background

One key consideration with respect to interpreting and clarifying the cited guidance is the manner in which the available test data were evaluated in the generation of the current estimates of spurious actuation likelihood. In that evaluation (e.g., see the expert panel report, EPRI 1006961), circuit faults given cable failure were classified as either "spurious actuation" or "fuse blow." That is, the panel did not explicitly consider potential intermediate modes of cable faulting, but looked at effectively the "bottom line" question; namely, did the cable's failure lead to a spurious operation prior to loss of circuit power, or did circuit power trip prior to observation of a spurious actuation?

To illustrate the potential for misapplication of the existing guidance, consider a case where either of two cables in the same fire area might cause spurious actuation of a motor-operated valve. This situation is not uncommon for areas such as motor control center (MCC) or switchgear rooms where one control cable runs from the control room to the switchgear or MCC, and a second control cable runs from the switchgear or MCC to the valve itself. In such cases, it is often possible to induce a spurious actuation due to faults in either cable. For this type of circuit, both of the control cables would typically be powered by a common control power transformer, likely located in the switchgear or MCC itself.

If any fire scenario in the room could fail both cables, then application of the passage cited above would imply that the total probability of spurious actuation would be based on combining the two individual values. Taking 0.3 as an example of a typical spurious actuation conditional probability value (given cable failure), the combined probability would be (0.3+0.3–(0.3*0.3)), or 0.51.

However, for this particular case, the actual spurious actuation behavior would be driven entirely by the first cable failure (regardless of which of the two cables actually fails first). Once the first cable fails, only two results are possible in the context of the spurious actuation likelihood values. Either a spurious actuation would occur, or a fuse-blow failure would deenergize the circuit prior to spurious actuation. In either case, failure of the second cable is irrelevant. In particular, for this type of case, a fuse-blow failure induced by the first cable failure would also deenergize the second cable. Thus the second cable would be unable to induce a spurious actuation, lacking the necessary control power energized source. Hence for this case, the correct spurious actuation likelihood would be that associated with the first cable to fail, or 0.3.

In order for the "exclusive or" combinatorial approach to be appropriate, the different cables would need to be independently capable of actuating the component of interest. This might, for example, be the case when a single valve is controlled by more than one control circuit, each with its own independent power supply. For example, a pump outlet valve would typically be controlled by one circuit associated with operation of the pump itself, but might also be controlled by a second independent circuit if, for example, closure of the valve was necessary to the successful operation of another plant system (e.g., to prevent backflow through the pump given reorientation of the plant flow configuration). Another example of this independence test would be an air-operated valve that is controlled by two or more separate solenoid valves. The valve is controlled mechanically through the porting of air to/from the AOV actuator, which can be controlled by one or more SOVs. These SOVs may be provided with independent electrical circuits and cables. Since each solenoid/electrical circuit can independently cause the valve to actuate, the probability for spurious operation is the mathematic sum of the independent hot short probabilities (a blown fuse in the first solenoid circuit does not prevent a spurious actuation from a hot short in the second SOV circuit).

However, in most cases, the circuit failure probability for a single cable should be used rather than adding the failure probability for each cable. A general exception, in addition to the specific examples above, is as follows:

- Target cables that are powered from a separate/alternate power supply, typically powering a relay or other separate device, where a ground fault (single or multiple ground fault) or blown fuse would not affect the primary circuit, should be considered separately. These circuits, referred to as either auxiliary or "off-scheme" circuits, often provide automatic operation of the component from an instrument/control circuit. Failure of these circuits would not, in general, prevent operation of the component through either operator action or by spurious operation of the circuit.

The following guidance is recommended for determination of the circuit failure probability for both initial screening and detailed FPRA analysis. The guidance applies for both intercable and intracable failures.

15.2.2 Initial Circuit Failure Probability Determination

1. For components with no auxiliary or off-scheme circuits (powered from a separate power supply), the circuit failure probability is assigned based on the limiting (highest) circuit failure probability for the cables within the fire area/compartment.
2. For components with auxiliary or off-scheme circuits, the circuit failure probability is based on the sum of a) the limiting (highest) circuit failure probability for the primary circuit and b) the limiting (highest) circuit failure probability for the auxiliary/off-scheme circuit. The individual circuit failure probabilities should be combined using the “exclusive or” method.
3. If circuit analysis has not been performed to determine if auxiliary or off-scheme circuits are present for the component, then the circuit failure probability is assigned based on an “exclusive or” sum of the two highest circuit failure probabilities for the component cables.

The auxiliary or off-scheme circuits would not include a second/alternate power supply. Components with separate power supplies are not affected by hot shorts in the separate supply, since the required electrical separation requires isolation from the main supply. Therefore, only a single cable from an auxiliary or off-scheme circuit contributes to the increased spurious actuation probability. For example, if a swing pump can be powered from both the A train and the B train, hot shorts on the B train should not affect pump operation when the pump is physically connected to the A train power supply. The detailed circuit analysis should include this consideration when determining cables and circuits that can affect component operation.

