ROADMAP FOR ATTAINING REALISM IN FIRE PRAS

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TABLE OF CONTENTS

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EXECUTIVE SUMMARY

Purpose

Over the past several years, industry has undertaken a large number of plant-specific Fire Probabilistic Risk Assessments (FPRAs). Many of these FPRAs have been performed in support of a transition to the risk-informed, performance-based fire protection requirements under 10 CFR 50.48(c). As these fire PRAs have moved toward completion, it has become evident to the industry practitioners that:

- The manner in which fires are characterized does not conform with operating experience;
- The level of quantified risk is overstated, as compared to operating experience; and
- There is an unevenness in the level of conservatism in the results that can mask key risk insights and result in inappropriate decision-making.

The purpose of this paper is to describe the departures from realism in the FPRAs that lead to these insights and to offer a path forward. Specifically, the paper provides evidence of the lack of realism, identifies the specific areas where the current methods are departing from realism, and provides a roadmap for the research and development of realistic methods and data needed to address these insights. This paper is built from the insights gained from the performance of a large number of industry FPRAs.

Background

The NRC Staff has communicated to the industry on a number of occasions that they consider the methods contained in NUREG/CR-6850/EPRI-1011989 [Ref. 1] to be "state-of-the-art." While NRC Regulatory Guide 1.200 Revision 2 addresses an ASME/ANS consensus fire PRA standard and provides for peer review to that standard, NRC has determined that fire PRAs developed for NFPA 805 must additionally justify departures from the specific methods contained in NUREG/CR-6850. For this reason, NUREG/CR-6850 is used as the primary reference for the methods and data used in the FPRAs reviewed to develop this report.

Fire PRAs are complex analyses. The realistic assessment of fire initiation, development, and plant response involves consideration of complex physical phenomena, system interactions, and human actions. The original plant-specific fire PRAs were developed to identify plant vulnerabilities as required by GL 88-20 Supplement 1, Individual Plant Examination for External Events (IPEEE). At that time, in the 1990s, there was limited detailed guidance on the methods and assumptions to be employed in these analyses. Consequently, the fire IPEEE analyses were not consistent, relied heavily on the judgment of analysts and reviewers, and were primarily focused on identifying vulnerabilities. While sufficient for the purposes of the IPEEE, these many of the plant-specific implementations of these methods were not robust enough to support the type of risk-informed regulatory applications being performed today.

In the late 1990s, NRC's Office of Research and EPRI established a joint activity to develop and document an improved methodology for FPRA. This methodology was published in 2005 as a joint publication, NUREG/CR-6850/EPRI 1011989. A subsequent supplement was published in late 2010 [Ref. 2] containing the results of some methods refinements specified by the NRC in responses to industry frequently asked questions (FAQs) addressed in the piloting of the evaluation process required by 10 CFR 50.48(c). These reports, henceforth referred to simply as NUREG/CR-6850, provide a set of methods, tools, and data for the conduct of a FPRA for a commercial nuclear power plant (NPP) application and provide a structured framework for the conduct of the overall analysis, as well as specific recommended practices to address each key aspect of the analysis.

The complexity of the FPRA process is addressed in NUREG/CR-6850 by establishing a structured set of discrete technical tasks that comprise the systematic evaluation of the fire hazards and risks, with each task having a set of simplifications and bounding assumptions. A key element of NUREG/CR-6850 is that it requires each task to create stand-alone work products that are passed from one task to the next. The methodology development process included attempts to pilot each of the tasks individually. An integrated pilot was never performed. Instead, the pilots tested only individual tasks. While this pilot process was effective in enhancing the methodology in many areas, it failed to investigate the implications of combining of the discrete tasks into an overall characterization of fire risk. Ultimately the methodology was published in 2005 without the benefit of a complete reference analysis. At that time, the report represented the collective best efforts of the authors to improve the state of practice.

In 2004, the NRC promulgated regulatory changes that allowed voluntary adoption of a new risk-informed, performance based approach to fire protection under 10 CFR 50.48(c) [Ref. 3]. These requirements incorporate by reference the requirements of National Fire Protection Association (NFPA) Standard 805 (NFPA-805) [Ref. 4]. The implementation of NFPA-805 under 10 CFR 50.48(c) depends on a plant-specific fire PRA.

In late 2007, risk quantification by the NFPA-805 pilot plants and others were arriving at unrealistic results. It became clear that the simplifications and bounding assumptions employed in the discrete tasks were contributing to these unrealistic results. The untested nature of the methodology and the incomplete piloting of the data, tools and method had not provided the opportunity earlier for the developers to modify those simplifications and assumptions that inappropriately drive the results. The NUREG/CR-6850 methods, tools, and data, including the refinements from Supplement 1, retain simplifications and bounding assumptions that skew the FPRA results such that they do not accurately characterize the risk profile and do not comport with industry operating experience.

In January 2008, a number of significant problems with the NUREG/CR-6850 methods were identified by the industry and documented in a letter from NEI to the NRC [Ref. 5]. The NFPA-805 Frequently Asked Question (FAQ) program was chosen as the means to document the resolution of issues. By the end of 2009, a number of FPRA-related FAQs had been closed by the NRC and one FPRA-related FAQ was withdrawn. In every case, the FAQ resolution incrementally moved the FPRA methods toward more realism, thus substantiating industry's claim that the methods were conservative. However, many of the final FAQs only partially resolved the original technical issue. By mid-2009, fire PRA FAQs were no longer being submitted. In December 2009, NEI notified the Commission [Ref. 6] that the FAQ process had failed to result in realistic methods and provided an initial draft of an EPRI FPRA action matrix that targeted the large number of areas of residual conservatism.

This report provides an update of the industry research activities in the areas that contribute significantly to the lack of realism in FPRAs.

Findings

A fire PRA is the aggregation of risks from a very large number of individual fire scenarios. Most recent FPRAs are comprised of many hundreds (some have more than a thousand) of individual fire scenarios. The risk from an individual fire scenario is a function of:

- The frequency of the fire event (F_{fire})
- The fire severity characteristics as a function of time (S(t))
- The probability of suppressing the fire event as a function of time (NSP(t)[1])
- The conditional core damage probability given the damage caused by the postulated fire ($CCDP_{damage}$)

$$\text{Scenario Fire Risk} = f\,(F_{fire}, S(t)_{fire}, NSP(t), CCDP_{damage})$$

In the NUREG/CR-6850 methodology, each of these inputs rely on simplified compartmentalization (e.g., binning) with generally bounding assumptions to define the scenario. This approach is useful for the scoping of the potential fire impacts, but does not represent the realistic likelihoods or effects. The implementation of the simplified approach and bounding assumptions has introduced biases that undermine scenario coherency. While some of these biases are individually modest, the combined effect is an overstatement of fire risks. In addition, the degree of the overstatement varies greatly from scenario to scenario, resulting in an unevenness that makes good risk-informed decision-making more difficult.

The problem lies not only in the individual tasks, but also in the way they are combined, therefore making enhancement of fire PRA methods complex. There is no single technical element that is driving the lack of realism. As identified in NEI's 2008 letter, it is the compounded conservatisms that are the problem.

[1] Typically this is expressed as a non-suppression probability, or the probability that the fire is not suppressed. It is defined as one minus the probability of successful suppression.

This report identifies 13 technical areas where further development and research is necessary to achieve improved realism:

- Fire event data characterization
- Fire severity characterization
- Credit for incipient detection
- Credit for suppression & control
- Fire growth assumptions
- Peak heat release rates
- Damage assessment
- Fire propagation
- Fire modeling
- Treatment of hot shorts
- Human reliability
- Modeling of control room fires
- PRA model advancement

<u>Results Inconsistent with Operating Experience</u>

The results of several industry fire PRAs have been reviewed and compared with operating experience. The evidence supports the industry's contention that the fire PRA methods are not generating realistic results, i.e., are not consistent with operating experience.

Since fire CDF values cannot be directly compared to operating experience, a number of intermediate results were compared to actual events documented in NRC programs that track events and event severity. First, a comparison of the predicted frequency of a fire involving one or more spurious operations was extracted from representative FPRAs. The frequency was on the order of 4E-3/reactor year, or once in every 250 operating years. Given a U.S. fleet of about 100 reactors, these FPRAs predict that a fire involving a spurious operation is expected to occur every 2 or 3 years across the industry. However, there have not been any fires that caused a spurious operation since the Browns Ferry fire in 1975.

Second, a comparison of the predicted frequency of a fire resulting in significant plant degradation was investigated. A FPRA can be interrogated to identify the computed conditional core damage probabilities (CCDP) for each scenario. These are a reflection of the damage considered for the fire scenario. The NRC uses CCDP as a measure of significance for events under the Reactor Oversight Process (ROP) and Accident Sequence Precursor (ASP) programs. A review several of FPRAs found that they predict multiple fire events per year involving high computed CCDPs. In fact, there is no evidence of this in either the ASP or ROP results. Thus, the NRC's operating experience programs do not align with the predictions generated by fire PRAs.

<u>Masking of Risk Insights</u>

The NRC's PRA Policy statement states that PRAs should be realistic. Consistent with this, the ASME/ANS PRA Standard [Ref. 7] identifies increasing realism as an indicator of increasing PRA capability. Significant conservatisms, especially in dominant contributors, are problematic in PRAs because they make identifying and understanding the important risk insights very difficult. Specifically, if the fire is assumed to damage more equipment and cables than would be realistically expected, then the computed baseline CDF will be conservatively estimated. The unintended consequence is that this conservatism can:

- Mask other important contributors
- Reduce understanding of the most effective means to reduce risk
- Potentially lead to underestimation of risk increases/decreases associated with plant changes/ configurations

These impacts confound risk-informed decision-making supported by these FPRAs and will hamper other efforts to apply these FPRAs in risk-informed applications.

Conclusions & Recommendations

Based on the results and insights from industry fire PRAs, the methods described in NUREG/CR-6850/EPRI TR-1011989 lead to significant conservatisms that bias the FPRA results and skew insights. Although the prior FAQ process made incremental progress in addressing some areas of conservatism, many more remain in need of enhancement.

The primary source of these issues is the simplified approach taken in defining fire hazards and the bounding assumptions made in characterizing the fire events. The net result is that FPRAs based on NUREG/CR-6850 are not realistic. The conclusions from this review are summarized in Table ES-1.

Table ES-1
Summary of Conclusions and Bases

Conclusion	Selected Bases
Fire characterization does not conform with operating experience	• Over-prediction of number of severe fires • Assumed rate of fire growth & severity, e.g., 12 mins in electrical cabinets, oil fire severity • No credit for control of fires
The level of quantified risk is overstated	• FPRAs based on NUREG/CR-6850 predict high frequency of fires with high CCDPs, but NRC's ASP & ROP have demonstrated this • Predicted frequency of spurious operations not consistent with operating experience
Uneven level of conservatism can mask key risk insights and lead to inappropriate decision-making	• Simplifications result in bounding treatment of "bin" • Overstated fire damage can lead to underestimation of risk increases from plant changes • Assumes plant challenge for all fires, e.g., plant trip • No credit for administrative controls

Realistic FPRAs are necessary for both the NRC and industry. Conservatively biased PRAs do not support good decision-making:

- Conservatisms in the results can mask important risk contributors
- Conservatisms in the characterization of fire damage can mask the significance of plant changes, including the risk increase of equipment out of service
- Conservatisms overall can misdirect decision-makers

EPRI has developed a coordinated industry research program with activities targeting the key areas where the level of realism needs to be improved in FPRAs. Table ES-2 provides a summary of the activities organized based on the technical area of fire PRA in need of additional realism.

Table ES-2
Major Industry Research Activities Related to Achieving Realism in Fire PRAs

Area of Needed Realism	Research Area	EPRI Research Activity
Fire event data characterization	1.1 Fire events database	1.1.1 Revise the database structure to fit the current uses in Fire PRAs such as ignition frequency, detection and suppression probability, brigade response, and others
		1.1.2 Collection of fire event information from industry
		1.1.3 Define realistic fire event categorization scheme and apply to events
		1.1.4 Collect component counts and apply to database
		1.1.5 Develop Fire Events Database (FEDB) revision 1 and report
		1.1.6 Transition long-term data collection efforts
	1.2 Fire ignition frequency	1.2.1 Improve methods for ignition frequency calculation
		1.2.2 Develop Fire Ignition Frequencies
		1.2.3 Develop component-based ignition frequencies
		1.2.4 Update ignition frequencies using insights from initial implementation experience
Fire severity characterization	1.3 Incipient fire growth in electrical cabinets	1.3.1 Utilize information from the FEDB to characterize detection and termination prior to an actual fire event.
	1.4 Oil Fire Severity	1.4.1 Pumps
		1.4.2 Transformers
		1.4.3 Diesel Generators
Credit for incipient detection	1.5 Credit for incipient detection	1.5.1 Refine FAQ 08-0046
		1.5.2 Incipient fire detector testing (NRC lead)
Credit for suppression & Control	1.6 Fire suppression probabilities	1.6.1 Develop recommended approach for non-suppression curves
		1.6.2 Refine treatment based on current database
		1.6.3 Refine treatment based on updated database

Table ES-2
Major Industry Research Activities Related to Achieving Realism in Fire PRAs

Area of Needed Realism	Research Area		EPRI Research Activity	
Fire growth assumptions	2.1	Fire growth and comparison with data	2.1.1	Review of data to distinguish factors impacting fire growth rate (qualified vs. non-qualified, ventilation, etc.)
			2.1.2	Refine treatment based on updated database
Peak heat release rates	2.2	Electrical cabinet peak heat release rate (HRR)	2.2.1	Review of available data
			2.2.2	Treatment for ventilation limited cabinets
			2.2.3	Testing plan, as needed
	2.3	Transient ignition source HRR	2.3.1	Review of database and development of revised treatment
	2.4	Hot work HRR	2.4.1	Review of database and development of revised treatment
	2.5	Other HRRs	2.5.1	Review of database and development of revised treatment
Damage assessment	2.6	Switchgear HEAF zone of influence (ZOI)	2.6.1	Review of data from switchgear events
			2.6.2	Formulation of revised treatment for medium voltage switchgear
			2.6.3	Formulation of revised treatment for low voltage switchgear
	2.7	Bus duct HEAF ZOI	2.7.1	Review of data from bus duct events and formulation of revised treatment
	2.8	Damage to sensitive electronic equipment	2.8.1	Formulation of revised treatment to avoid assumption of failure for all
Fire propagation	2.9	Electrical cabinet propagation	2.9.1	Review of database and development of revised treatment based on cabinet-specific factors
Fire modeling	2.10	Fire modeling guidance	2.10.1	Completion of Fire Modeling Users Guide (FMUG)
			2.10.2	Update FMUG to address propagation of modeling uncertainty in the PRA

Table ES-2
Major Industry Research Activities Related to Achieving Realism in Fire PRAs

Area of Needed Realism	Research Area		EPRI Research Activity	
Treatment of hot shorts	3.1	AC circuits hot short probability and duration	3.1.1	Review of test results and development of revised treatment to enhance FAQ 08-0051
	3.2	DC circuits hot short probability and duration	3.2.1	Review of test results and development of revised treatment
			3.2.2	Conduct phenomena identification and ranking table (PIRT) panel
			3.3.3	Peer review of results
			3.3.4	Issue report
Human Reliability	3.3	Human reliability analysis (HRA) methods and performance shaping factors for fire PRAs	3.3.1	Update of NUREG-1921
			3.3.2	Refinement of EPRI HRA report, as needed
Modeling of control room fires	3.4	Control room modeling and treatment in the fire PRA	3.4.1	Refinement of treatment
PRA model advancement	3.5	Address unrealistic model simplifications	3.5.1	Address assumption that there is always a plant trip following each fire event
			3.5.2	Address assumption that failed ventilation causes immediate failure of equipment

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1.0 INTRODUCTION

1.1 Purpose

Over the past several years, industry has undertaken a large number of plant-specific Fire Probabilistic Risk Assessment (FPRAs). Many of these FPRAs have been performed in support of a transition to the risk-informed, performance-based fire protection requirements under 10 CFR 50.48(c). As these fire PRAs have moved toward completion, it has become evident to the industry practitioners that:

- The manner in which fires are characterized does not conform with operating experience;
- The level of quantified risk is overstated, as compared to operating experience; and
- There is an unevenness in the level of conservatism in the results that can mask key risk insights and result in inappropriate decision-making.

The purpose of this report is to describe the departures from realism in the FPRAs that lead to these insights and to offer a path forward. Specifically, the paper provides evidence of the lack of realism, identifies the specific areas where the current methods are departing from realism, and provides roadmap for the research and development of realistic methods and input data needed to address these insights. This paper is built from the insights gained from the performance of a large number of industry FPRAs.

1.2 Background

In the late 1990s, NRC Research and EPRI established a joint activity to develop and document an improved methodology for FPRA. This methodology was published in 2005 as a joint publication, NUREG/CR-6850/EPRI 1011989 [Ref. 1]. A subsequent supplement was published in late 2010 [Ref. 2] containing the results of methods refinements specified by the NRC in responses to industry frequently asked questions (FAQs) addressed in the piloting of 10 CFR 50.48(c). These reports, henceforth referred to simply as NUREG/CR-6850, provide the methods, tools, and data for the conduct of a FPRA for a commercial nuclear power plant (NPP) application and provide a structured framework for the conduct of the overall analysis, as well as specific recommended practices to address each key aspect of the analysis.

The complexity of the FPRA process is addressed in NUREG/CR-6850 by establishing a structured set of 17 technical tasks that comprise the systematic evaluation of the fire hazards and risks. One ramification of this structured process is that it requires each task to create stand-alone work products that are passed from one task to the next. The methodology development process included attempts to pilot each of the tasks individually. Due to competing priorities at the plants supporting the pilot activities, no integrated pilot was performed. Instead, the pilots tested only individual tasks. While this pilot process was effective in enhancing the methodology in many areas, it failed to investigate the implications of combining the discrete tasks into an overall characterization of fire risk. Ultimately the methodology was published in 2005 without a complete reference analysis. At that time, the report represented the collective best efforts of the authors to improve the state of practice.

In 2004, the NRC promulgated regulatory changes that allowed voluntary adoption of a new risk-informed, performance based approach to fire protection under 10 CFR 50.48(c) [Ref. 3]. These requirements incorporate by reference the requirements of National Fire Protection Association (NFPA) Standard 805 (NFPA-805) [Ref. 4]. The practical implementation of NFPA-805 under 10CFR50.48(c) requires a plant-specific fire PRA. In late 2007, as the NFPA-805 pilot plants and others reached the quantification phase of their NUREG/CR-6850-based FPRAs, it became clear that the simplifications and bounding assumptions employed in the discrete tasks were creating unrealistic results. In some respects, this should not have been a surprise given the fledgling, untested state of the data, tools and methods. It is not uncommon to start a PRA will simplifications and bounding assumptions, and then modify those simplifications and assumptions that inappropriately drive the results in order to achieve realistic characterization of the risk profile. In this case, the NUREG/CR-6850 methods, tools, and data, including the refinements from Supplement 1, retain simplifications and bounding assumptions that skew the FPRA results such that they do not accurately characterize the risk profile and do not comport with industry operating experience.

In January 2008, the major problems identified to date were documented in a letter from NEI to the NRC [Ref. 5]. Eventually, this led to the NFPA-805 Frequently Asked Question (FAQ) program being identified as the means document the resolution of issues. Industry provided what were felt to be the most straightforward technical issues in the form of FAQs. A total of 11 FPRA-related FAQs were submitted. By the end of 2009, nearly two years after the issue was identified, a total of 10 FPRA FAQs had been closed by the other NRC (the eleventh FPRA-related FAQ was withdrawn). Many of the final FAQs only partially resolved the original technical issue. However, in every case, the FAQ resolution incrementally moved the FPRA methods toward more realism.