15.2.3 Detailed FPRA Circuit Failure Probability Determination

Once a detailed fire scenario analysis is performed, where detailed circuit routing has been determined, the location of each circuit can be accounted for in the FPRA. In this case, the cable initially damaged determines the circuit failure probability. If the primary and auxiliary/off-scheme circuit cable are contained within the same cable tray or are estimated to be damaged at the same time, the guidance above for initial circuit failure probability determination would apply. For other circuits, the following can be used:

1. If the primary circuit cable is damaged first, then the circuit failure probability is assigned based on the initial cable damaged.
2. If the auxiliary or off-scheme cable is damaged first, then the circuit failure probability for the component is determined from the “exclusive or” sum of circuit failure probabilities for a) the initial auxiliary/off-scheme circuit cable damaged, and b) the initial primary circuit cable damaged.

Detailed circuit analysis and cable routing for the component should be performed to confirm application of the above guidance. When component circuits are determined to be unique, adjustments to the above guidance may be needed. For example, if spurious operation of a component requires circuit failures in two cables, then the model would need to be adjusted to account for damage to each of the various combinations of cables within the fire scenario. Another example would be if the component contained two independent auxiliary/off-scheme circuits, both powered from separate power supplies. In this example, the initial spurious operation probability assigned would be a sum of the three circuit failure probabilities, and the detailed analysis could include consideration for the location and damage time for each of the cables. Finally, if failure of the auxiliary/off-scheme circuit prevents spurious operation of the component, then the off-scheme circuit would be treated as if it was a primary circuit, and the component circuit failure probability (initially assigned) would be based on the limiting (highest) circuit failure probability.

15.2.4 Summary

It is recommended that the “exclusive or” combinatorial approach for spurious actuation probabilities only be applied in cases where multiple cables can cause the undesired component effect and the postulated cable failure modes and effects are found to be independent. In cases where the cables of concern are dependent, the likelihood of spurious actuation should be determined by the first cable failure only. If the spurious actuation probability is different for the different cables of concern (e.g., due to differences in the cable or routing configuration), the analysis can either determine which cable would likely fail first for the given scenario, or simply bound the individual cable values.

16
TRANSIENT FIRE GROWTH RATE (FAQ 08-0052)

16.1 Background

FAQ 08-0052 was proposed on the treatment of transient fuel fires provided in NUREG/CR-6850 (EPRI 1011989), "EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities." The guidance was not explicit in two regards. First, the guidance does not explicitly state which of the available manual fire suppression reliability curves (the nonsuppression probability curves) should be applied to the case of transient fires in the main control room; the choices being the transient fire curve or the main control room (MCR) curve. Second, the guidance discusses fire modeling assumptions related to time-dependent fire growth profiles in general terms and in the specific case of electrical cabinet fires, but it does not discuss fire growth times for trash fires, one of the most commonly postulated transient combustible fires. The purpose of this FAQ is to clarify and update guidance provided in NUREG/CR-6850 (EPRI 1011989), Appendices G and P, for the treatment of transient fires in terms of both manual suppression and time-dependent fire growth modeling.

16.2 Resolution

16.2.1 Nonsuppression Curves for Transient Fires in the MCR

NUREG/CR-6850, EPRI 1011989, Appendix P, provides fire nonsuppression curves that characterize manual fire fighting effectiveness as a function of elapsed time since fire detection. Separate curves are provided for transient fires and for MCR fires. The guidance does not explicitly state which of these two fire nonsuppression curves should be applied to the case of a transient fire in the MCR. The recommended practice is that all fires occurring in the MCR, including transient fires, should be treated using the MCR fire nonsuppression curve.

This recommended guidance reflects (1) that application of the general transient fire nonsuppression curve would not be accurate because the MCR is continuously occupied; (2) that in developing the nonsuppression curves, the MCR curve included all reported MCR fires regardless of the fire source; and (3) the intent of the original authors of the RES/EPRI consensus methodology.

16.2.2 Transient Fire Growth Rates/Times

NUREG/CR-6850, EPRI 1011989, Appendix G, discusses in general terms the treatment of fires using a time-dependent fire growth profile. Specific fire growth time (time from ignition to peak fire heat release rate) recommendations are made for electrical cabinet fires. The guidance does not, however, address estimating the fire growth rate/time of transient fires.

The original intent of the authors of the RES/EPRI consensus method was that the use of a time-dependent fire growth profile is appropriate for any fire modeling case where a basis for such a profile can be established. It was not intended that this treatment be limited to cabinet fires. Hence, use of a time-dependent fire growth profile for transient fires, given adequate basis for the assumed growth time, is both appropriate and consistent with the intent of the original guidance.

Transient fires represent a wide range of potential fire sources, from liquid fuels (e.g., solvents) to solid fuels of various sizes, types, and configurations. It would be inappropriate to assume a single fire growth time for all transient fire sources. Rather, the fire growth time should reflect the nature of the transient fuel package that is assumed to be present in the fire scenario. Recommendations for appropriate fire growth times for three specific and common transient fire sources are detailed below. The following recommended fire growth times are the times from fire ignition to peak fire heat release rate. The fire growth profile is assumed to follow the classic “t-squared” curve as discussed in Appendix G of NUREG/CR-6850, EPRI 1011989. The three case recommendations are as follows.

Common trash cans (i.e., plastic or metal receptacles up to 33 gallons in size intended for temporary trash collection) that contain routine types of refuse (paper, plastics, and other solid materials) may be assumed to grow from zero to peak heat release rate in 8 minutes. This guidance is based largely on two experimental programs that have tested transient fuel packages of this type. The details are provided in Appendix A.

Common types of plant trash (paper, plastics, and other solid materials) that are contained in plastic trash bags but that are <u>not</u> contained within a plastic or metal receptacle may be assumed to grow from zero to peak heat release rate in 2 minutes. This guidance is based largely on one experimental program that has tested transient fuel packages of this type. The details are provided in Appendix B.

Transients associated with spilled solvents or other combustible or flammable liquid fuels should be assumed to reach peak intensity immediately upon ignition. This guidance is the most conservative possible approach but also reflects the fact that fires associated with a spill of a liquid fuel would, in fact, grow to peak intensity in a very short period of time.

It may be appropriate to assume a fire growth period for other types of transient fuels and, as noted above, it is the intent of the original guidance to allow for use of a time-dependent fire growth profile wherever appropriate. If a time-dependent fire growth profile is assumed for other types of transient fuel packages (e.g., packing material, boxes, wooden pallets, etc.) then the analyst should provide a basis for the assumed growth behavior that includes consideration of applicable fire test data and reflects the nature of the transient fuel package being considered.

16.3 References

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2. NEI 04-02, Guidance for Implementing a Risk-Informed, Performance-Based Fire Protection Program Under 10 CFR 50.48(c), Revision 1, Accession No. ML052590476
3. NFPA 805, Performance-Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants, 2001 Edition (available through the Public Document Room or NFPA)
4. Regulatory Guide 1.205, Risk-Informed, Performance-Based Fire Protection for Existing Light-Water Nuclear Power Plants, Accession No. ML061100174
5. NRC Regulatory Information Summary 2007-19, Process for Communicating Clarifications of Staff Positions Provided in Regulatory Guide 1.205 Concerning Issues Identified During The Pilot Application of National Fire Protection Association Standard 805, Accession No. ML071590227
6. NUREG/CR-6850 (EPRI 1011989), Accession Nos. ML050940183 (Vol. 1) and ML050940189 (Vol. 2)

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1. Performance-Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants, National Fire Protection Association, Brainard, MA, 805 Standard, 2001 Edition.
2. U.S. Nuclear Regulatory Commission, 10 CFR 50, RIN 3150-AG48, “Voluntary Fire Protection Requirements for Light Water Reactors Adoption of NFPA 805 as a Risk-Informed, Performance-Based Alternative,” Final Rule, June 2004 (Volume 69, Number 115).
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4. NEI 04-02, “Guidance for Implementing a Risk-Informed, Performance-Based Fire Protection Program Under 10 CFR 50.48(c),” Revision 1, September 2005. Accession No. ML052590476.
5. Regulatory Guide 1.205, “Risk-Informed, Performance-Based Fire Protection for Existing Light-Water Nuclear Power Plants,” May 2006. ADAMS Accession No. ML061100174.
6. ASME/ANS RA-Sa–2009, “Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications (Addenda to ASME/ANS RA-S-2008),” February 2009.
7. *Fire PRA Methods Enhancements: Additions, Clarifications, and Refinements to EPRI 1011989*. EPRI, Palo Alto, CA: 2008. 1016735.
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9. *Fire Events Database and Generic Ignition Frequency Model for U.S. Nuclear Power Plant*s. EPRI, Palo Alto, CA: 2001. 1003111.
10. “Experimental Investigation of Internally Ignited Fires in Nuclear Power Plant Control Cabinets: Part II, Room Effects Tests.” NUREG/CR-4527 Volume 1, January 1988.
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12. S. Nowlen, F. Wyant, Cable Response to Live Fire (CAROLFIRE) Test Report Volume 1: General Test Descriptions and the Analysis of Circuit Response Data, NUREG/CR-6931/V1, SAND2007-600, Sandia National Laboratories, Albuquerque, New Mexico, March 2007.
13. NRC Inspection Manual Chapter 0609, App. F – Fire SDP.
14. Gallucci, Raymond HV, PhD, Probabilistic/Statistical Examination of Cable Hot Short Durations Due to Nuclear Plant Fires, ANS PSA-08, Knoxville, TN, September 2008.