The failure of the FAQ process to efficiently and effectively process and address FAQs led to the industry taking a different course. In December 2009, NEI notified the Commission [Ref. 6] that the FAQ process had failed to result in realistic methods and provided an initial draft of an EPRI FPRA action matrix that targeted the large number of areas of residual conservatism.

This report provides an update on the areas of excess conservatism in FPRAs that are contributing to non-realistic results and the attendant distortion of the risk profiles and provides an update of the industry research activities in the these areas. It is important to note is that the majority of these issues were identified in the original NEI letter in 2008 and, despite the incremental enhancements documented in the FAQ resolutions, the simplifications and bounding assumptions of the methods and data in NUREG/CR-6850 remain obstacles to the goal of plant-specific FPRAs that realistically reflect fire risks such that it is difficult to use FPRAs in risk-informed decision-making.

1.3 Approach

This report is developed using the results and insights from a large number of fire PRAs. Section 2 provides a brief summary of the insights from completed fire PRAs and identifies some of the key risk drivers and challenges to realism. As is typical of a spatial hazard such as fire, the specific risk contributors are unique to each plant. However, a number of technical areas are identified as important contributors across a variety of plants. Section 3 of this report provides specific areas needing increased realism and provides examples of the consequences of these departures from realism. Section 4 identifies industry research activities to address the areas needing additional realism. Appendices provide data that supports various conclusions drawn in this report.

2.0 INSIGHTS FROM RECENT FIRE PRAs

Nearly half of the U.S. fleet of reactors are making preparations to transition to risk-informed, performance-based fire protection under 10 CFR 50.48(c). As part of this transition, each plant is developing a fire PRA. The NRC Staff has made it clear that the FPRA methods described in NUREG/CR-6850 , supplemented by the FPRA FAQs, are their standard for acceptance. As a result, the industry is gaining substantial experience in applying these methods to actual plant configurations. This experience hilights the lack of realism inherent in these methods.

This section provides a brief summary of some of the insights from these fire PRAs and provides evidence of the conservatism observed in the results. These insights support industry's prior concerns that:

- The manner in which fires are characterized in NUREG/CR-6850 does not conform with operating experience,;
- The level of quantified risk is overstated, as compared to operating experience; and
- There is an unevenness in the level of conservatism in the results that can mask key risk insights and result in inappropriate decision-making

2.1 Overview of Fire PRA Scenario Definition

The realistic assessment of nuclear power plant fire risks requires consideration of fire scenarios, progressing from an initial adverse condition through fire growth to fire damage. The assessment of the fire damage can be translated into an affect on plant mitigation systems and operator responses, which in turn can be evaluated using a PRA model to consider the likelihood of core damage occurring given the effects of the fire.

The hazard posed by a postulated fire begins with an adverse condition in the plant. This might be a problem with an electrical connection or an oil leak on a pump or the presence of a transient ignition source in a particular location. In some cases, the adverse condition can develop into a fire rapidly, e.g., a high energy arching fault that occurs during breaker repositioning. In other cases, the adverse condition can exist for an extended period of time before a fire begins to develop. The U.S. nuclear power industry has experienced relatively few serious fires. This is due in large part to the reliability of detection and termination or suppression of adverse conditions that could have led to a fire.

The progression of an adverse condition into a potential core damage scenario can be considered as a continuous process, i.e., a specific adverse condition occurs, develops to the point of a fire, the fire grows based on the specific condition and available combustible materials, and results in conditions that are potentially damaging to nearby components and cables. This progression can stop at any point. The adverse condition may not evolve to a fire, e.g., it may only involve smoke or odors. The fire may self-extinguish or be extinguished by manual or automatic suppression. The growth of the fire may involve more or less combustible material and may or may not be limited by the availability of oxygen.

2.2 NUREG/CR-6850/EPRI-1011989 Approach

The technical approach described in NUREG/CR-6850/EPRI-1011989 relies upon a set of tasks that subdivides the analysis of the fire scenario into discrete steps in order to make the analysis tractable. . When transferring information from task to task, simplifications and bounding assumptions are applied to ensure that the analysis does not become too burdensome and at the same time potentially important sequences are not missed. Conversely, these simplifications and bounding assumptions have the potential overstate the risk. This will be described in subsequent sections.

The basic approach taken in NUREG/CR-6850 for constructing a fire scenario involves the following:

- Utilization of individual ignition source bins, assigned as a plant-wide frequency, derived from industry operating experience (e.g., pumps, electrical cabinets, transient sources, diesel generators)
- Computation of ignition frequency for a specific source based on an allocation process
- Application of fire growth rates and peak heat release rate distributions assigned to each bin
- Credit for automatic and manual suppression based on broad class of fire (i.e., electrical, oil, welding, transients, etc.)
- Fire modeling to define damage footprint (i.e., zone of influence)
- Translation of damage into PRA model for computation of conditional core damage probability (CCDP) and conditional large early release (CLERP)
- Integration of fire scenario frequency with CCDP to compute scenario core damage frequency (CDF) large early release frequency (LERF)

In the simplest form, the risk from an individual fire scenario is a function of:

- The frequency of the fire event (F_{fire}),
- The fire severity characteristics as a function of time (S(t)),
- The probability of suppressing the fire event as a function of time (NSP(t)[1]), and
- The conditional core damage probability given the damage caused by the postulated fire ($CCDP_{damage}$)

$$\text{Scenario CDF} = f(F_{fire}, S(t)_{fire}, NSP(t), CCDP_{damage})$$

[1] Typically this is expressed as a non-suppression probability, or the probability that the fire is not suppressed. It is defined as one minus the probability of successful suppression.

The challenge created by the approach used in developing NUREG/CR-6850 is that small to modest departures from realism exist in each of these PRA elements. Individually, these do not typically drive the risk results, but the compounded effect is substantial. Specifically, the methods include the following:

- Overstated fire frequencies
- Overstated fire severities
- Under-credited fire suppression
- Overstated resulting CCDPs

In addition, information must be passed from one task to the next, where the simplifications and assumptions within each task may not be adequately addressed in the subsequent task, in a manner that is self-consistent within the scenario ("coherency" as observed in the WASH-1400 peer review). As a result, the fire scenarios use the worst characteristics of a fire source bin are passed to the next task as the actual characteristics of all of the fires in the bin.

As a consequence, there is no single factor causing the unrealistic results; it is the compounded effect that is noticeable. Furthermore, while there are some general trends, like many spatial analyses, the results are very scenario specific, e.g., dependent on the plant design, location, ignition source.

2.3 Risk Drivers

As input to the development of this Roadmap, the results of several industry FPRAs were reviewed to identify the key risk drivers influencing the results. The first insight gleaned from these FPRAs is that the overall computed CDF is significantly higher than expected. With this said, it is impossible to compare computed plant-specific CDF values to operating experience because there are no core damage events in the available operating experience. Nevertheless, the results from plant-specific FPRAs can be used to identify risk drivers and to look at intermediate results, for example precursors to core damage such as the frequency of severe fires.

The first investigation of the FPRA results focuses on the fire ignition sources that drive the risk results. NUREG/CR-6850 utilizes a specified list of fire ignition bins which are mapped to specific scenarios in the FPRA. Table 2-1 provides a list of these fire ignition bins.

A typical FPRA performed using NUREG/CR-6850 includes a very large number of individual scenarios (ranging from 500 to 2,000 individual fire scenarios), depending upon the plant and the risk drivers identified. As described in Section 2.2, the FPRA scenarios are structured around fire ignition bins. NUREG/CR-6850 defines the key properties for modeling each fire ignition source bin. In order to glean more insight into the risk drivers, the results from a sampling of current FPRAs were interrogated to identify which fire ignition source bins were the most important contributors to comnputed fire risk. The results are shown in Figure 2-1. The x-axis of Figure 2-1 identifies the fire ignition source bin, the z-axis identifies the plant, and the y-axis and the height of the bar identifies the fraction of computed fire CDF contributed by each bin at each plant.

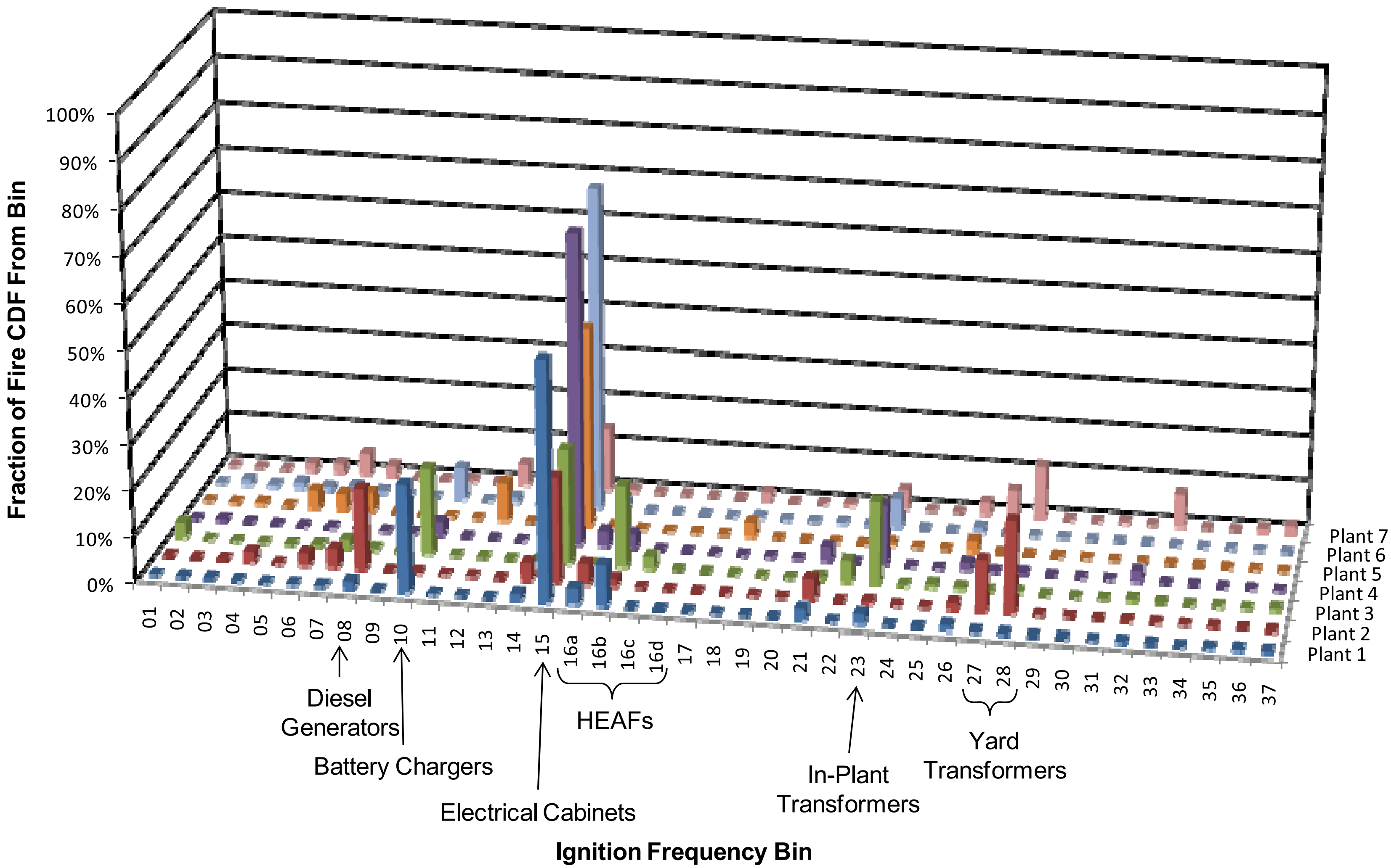
This chart identifies that electrical cabinets (Bin 15) are generally important for all the plants included in the sample. However, what is also apparent is that other sources can be important on a plant-specific basis. For example, diesel generators (Bin 8), battery chargers (Bin 10), high energy arcing faults (HEAFs) (Bins 16a/b/c/d), in-plant transformers (Bin 23), and yard transformers (Bins 27 and 28) all show up as significant contributors (>10% of Fire CDF) at one or more of plants in this sample. This characteristic is based on the unique design features of those plants.

This is not an exhaustive compilation of FPRA results, but the conclusions regarding the applicability of these insights has been vetted with industry FPRA analysis . Analusts generally agree that electrical cabinets are an area to focus on, but simply improving the realism of treatment in that area will be insufficient to assure that other departures from realism are not skewing results and masking insights. For example, Plants 2 and 3 (burgundy and green bars on Figure 2-1) have other contributors that are roughly the same contribution as Bin 15.

Table 2-1
NUREG/CR-6850 Fire Ignition Bins

6850 Bin #	Fire Ignition Component	Location
1	Batteries	Battery Room
2	Reactor Coolant Pump	Containment (PWR)
3	Transients and Hotwork	Containment (PWR)
4	Main control board	Control Room
5	Cable fires caused by welding and cutting	Control/Aux/Reactor Building
6	Transient fires caused by welding and cutting	Control/Aux/Reactor Building
7	Transients	Control/Aux/Reactor Building
8	Diesel generators	Diesel Generator Room
9	Air Compressors	Plant-Wide Components
10	Battery Chargers	Plant-Wide Components
11	Cable fires caused by welding and cutting	Plant-Wide Components
12	Cable run	Plant-Wide Components
13	Dryers	Plant-Wide Components
14	Electric motors	Plant-Wide Components
15	Electrical Cabinets Non-HEAF	Plant-Wide Components
16a	Low Voltage Switchgear HEAF (<1000V)	Plant-Wide Components
16b	Medium Voltage Switchgear HEAF (>1000V)	Plant-Wide Components
16c	Segmented Bus Duct HEAF	Plant-Wide Components
16d	Iso-phase Bus Duct HEAF	Plant-Wide Components
17	Hydrogen Tanks	Plant-Wide Components
18	Junction box	Plant-Wide Components
19	Misc. Hydrogen Fires	Plant-Wide Components
20	Off-gas/H2 Recombiner (BWR)	Plant-Wide Components
21	Pumps	Plant-Wide Components
22	RPS MG sets	Plant-Wide Components
23	Transformers	Plant-Wide Components
24	Transient fires caused by welding and cutting	Plant-Wide Components
25	Transients	Plant-Wide Components
26	Ventilation Subsystems	Plant-Wide Components
27	Transformer - Catastrophic	Transformer Yard
28	Transformer – NonCatastrophic	Transformer Yard
29	Yard transformers (Others)	Transformer Yard
30	Boiler	Turbine Building
31	Cable fires caused by welding and cutting	Turbine Building
32	Main Feedwater Pumps	Turbine Building
33	T/G Excitor	Turbine Building
34	T/G Hydrogen	Turbine Building
35	T/G Oil	Turbine Building
36	Transient fires caused by welding and cutting	Turbine Building
37	Transients	Turbine Building

Figure 2-1
Fire CDF Contributors by Fire Ignition Bin Based on a Sampling of Fire PRA Results



2.4 Evidence of Conservative Results

For the past several years, industry has pointed out that the results of the FPRAs are conservative with respect to operating experience. The purpose of this section is to provide evidence based on results from current fire PRAs, to support this observation. While total fire CDFs are believed to be overstated, there is no effective way to benchmark at the CDF level directly. In the following subsections, evidence is provided to support the following:

- The inputs defined in NUREG/CR-6850 do not always comport with operating experience
- The frequency of spurious operations is over-predicted using the NUREG/CR-6850 inputs, as compared to operating experience
- The frequency of severe fires with significant risk implications, i.e., fires with conditional core damage probabilities that would receive increased regulatory and industry review, is over-predicted using the NUREG/CR-6850 inputs, as compared to operating experience

2.4.1 Conformance with Operating Experience

The use of fire ignition source bins is a useful simplification, but the details of implementation have contributed to the introduction of conservatisms that lead to a departure from operating experience and an overstatement of the consequences for the assigned frequency. An example is presented to further explain the manner in which the NUREG/CR-6850 methodology works and illuminate some of challenges associated with this approach: diesel generator fires. Diesel generator fires are not selected because of their risk significance, but rather because they are a straightforward example of the process and readily allows the comparison with operating experience.

Diesel generator fires are identified in NUREG/CR-6850 as Fire Ignition Source Bin 8. This bin applies to all diesel generators and the analysis of fires in Diesel Generator Rooms. Bin 8 has a plant-wide frequency in the original NUREG/CR-6850 of 2.1E-2/yr. This value is based on a total of 49.5 events over 2486 reactor operating years [Table C-3, Ref. 1]. The 49.5 events are derived from a total of 60 actual events, with 39 of the events fully counted and another 21 events counted as “Indeterminate” with weight of 0.5 (49.5 = 39 + 0.5*21).

In the original work, 53 of the 60 diesel generator fires occurred prior to 1990. As part of the technical work that addressed FAQ-048, NUREG/CR-6850 Revised Fire Ignition Frequencies, EPRI developed an updated diesel generator fire ignition frequency of 5.E-3/yr. This is considered to be a better representation of the current performance in the industry .

Under the process defined in NUREG/CR-6850, the plant-wide frequency of 5E-3/yr is allocated across the number of diesels considered in the FPRA. This same approach is used for many other fire ignition source bins, including electrical cabinets, pumps, etc. In the case of Bin 8, a plant with 2 diesels would have a per diesel frequency of ~2.5E-3/diesel-yr and a plant with 4 diesels would have a per diesel frequency a factor of two lower, or ~1.3E-3/diesel-yr. This example points out one of the more problematic aspects of the methodology. The more components in a specific bin, the lower the ignition frequency on a per component basis. This was acknowledged as a limitation of the NUREG/CR-6850 methodology but was felt to be adequate at the time that report was published. Sections 3 and 4 will discuss the industry activities underway to support the modification of this approach so that the frequency is applied on a per component basis when it is appropriate to do so.

According to NUREG/CR-6850, the frequency of diesel fires is to be partitioned into two classes of fires:

- 16% are to be considered electrical fires
- 84% are to be considered oil fires

Electrical fires are to be characterized by electrical components identified in diesel room inventory. The oil fires are to be characterized by a distribution of oil spill sizes:

- 2% of oil fires assumed to involve 100% of oil inventory
- 98% of fires assumed to involve 10% of oil inventory

The HRR computed is based on spread of the specified volume of oil and depending on the degree of confinement. A typical diesel day tank could contain 500 to 1,000 gallons of fuel oil. So, the more likely "small" spill would involve 50 to 100 gallons of fuel oil.