A
SUMMARY OF EXPERIMENTAL INSIGHTS FOR TRASH FIRES

There have been at least three studies that have experimentally evaluated fires involving trash receptacles (trash cans). The guidance in this FAQ resolution relies primarily on two of these three studies, the third being discounted as nonrepresentative to nuclear power plant (NPP) applications.

The first study was conducted at the University of California, Berkeley, Lawrence Berkeley Laboratory (LBL) [A-1]. This report describes a series of fire tests involving unconfined bags of trash and trash in commercial plastic trash receptacles. The difficulty with this particular test set lies in the nature of the “trash” used. The plastic bags were filled with either “eucalyptus duff,” which is to say, leaves and twigs gathered from under local eucalyptus trees, or with polystyrene cups, paper cups, and “fluffed up paper towels.” The trash cans were filled using empty pint-size wax/paper milk cartons obtained from the campus cafeteria. Many of the milk cartons were opened at both ends and then stacked in several layers filling the receptacle. The open ends of the carton were placed facing up/down. These open cartons were then loosely filled with shredded pieces from additional milk cartons.

These fuel packages are clearly not typical of the types of general refuse one might expect to find in a NPP. They had a clear tendency to maximize both fire growth rates and peak fire intensity given both the rather flammable nature of the fuels and the fact that the fuel configuration maximized the fuel surface area. As a result, great care should be exercised when applying these tests to NPP situations. In the case of the trash can fires, two other quality data sets of more direct relevance are available, so the LBL tests are discounted as nonrepresentative of NPP applications.

The second study was performed as a part of the early Nuclear Regulatory Commission (NRC) Fire Protection Research Program and involved a series of tests designed to characterize a range of transient fuel fire source packages that might be found, in particular, in the control room of a NPP [A-2]. This included testing of both large (30 gallon) and small (typical office-size) plastic trash receptacles filled with crumpled paper. The results of particular interest are those for fuel package 4 (tests 7 and 8) and fuel package 5 (test 9). The most relevant results for these tests are reproduced in Figures A-1 through A-3, which illustrate the heat release rate profiles for tests 7–9.

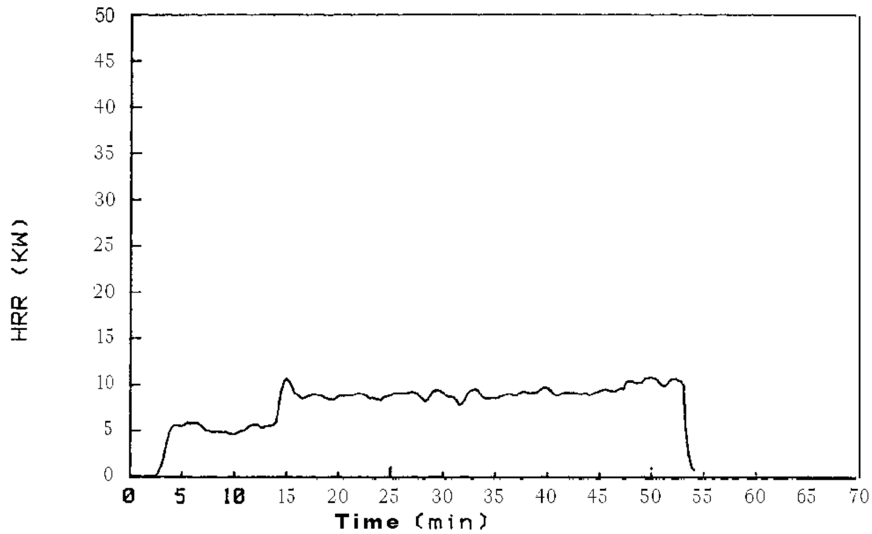

Figure A-1
Heat release rate for NUREG/CR-4680 test 7, small trash can fire

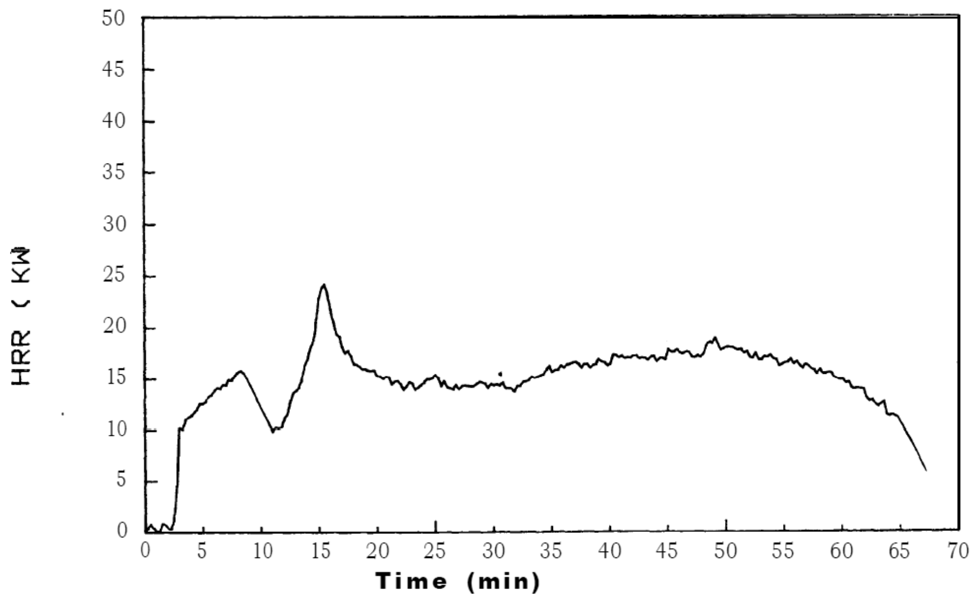

Figure A-2
Heat release rate for NUREG/CR-4680 test 8, small trash can fire

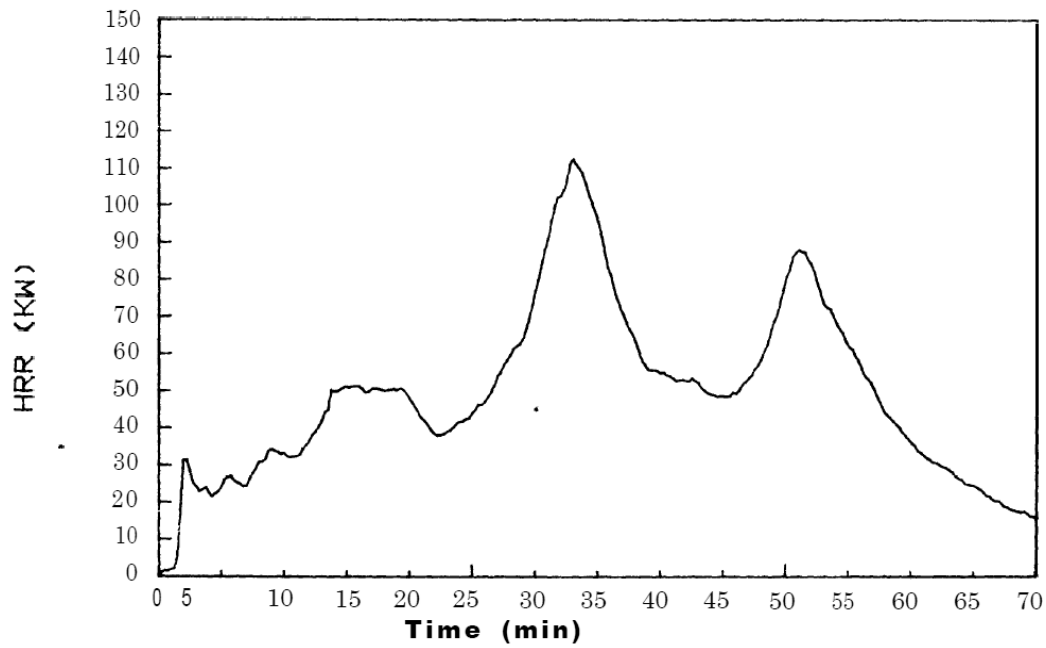

Figure A-3
Heat release rate for NUREG/CR-4680 test 9, large trash can fire

Fire intensity in all three tests follows a similar general trend with respect to the heat release rate profile. In the case of test 7, the trend is observable but generally less pronounced because this fire remained at a relatively low intensity throughout. The behaviors of primary interest are those trends that occur on a time scale of minutes rather than the shorter-term variability that occurs on a time scale of seconds or tens of seconds. Note that in each case, the fires show a rapid rise in fire intensity over the first 2–4 minutes, reflecting fire spread across the top surface of the paper filling the trash can. The general trend of increasing fire intensity continues as the fire spreads deeper into the crumpled paper filling the trash can. This continuation of the initial growth stage lasts for several additional minutes (up to 7–15 minutes), at which time an initial peak in fire intensity is observed. After this initial peak intensity is reached, the fires subside somewhat. During this subsidence period the trash can itself was observed to begin melting and to collapse in upon itself. Once the trash container itself ignites, fire intensity grows relatively quickly, reaching a second higher peak after 15–33 minutes. Overall, the behaviors of primary interest in each of the three tests are the initial peak reached in 7–15 minutes and the second larger peak reached in 15–33 minutes. In interpreting these test results, weight is given primarily to the observed time to reach the initial peak in fire intensity, which for these three tests were 7, 8, and 13 minutes, respectively.