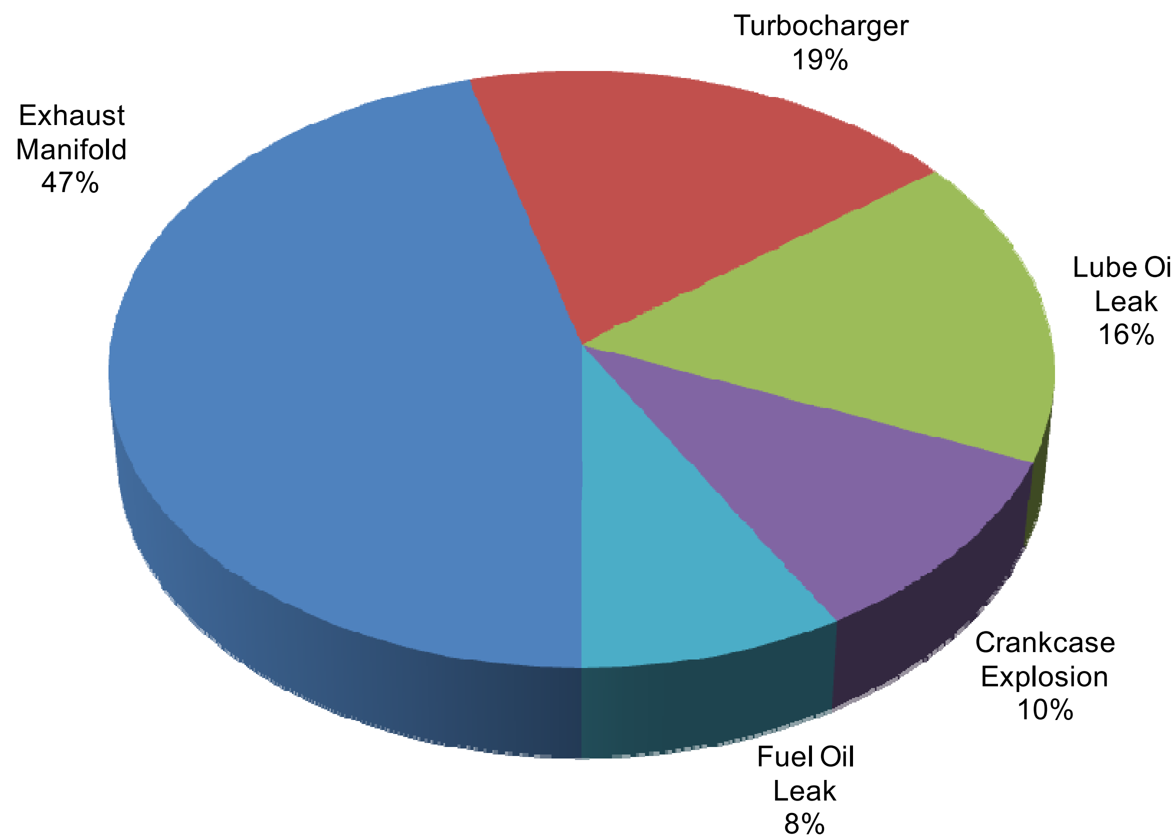
These assumptions do not comport with the actual events in the fire events database used to support NUREG/CR-6850. Appendix A provides a listing of the 60 events involving diesel fires. Figure 2-2 provides a pie chart that classifies the oil-related fires into five categories: exhaust manifold fires, turbocharger fires, lube oil leaks, crankcase ruptures, and fuel oil leaks (not spills). It is readily apparent from Figure 2-2 that this distribution does not align with the assumption that 98% of the time 50 to 100 gallons of oil will be spilled in the room. Most of the events involve fires on or inside the exhaust manifold or turbocharger or inside the crankcase. Of the events involving leaks, most appear to be minor leaks, far less than the 10% assumed in NUREG/CR-6850. Based on the observed events, it would be anticipated that the HRR from the diesel generator fire events would be much, much less than those assumed in NUREG/CR-6850.

The insights from the example above are the following:

- FAQ-048 resulted in significant decrease in ignition frequency for Bin 8
- Allocation of plant-wide frequency can distort results, i.e., a plant with more diesels has lower per room frequency.
- Oil fire HRR is not consistent with actual fires:
    - Most actual fires are localized, not spills of oil
    - None of the actual fires involve 10% of total oil inventory
    - Assumed HRR (even for the reduced inventory case) likely results in full room damage, unless automatic suppression is available
    - Most fires did not appear to involve actuation of automatic suppression
- A review of events indicates that plant shutdown was not required in most fire events
    - All FPRA fires are assumed to lead to plant shutdown

This leads to the obvious conclusion that the severity of assumed diesel generator fires is significantly overstated versus operating experience.

Figure 2-2
Operating Experience: Diesel Generator "Oil Fires"



2.4.2 Conformance with Spurious Operations Experience

Addressing spurious operations is an important element of a comprehensive FPRA and an essential part of 10 CFR 50.48(c). Addressing spurious operations is a resource intensive aspect of both the fire PRA and the deterministic fire protection programs. While stylized fire testing has demonstrated that spurious operations are possible during a fire, the industry operating experience is that spurious operations have not occurred in obsreved fire events with the exception of the Browns Ferry event in 1975. So, the industry operating experience is one fire involving spurious operations in over 3,000 reactor years of operating experience.

In order to assess the significance of spurious operations in a FPRA and the predicted likelihood of spurious operations, two plant-specific fire PRAs were interrogated to identify the predicted frequency of fires involving one or more spurious operations. This was done by reviewing the hundreds of fire scenarios contained in the FPRA and summing the frequency of scenarios containing spurious operations:

$$\text{Plant-wide SO frequency} = \Sigma \text{ Frequency of Scenarios involving one or more SOs}$$

Each individual scenario frequency includes the applicable ignition source frequency, severity factor, non-suppression probability, and a probability for the spurious fault condition. For both of the plants reviewed, the results indicate that the predicted frequency is approximately 0.004/yr :

Plant X:	0.0041/yr
Plant Y:	0.0043/yr

An additional qualitative review of another FPRA, performed by an independent team, found that this value was consistent with their results, although no specific value was calculated. Thus, a frequency on the order of 4E-3/reactor year is considered to be representative of the body of FPRAs.

If this computed frequency of fire-induced spurious operations is extrapolated across the entire U.S. industry (100 plants), then the annual industry-wide frequency would be on the order of 0.4 per year. In other words, fire PRAs would predict a fire involving spurious operations occurring, on average, every 2 or 3 years.

As noted above, none have been observed since Browns Ferry fire in 1975. Fire PRAs would have predicted that we should have seen many such events since 1975. Based on this evaluation it appears that the likelihood of significant fires involving spurious operations is overstated in FPRAs, as compared to operating experience.

2.4.3 Conformance with Risk from Actual Fire Events

As described in Section 2.1, each fire scenario includes a computed conditional core damage probability that is the translation of the predicted damage into the effects of the damage on the capability of the plant to prevent core damage. This is typically done by computing the predicted fire damage zone associated with the severity of the fire and identifying the cables and equipment that would be made unavailable directly or indirectly by the fire, including the failure of the fire ignition source itself. The plant-specific PRA model is then used to compute a conditional probability of core damage, given that damage condition. The core damage frequency for a scenario is the product of this CCDP, the frequency of the specific fire ignition source bin, the probability of the fire severity assumed, and the probability of non-suppression prior to core damage.

When an actual plant event occurs (fire related or other) an associated CCDP can be computed. For a fire event, a fire PRA model is not required because the actual damage from the fire is known and because the event occurred, the frequency of scenario occurrence does not apply. It simply requires application of the observed damage condition to the plant-specific PRA model in order to compute the resulting CCDP.

The NRC has two programs that use CCDP to consider the significance of plant events and conditions: the Accident Sequence Precursor (ASP) program [Refs. 8, 9] and the Significance Determination Process of Reactor Oversight Program (ROP).

ASP Program Use of CCDPs

The NRC's ASP program reviews industry operating experience to assess precursor events. An annual report is provided to the Commission on the significant events that have occurred and on the operating experience trends with respect to two categories of precursors:

- "Significant precursor" events - CCDP $\geq$ 1E-3
- "High CCDP" events - CCDP $\geq$ 1E-4

"Significant precursor" events are rare in recent operating experience. In fact, no "significant precursor" events have occurred in the industry since 2002 (Davis Besse vessel head issue). Of the 34 "significant precursor" events in all US operating experience, only one involves a fire (the 1975 fire at Browns Ferry).

Because each scenario in the FPRA has a computed CCDP, the computed frequency of scenarios for a range of CCDPs can be developed. Typically, a fire scenario can be represented in a tabular form. Each row of the table is a fire scenario. Each scenario is described by the Fire Compartment, a Scenario ID, a Scenario Description and Zone Description. The PRA information for the scenario includes the ignition frequency, the non-suppression probability and the severity factor. The product of these three values is the individual fire scenario frequency:

*Individual Scenario Frequency (/yr) = Ignition Frequency (/yr) * Non-Suppression Probability * Severity Factor*

The product of the individual scenario frequency and the scenario CCDP yields the scenario CDF.

In the simplest form, the FPRA scenarios can be sorted in descending order based on scenario CCDP, i.e., highest CCDP at the top, lowest at the bottom. A cumulative sum of the individual scenario frequencies can be developed. In this manner, the cumulative scenario frequency represents the total predicted frequency of scenarios with a CCDP equal to or greater than the CCDP of that scenario.

A plant-specific summary of the cumulative scenario frequency for various CCDP levels extracted from a completed FPRA is provided in Table 2-2.

Table 2-2
Summary of Example Plant CCDP Results

CCDP Threshold	Cumulative Scenario Frequency
≥ 0.01	9.9E-4/yr
≥ 0.001	3.2E-3/yr
≥ 0.0001	1.4E-2/yr
≥ 0.00001	6.3E-2/yr
≥ 0.000001	1.7E-1/yr

This process was applied to a variety of FPRAs for a spectrum of plants utilizing different analysis teams and contractors in order to assess the predicted likelihood of "significant precursors" and "high CCDP" conditions tracked by the NRC's ASP program [Refs. 8, 9]. The results are provided in Table 2-3.

Based on this assessment, the current fire PRA methods would predict that a fire designated as a "significant precursor" would be expected to occur every one to ten years across the industry. However, there has not been a significant precursor involving a fire since 1975 when the Browns Ferry fire occurred [Refs. 8, 9], well before implementation of fire protection programs across the industry.

The predicted frequency of the "high CCDP" events (CCDP > 1E-4) was also calculated. In this case, the results showed that FPRA would predict one to three events each year, across the industry. According to the NRC's latest ASP program report [Ref. 8], there have been none from 2001 to 2009.