The third study of interest [A-3] was performed at NIST and involved two experiments "conducted to help characterize the potential hazard from ignition of nominal 136 L (30 gal) trash containers made from high density polyethylene (HDPE) and loaded with cellulosic debris." The trash containers tested are illustrated in Figure A-4, and are quite similar to fuel package 5 as tested in NUREG/CR-4680, with the exception of the trash loading.

Figure A-4
Photograph of the trash receptacle tested in NISTFR-4018

In the case of the NIST tests “each trash container had 10 kg (22 lbs) of debris ‘typical’ of a construction site. The debris consisted of cut pieces of 2" X 4" lumber, sawdust, cardboard, paper, and cups, food wrappers, and paper bags from a fast food restaurant.” Again, the results of direct interest to this FAQ are the heat release rates. These results are reproduced in Figure A-5.

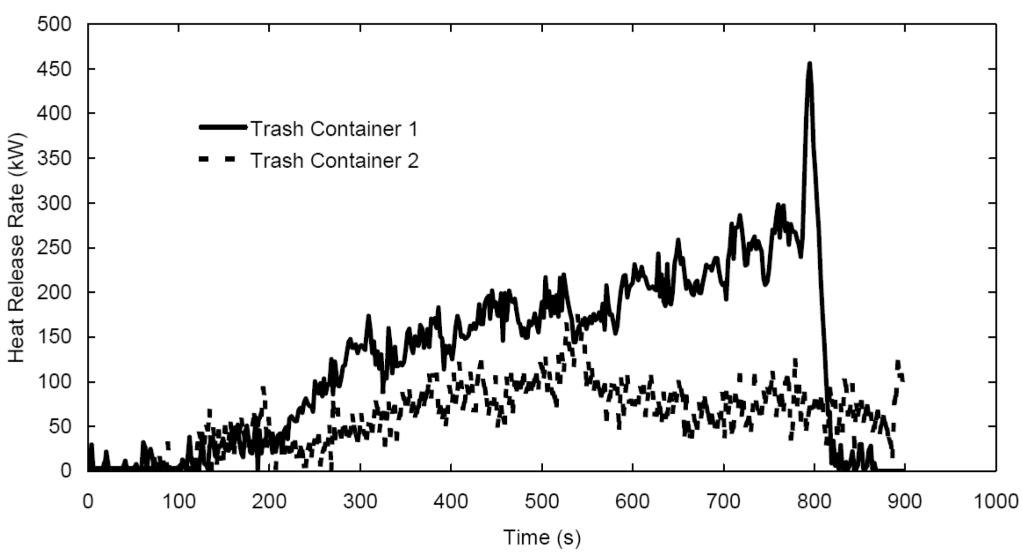

Figure A-5
Heat release rate test results for the two tests documented in NISTFR-4018

The NIST tests show a somewhat similar behavior to the SNL tests in terms of the initial fire growth. The first of the NIST tests (trash container 1) actually shows a steady climb in fire heat release throughout the test; the fire had not yet reached a true peak when it was suppressed at about 800 seconds (about 13 minutes). For the second test (trash container 2) a peak heat release rate is observed at about 550 seconds (about 9 minutes), followed by a period of relatively steady burning at a somewhat reduced intensity.

Overall, the five available tests indicate fire growth times that range from about 7 to 13 minutes. Based on these test results, the recommended practice for this type of fuel source, general refuse in a plastic trash receptacle, is to assume a fire growth time of 8 minutes.

It is also recommended that the same result be extrapolated to fires involving general refuse in a metal trash receptacle of similar size. This is because both of the cited studies noted that the initial fire growth behavior is actually associated with fire spread through the refuse and that the plastic trash receptacle became involved in the fire at a somewhat later time (i.e., after 8 or more minutes). Hence, similar initial growth behavior is likely to apply to metal trash receptacles, even though neither of the cited studies actually tested this type of receptacle.

It should be noted that a final study of potential interest is a National Bureau of Standards (NBS, now NIST) literature review completed in 1985 [A-4]. This review did not involve the conducting of any new tests, but did consider the results of prior test programs, including both the LBL and SNL tests cited here. There is one figure in particular presented in this report that is worthy of some discussion, namely Figure 11. This is a recommended heat release rate versus time profile that was developed to bound all of the observed trash fire curves. This particular figure shows an initial growth to peak of one minute. This initial growth rate is dominated by other types of trash fires and is not characteristic of the trash can fires. Hence, the application of this curve to a trash receptacle (trash can) fire would be conservative in comparison to the recommended practice developed here.

References

A-1. Von Volkenburg, D. R., et al., “Towards a Standard Ignition Source,” Lawrence Berkeley Laboratory, LBL-8306, October 1978.

A-2. S. P. Nowlen, “Heat and Mass Release for Some Transient Fuel Source Fires: A Test Report,” NUREG/CR-4680, SAND86-0312, Sandia National Laboratories (SNL), October 1986.

A-3. D.W. Stroup and D. Madrzykowski, “Heat Release Rate Tests of Plastic Trash Container,” National Institute of Standards and Technology (NIST), NISTFR-4018, April 24, 2003.

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B
SUMMARY OF EXPERIMENTAL INSIGHTS FOR TRASH BAG FIRES (FAQ 08-0052)

This appendix provides insights relative to the fire growth characteristics of trash bag fires as unique from the behavior of a fire involving trash confined to a trash receptacle (a trash can fire). The available tests potentially relevant to trash bag fires are documented in two reports [B-1, B-2].

The first report is the Lawrence Berkeley Laboratory (LBL) report cited and discussed in Appendix A of this report. The difficulties associated with the fuel loading in these tests have been described in Appendix A. Given the atypical nature of the fuel loading, care must be exercised in extrapolating these results to a more representative nuclear power plant (NPP) transient fuel load. Given that this is the only known study to report results for an actual trash bag fire, the results will be considered. The trash bag test results from the LBL study are summarized in Figures B-1 and B-2.

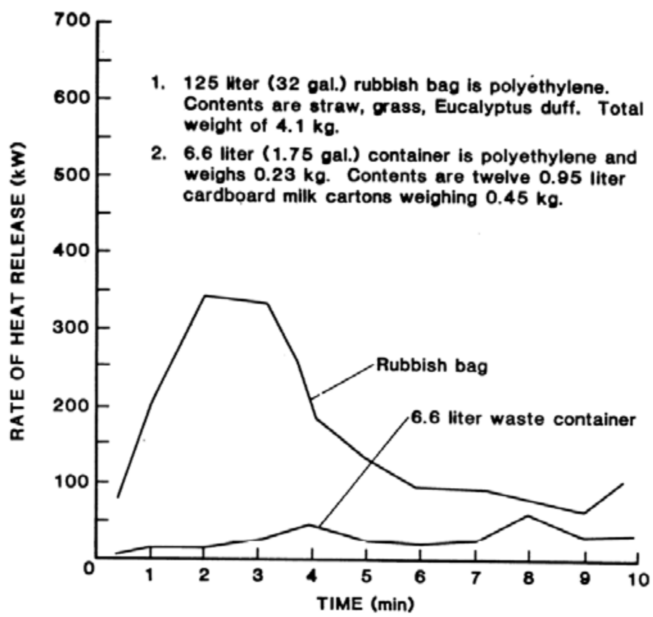

Figure B-1
Results of the LBL tests involving a trash bag filled with eucalyptus duff

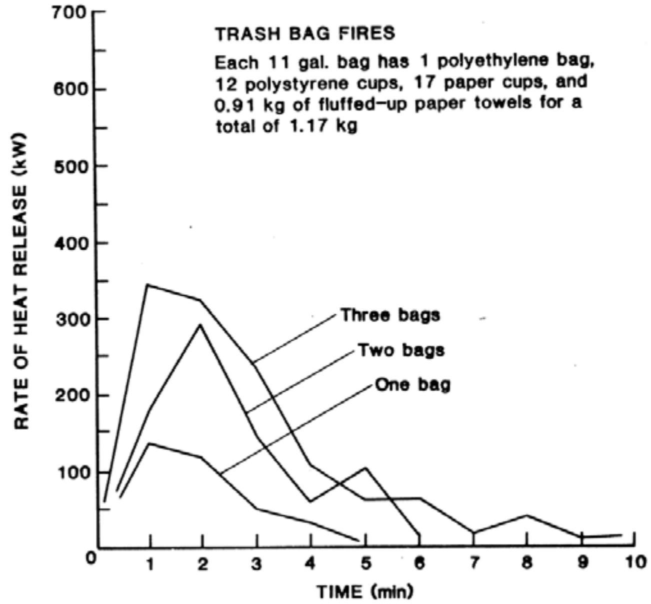

Figure B-2
Results of the LBL tests for trash bags filled with cups and paper towels

Figure B-1 compares the results of the first trash bag test to a test involving a small (6.6 liter or about 1.5 gallon) trash can. The trash bag fire grew to peak intensity in just 2 minutes. One interesting result here is that the trash bag fires grew in intensity more quickly than did nominally similar trash can fires. Figure B-2 illustrates the results of three tests involving one, two, and three trash bags, respectively. Note that the fires reached peak intensity in 1–2 minutes, again emphasizing the relatively rapid rate of fire growth compared to trash can fires. The explanation for this difference is that the trash bags alter two key factors. First, in the trash bag fires there is a relatively larger exposed fuel surface area compared to the trash can fires. In the trash bag fires, the fire is free to spread over the entire surface of the trash bags, whereas initial fire growth in the trash can was mainly associated with spread only over the upper surface of the trash within the trash can (e.g., rather than over the outer surface of the trash can itself). Second, the trash bag fires have freer access to oxygen in comparison to the trash can fires. For the trash can a two-way flow of oxygen into and then fire gases out of the trash can must be established (again given initial fire spread through the trash rather than the trash can itself). The trash bags create a more classical fire plume development pattern with cold air and oxygen flowing in from the sides and fire gases flowing upward above the fuel source. The trash bag configuration is more conducive to rapid fire development.