Table 2-3
Summary of Predicted Precursor Frequencies from Sampling of FPRAs

FPRA Model	Predicted Frequency of "Significant Precursor" Events (CCDP > 1E-3)	Predicted Frequency of High CCDP Events (CCDP > 1E-4)
Plant A	1.0E-3/yr	1.0E-2/yr
Plant B	9.9E-3/yr	2.0E-2/yr
Plant C	3.3E-3/yr	1.4E-2/yr
Plant D	1.3E-3/yr	3.2E-2/yr
Plant E	4.7E-3/yr	3.2E-2/yr
Range	1.0E-3/yr to 9.9E-3/yr	1.0E-2/yr to 3.2E-2/yr
Industry-wide Recurrence Interval	Every 1 to 10 yrs	1 to 3 every year
Actual Experience	None Since 1975	None from 2001-2009 based on SECY-10-0125

<u>ROP Use of CCDPs</u>

The Reactor Oversight Program utilizes conditional core damage probabilities (CCDP) in the Significance Determination Process (SDP) to evaluate the safety significance of performance deficiencies. The ROP uses a four color scheme to identify the significance of a condition:

<u>ROP Thresholds</u>

Green	CDP/CCDP	< 1E-6
White	CDP/CCDP	1E-6 to 1E-5
Yellow	CDP/CCDP	1E-5 to 1E-4
Red	CDP/CCDP	>1E-4

To date, no actual fire events have been considered Red or Yellow (CCDP >1E-5). This is one order of magnitude below the CCDP threshold reported for the ASP program. As shown in Tables 2-2 and 2-3, fire PRA models would predict that several of these events should be seen each year across the industry.

Overall, there is substantial evidence that the FPRA methods prescribed in NUREG/CR-6850 are leading to a significant over-prediction of the frequency of:

- spurious operations, and
- high CCDP conditions

as compared to actual industry experience. This directly contributes to the over-prediction of computed Fire CDF.

2.5 Why Conservatisms Can Confound Decision-making

Departures from realism in PRA can create problems in decision-making. At one level, a “conservative” result (i.e., one that over predicts the level of risk) might be seen as useful because it can be seen as providing some additional safety margin. Unfortunately, conservatism can be difficult to manage. It can unduly influence results, mask important contributors, and confound the decision-making process.

The U.S. NRC recognized this when formulating the PRA Policy Statement which says (emphasis added):

> *PRA evaluations in support of regulatory decisions should be as <u>realistic as practicable</u> and appropriate supporting data should be publicly available for review*

The U.S. nuclear power industry has benefited from a conservative decision-making process. Although not always efficient, this can work well in deterministic-based decision-making. However, in risk-informed decision, conservatism is problematic in that it can create unevenness in quantitative results that makes resource allocation decisions more difficult and, in some cases, masks important risk implications associated with these decisions.

There are two aspects to conservatism that must be dealt with separately. The first involves conservative estimates of the likelihood of occurrence. Such conservatisms tend to increase both the base result and changed result in a delta risk calculation. In many instances, this leads to an over-prediction of the delta risk, the primary risk metric used in risk-informed applications. From a regulatory perspective, this may be acceptable. However, such an approach can still confound prioritization efforts as the degree of conservatisms in the likelihood inputs will never be the same. That is, if a decision must be made to address one contributor or another, uneven conservatisms in likelihood estimates may lead to a less than optimum decision., i.e., lead to allocation of limited resources to those areas of public safety that are less important.

A more problematic aspect of conservatism in fire PRAs relates to the overstatement of fire damage, in the name of conservatism. Depending on the configuration and scenario, fire damage can disable systems beyond the initial ignition source. If conservative fire damage assumptions, i.e., assumptions of greater fire damage, are employed, then the baseline level of risk will be conservatively biased high. If the objective is to bound the baseline plant risk to demonstrate that it is below some threshold, then this may be acceptable. However, trying to use conservatively biased fire damage assumptions to support decision-making is more difficult.

A simple example is provided in Figures 2-3 and 2-4 to illuminate this concept.

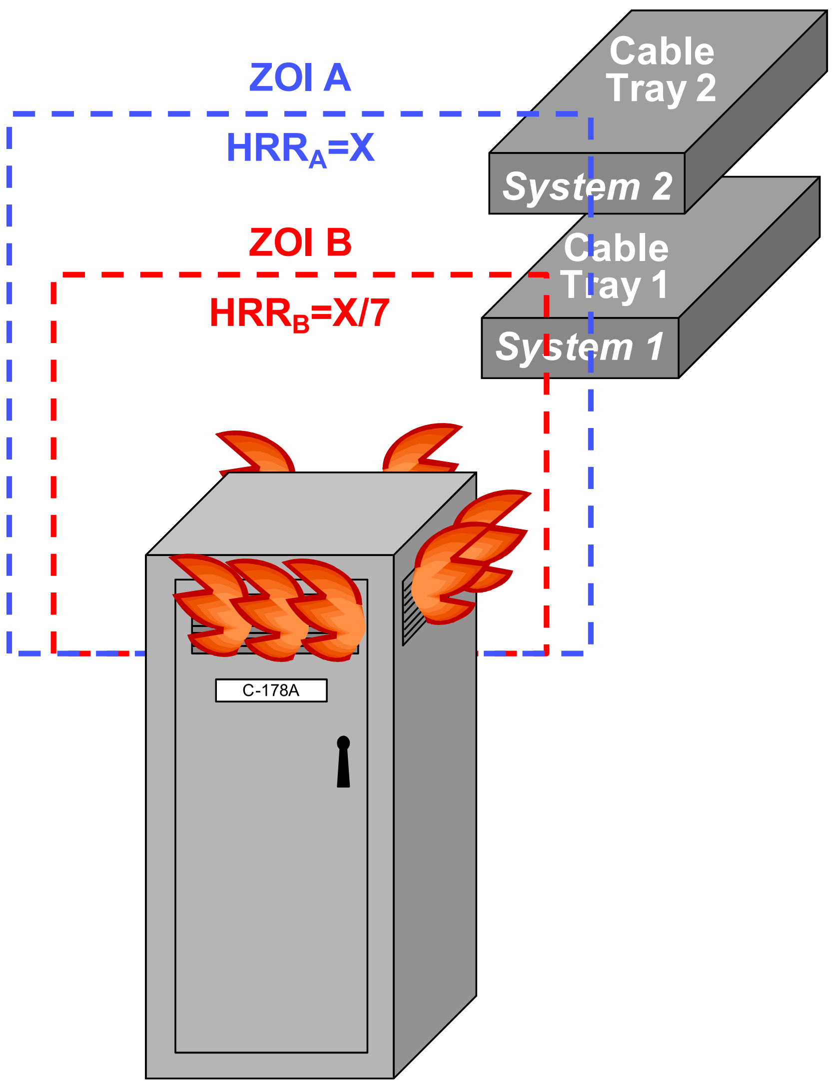
Figure 2-3 focuses on the implications of conservative damage assumptions on the baseline risk calculation. This figure depicts two fire damage vectors, Zone of Influence (ZOI) A based on an assumed heat release rate, X, and ZOI B based on a lower assumed heat release rate, X/7. For the case of ZOI A, both Cable Tray 1 and Cable Tray 2 are predicted to be damaged by the fire. For ZOI B, only the closer tray, Cable Tray 1 is predicted to be damaged.

The baseline risk calculation for these cases would predict that the CCDP for ZOI A would be greater beacuse damage to Cable Tray 2 results in failure of System 2. For ZOI B, the CCDP would be lower because the unreliability of System 2 would be probabilistically included in the CCDP. Thus, in the case where the more conservative fire damage (ZOI A), the resulting CDF would be greater. So, the conservative fire damage assumption results in a conservative estimation of the baseline fire CDF from this scenario.

Figure 2-4 shows how these ZOI assumptions can influence decision-making in cases where plant configuration changes are evaluated. This case considers these same two risk results with System 2 out of service. For ZOI A, the removal of System 2 from service has no impact on CDF because System 2 is damaged by the fire as in the base case. For ZOI B, the CCDP increases to be the same as ZOI A when System 2 is out of service.

So, the “conservative” assumption of ZOI A actually results in an underestimation of the risk increase from removing System 2 from service. In effect, while conservatively influencing the baseline risk calculation, ZOI A results in a non-conservative risk change calculation.

Figure 2-3
Implications of Conservatisms in Assumed Fire Damage in Baseline Risk Calculations



Baseline Risk Calculation

$CDF_A = Freq(S_i) * CCDP_A$ (Sys1,Sys2 failed)

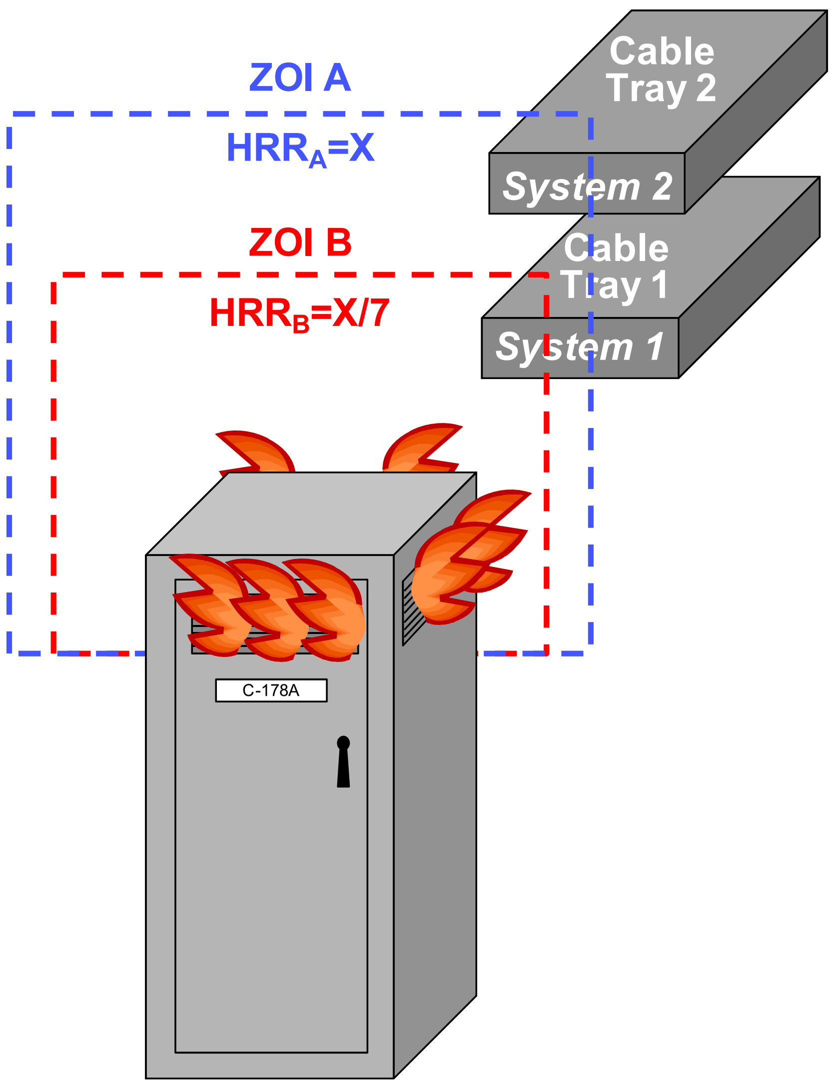
$CDF_B = Freq(S_i) * CCDP_B$ (Sys1 Only failed)

$CCDP_A$ (Sys1,Sys2 failed) >> $CCDP_B$ (Sys1 Only failed)

$CDF_A >> CDF_B$

Conservative ZOI Potentially Increases Baseline Risk

Figure 2-4
Implications of Conservatisms in Assumed Fire Damage in Delta Risk Calculations



Delta Risk Calculation

<u>Risk with System 2 Out of Service</u>

$CDF_{A2} = CDF_A = Freq(S_i) * CCDP_A$ (Sys1,Sys2 failed)

$CDF_{B2} = Freq(S_i) * CCDP_{B2}$ (Sys1, Sys2 failed)

$CCDP_A = CCDP_{B2}$

$CDF_{A2} = CDF_A = CDF_{B2}$

$\Delta CDF_A = CDF_{A2} - CDF_A = 0$

ZOI A = No Change in Risk

$\Delta CDF_B = CDF_{B2} - CDF_B >> 0$

ZOI B = Potentially Significant Change in Risk

"Conservative" ZOI Potentially Understates Delta Risk

2.6 Summary of Insights

Based on the results and insights from industry fire PRAs, it has been identified that the methods described in NUREG/CR-6850/EPRI TR-1011989 contain significant conservatisms that skew the results and therefore bias insights. The net result is that FPRAs based strictly on NUREG/CR-6850 are not realistic.

A review of risk drivers from these industry fire PRAs identifies electrical cabinet fires as a high priority area for additional methods refinement. However, simply addressing a single area such as electrical cabinet fires will not be sufficient to provide realistic results for all plants. This is because there are typically a variety of plant-specific risk contributors that result from specific configurations.

The predicted frequency of fires involving spurious operations and the frequency of fires involving high CCDP do not comport with industry operating experience, as documented in NRC's ASP and ROP/SDP analyses.

Overall, the insights from industry PRAs performed using NUREG/CR-6850, and associated FAQs, support industry's concerns that:

- The manner in which fires are characterized in NUREG/CR-6850 do not conform with operating experience,;
- The level of quantified risk is overstated, as compared to operating experience; and
- The uneven level of conservatism may mask key risk insights and confound decision-making

Section 3 provides more specific insights into the areas where industry fire PRAs based on NUREG/CR-6850 would benefit from additional realism.

3.0 AREAS REQUIRING ADDITIONAL REALISM

The realistic assessment of nuclear power plant fire risks requires comprehensive consideration of fire scenarios, progressing from an initial adverse condition through fire growth to fire damage and impact on plant mitigation systems and operator actions.

The hazard posed by a postulated fire begins with an adverse condition in the plant. The progression of an adverse condition into a potential core damage scenario is a continuous process, i.e., a specific adverse condition occurs, develops to the point of a fire, the fire grows based on the specific condition and available combustible material, and results in conditions that are potentially damaging to nearby components and cables. This progression can stop at any point. The adverse condition may not evolve to a fire, e.g., it may only involve smoke or odors. The fire may self-extinguish or be extinguished by manual or automatic suppression. The growth of the fire may involve more or less combustible material and may or may not be limited by availability of oxygen.

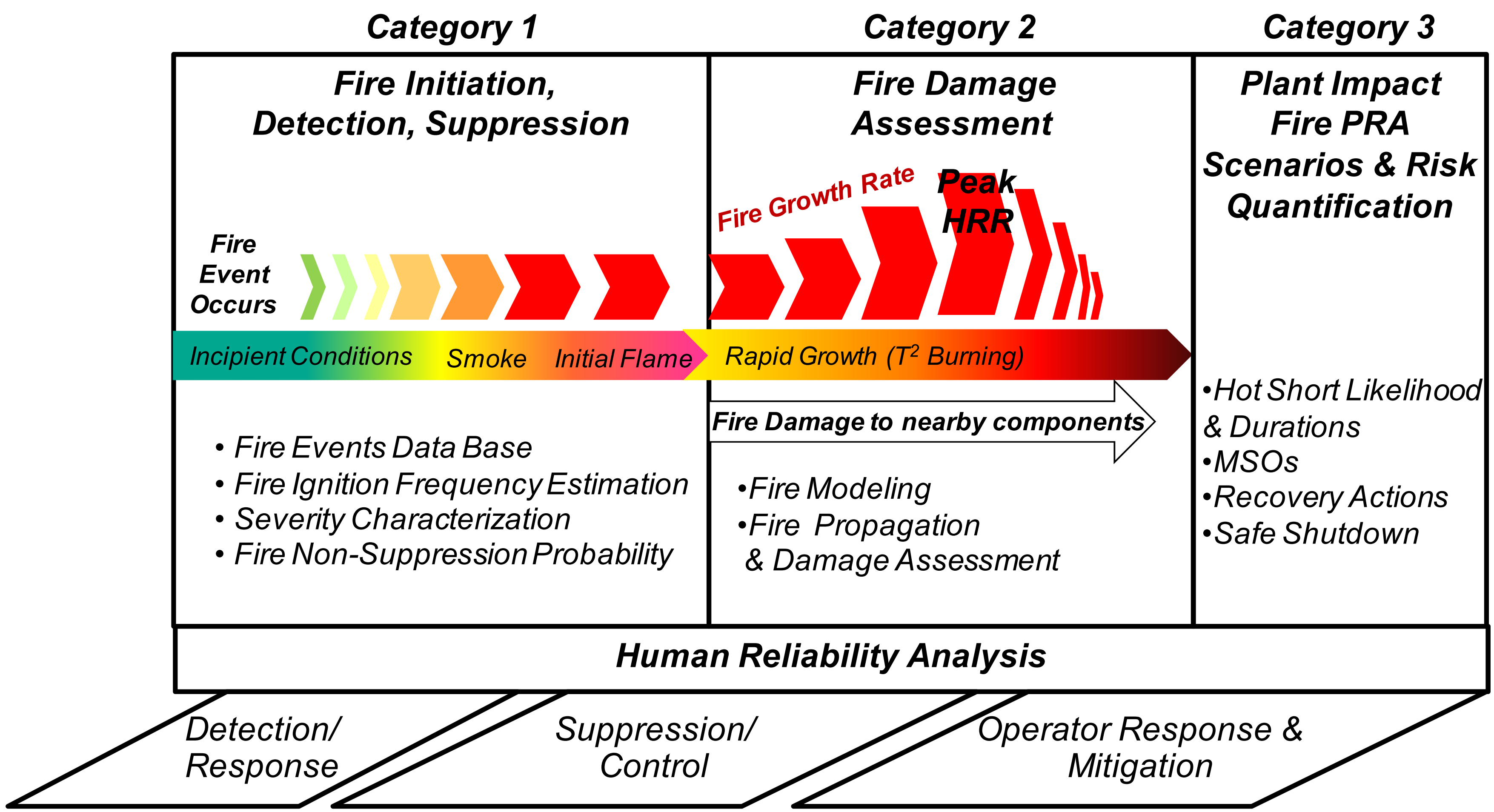
One of the problems with the NUREG/CR-6850 approach is the compartmentalization of information into discrete tasks. This process requires simplifications and the bounding assumptions that when combined lead to compounding effects that skew the results away from a realistic treatment. This report organizes the research needs into logical sets of activities consistent with the continuous process portrayed in Figure 3-1:

- Category 1 Activities: Fire Initiation, Detection, Suppression
- Category 2 Activities: Fire Damage Assessment
- Category 3 Activities: Plant Impact, Fire PRA Scenarios, & Risk Quantification

Simplifications and conservatisms are necessary to make modeling a plant feasable, but they can erode the level of realism in the analysis. Internal events PRAs utilize simplifications and bounding assumptions, but these do not involve the significant contributors to risk. An example is the treatment of large break LOCAs. In the internal events PRA, the large LOCA is modeled using the frequency of all breaks greater than 5 - 6 inches in diameter, but the plant response is modeled as if it is a double-ended guillotine break of the largest pipe connected to the reactor coolant system. This is analogous to calculating a fire ignition frequency for a source including relatively benign fires, but modeling them as large-scale, rapidly developing fires. In the large LOCA case, the scenarios are not significant contributors in most internal events PRAs. If they were, they would be further refined and subdivided in order to add realism. The same is necessary for fire contributors. In fact, the ASME/ANS PRA Standard has specific requirements focused on assuring realism for the significant contributors.

As part of the transition to 10 CFR 50.48(c), the NRC Staff has communicated that its expectations are very high for justifications of treatment outside of the methods provided in NUREG/CR-6850. As an example, the FAQ process demonstrated that even strong technical work done by EPRI was insufficient to convince the staff to allow relaxation of conservative assumptions documented in NUREG/CR-6850 in favor of more realistic assumptions.