The only other effort that has explored transient fuel sources other than trash receptacles (trash cans) is the previously cited NUREG/CR-4680 [B-2]. This test program did not involve trash bags, but did include testing of a transient fuel package made up of stacked computer paper (15 lbs or a 3" stack) and crumpled paper (1.5 lbs) in a 12"x16"x12" cardboard box (fuel package 3, fire test 5). Figure B-3 illustrates this fuel package. This particular fuel package is roughly similar in nature to a trash bag fire in that the cardboard became involved in the fire relatively quickly and the box did not appear to substantially inhibit air flow to the burning fuel. The heat release rate result for this test is illustrated in Figure B-4. For the SNL test, the time to peak fire intensity was approximately 4 minutes.

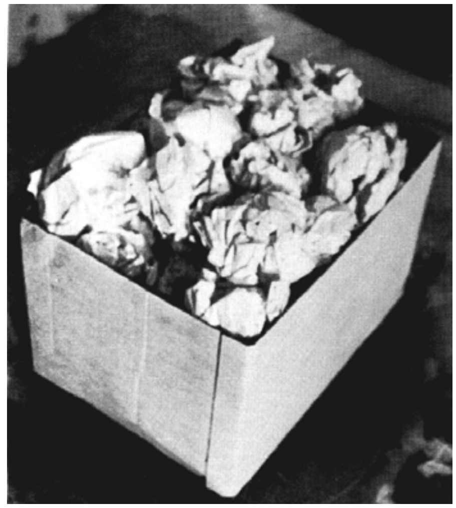

Figure B-3
SNL fuel package 3—box with crumpled paper

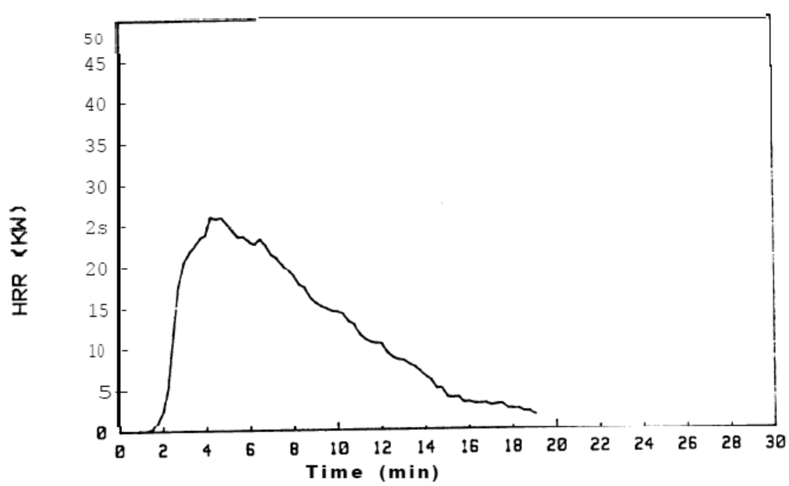

Figure B-4
The heat release rate profile from SNL test 5 involving fuel package 3

Overall, it is concluded that the LBL test results showing peak heat release rates being reached within 1 minute in two cases and 2 minutes in the third likely exaggerate the early rate of fire growth as compared to more typical trash fire configurations. However, the SNL tests showed a fire growth time of 4 minutes for a roughly similar fuel package. Both test efforts illustrate that trash fires occurring outside of a trash receptacle (trash can) will grow more rapidly than will fires involving similar fuels that are confined within a trash can.

Given the available test results, the recommended general practice for the case of a trash bag fire (i.e., general refuse collected into a plastic bag but not contained within a trash receptacle) is based on a blending of the SNL and LBL test results. For NPP applications, recommended practice for trash bag fires is to assume a fire growth time of 2 minutes.

As a final note, the SNL tests did involve two other small transient fuel source packages (fuel packages 1 and 2). However, both of these packages involved use of a solvent (1 qt of acetone) as a part of the fuel loading. The ignition of this solvent dominated the early fire behavior for these tests. These fuel packages are not considered representative of typical solid refuse (trash) that would exclude flammable liquids. Hence, these tests have not been considered in developing the transient fuel fire growth times discussed here.

References

B-1. Von Volkenburg, D. R., et al., “Towards a Standard Ignition Source,” Lawrence Berkeley Laboratory, LBL-8306, October 1978.

B-2. S. P. Nowlen, “Heat and Mass Release for Some Transient Fuel Source Fires: A Test Report,” NUREG/CR-4680, SAND86-0312, Sandia National Laboratories (SNL), October 1986.

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