Figure 3-1
FPRA Issues Framework



While individual NUREG/CR-6850 tasks were demonstrated to be "accomplishable," the methods were not piloted in an integrated manner before being endorsed as a means to address NFPA-805 requirements. The issuance of NUREG/CR-6850 without an integrated pilot allowed the inherent conservatisms, the consequences of which could not have been evident to the authors, to be deployed without an adequate test. The timeline for resolution of the industry fire protection issues did not allow an adequate pilot and refinement. The FAQ process was slow and ineffective in processing substantive enhancements and was eventually avoided by the industry because of the lack of realistic technical resolution and responsiveness. As a result, the integrated implications of the simplifications and conservatisms were not known until the regulatory "clock" had started, i.e., the Harris & Oconee pilots and a few other FPRAs progressed to quantification.

Based on the methods review described here, several things are known:

- There is no single technical element driving the results
- The core problem is compounded conservatisms
- Each element of the fire PRA is inter-related with other elements, so enhancements must be made in a systematic, coordinated manner

This Roadmap has been created to identify the key areas and organize the industry activities focused on attaining realism in fire PRA results. The following sections describe the various areas requiring additional realism.

3.1 Category 1: Fire Initiation, Detection, Suppression

This category includes the initial phase of fire development from adverse condition to the evolution to the point of fire growth as an input to fire modeling and damage assessment.

3.1.1 Fire Event Data Characterization

The foundation for the characterization of fire events is the EPRI Fire Events Database (FEDB). The FEDB is a collection of fire event descriptions spanning from the early years of nuclear power plant operation to 2000 in its currently available form. The data describing the events is inconsistent and, in many cases, incomplete. This has led to the need for a number of assumptions and gaps in the characterization of fires. It is essential that this foundation be enhanced and updated to include better and more complete information, and a long-term program must be established to sustain the collection and analysis of high quality fire event data to support the future of risk-informed, performance-based fire protection. There are three primary areas of activity related to fire event data characterization.

<u>Fire Events Database (FEDB)</u>

The first is the collection, refinement, and analysis of the records in the Fire Events Database (FEDB). The events in the current FEDB do not align well with the manner in which they are used. This requires many assumptions to be made in order to link the events to the manner in which they are characterized in the FPRA. With a more robust and complete database, these assumptions could be supported by data. The current FEDB only includes data through 2000 and relies in many cases on weak event descriptions and a less than traceable categorization scheme. It is paramount that the database be developed in a systematic, traceable, and repeatable manner. EPRI and NRC have collaborated on the design of the database and categorization processes for a new database. The database will be built from detailed condition reports systematically collected from licensees and will focus on the timeframe from 1990 to 2009. The old data from the existing database will not be lost and could be used to support fire ignition sources with limited data, but for the more common (i.e., higher frequency) fires more high quality data will be available on which to build the FPRA inputs.

As part of FAQ 07-0048, the NRC deemed that certain of EPRI's revised fire ignition frequencies could not be relied upon until the FEDB was updated to include data after 2000. One of the key bins cited for special treatment in FAQ 07-0048 was Bin 15 for electrical cabinets. The EPRI work had justified nearly a factor of 2 decrease in the generic Bayesian prior, using the same techniques as used by the NRC for internal event initiating event analysis. The analysis of Bin 15 accounted for plant to plant variability and, as a result, had a relatively broad uncertainty distribution, despite the fact that 29.5 events were included in the event population. The FAQ resolution requires the continued use of the original NUREG/CR-6850 frequencies for Bin 15 in sensitivity analyses of the base FPRA results and in any "change" evaluations.

Finally, risk-informed, performance-based Fire Protection will require a long-term fire event data collection and analysis program. EPRI is actively working with other industry groups to define the long-term data collection and analysis process.

Computation of Ignition Frequencies

The second aspect involves the technical approach used to the computation of NUREG/CR-6850 fire ignition frequencies. An earlier stated premise from NUREG/CR-6850 is that fire ignition frequencies for individual bins are the same at all plants. Yet, NUREG/CR-6850 uses an approach that attempts to account for (or at least assumes) plant-to-plant variability. That disconnect does not represent a significant flaw, as plant-to-plant variability can be shown to be the more realistic modeling concept. A significant problem with the NUREG/CR-6850 methodology is that the documentation on key technical assumptions and details of the use of expert opinion are not provided. This is inconsistent with the ASME/ANS PRA standard. Perhaps more important is the use of prior distributions derived from expert opinion have no substantiated basis, yet conservatively influence the fire ignition frequency results for many bins. In addition, the NUREG/CR-6850 fire ignition frequencies were derived using data from as far back as 1968, when fire protection rules and practices were substantially different than the post 1990 era. ERPI Interim Technical Report 1016735 discusses the significance of this disconnect and provides statistical analyses that show a statistically significant decline in fire ignition frequencies in that post 1990 era compared to earlier periods.

EPRI is refining the fire ignition frequency approach to account for plant-to-plant variability in a scruitable and technically defensible manor that meets the intention of the ASME/ANS PRA standard and comports with expectations from actual operating experience. A key element of that work includes use of more current fire event data from the updated FEDB. The work is being coordinated with the NRC in accordance with the EPRI-NRC Memorandum of Understanding.

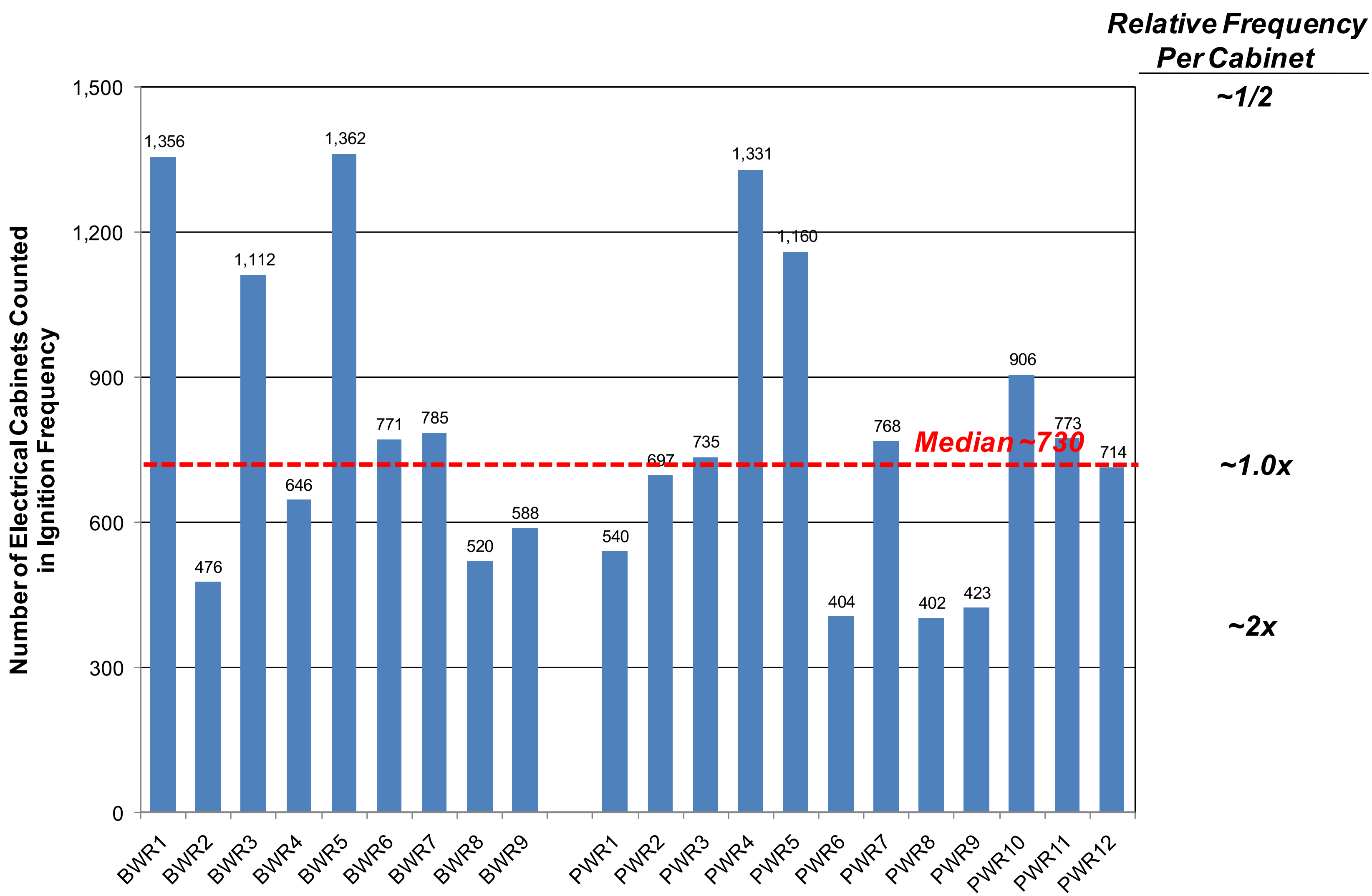
Component-based Ignition Frequencies

The third aspect of this fire event characterization is the refinement of the treatment of fire ignition frequencies. In addition to updating the frequencies with current data, the fundamental approach to the assignment of fire ignition frequencies requires refinement. The NUREG/CR-6850 approach to component-based ignition frequencies relies upon an allocation technique rather than component-specific ignition frequencies. This leads to illogical conclusions such as the plant with four EDGs having a per diesel ignition frequency that is half of the per diesel frequency for a plant with two EDGs. Similar problems exist in other bins. For example, as shown in Figures 3-2 through 3-5, there is a wide variance in the inventory of Electrical Cabinets (Bin 15), HEAF Sources > 1000V (Bin 16b), Pumps (Bin 21), and Air Compressors (Bin 9), respectively. EPRI and the Owners' Groups are collaborating to collect the necessary data to support this transition.

Another problem has to do with the nature of the actual events used in each bin and inconsistency with the specifics of the scenario for which the bin frequency is used. This is particularly notable for the transient fire ignition frequency bins where the content of the transient combustible in real events does not compare well with the associated fire experiments. In addition, the allocation technique for transient ignition frequencies is relatively simplistic and does not adequately address administrative controls such as transient free zones.

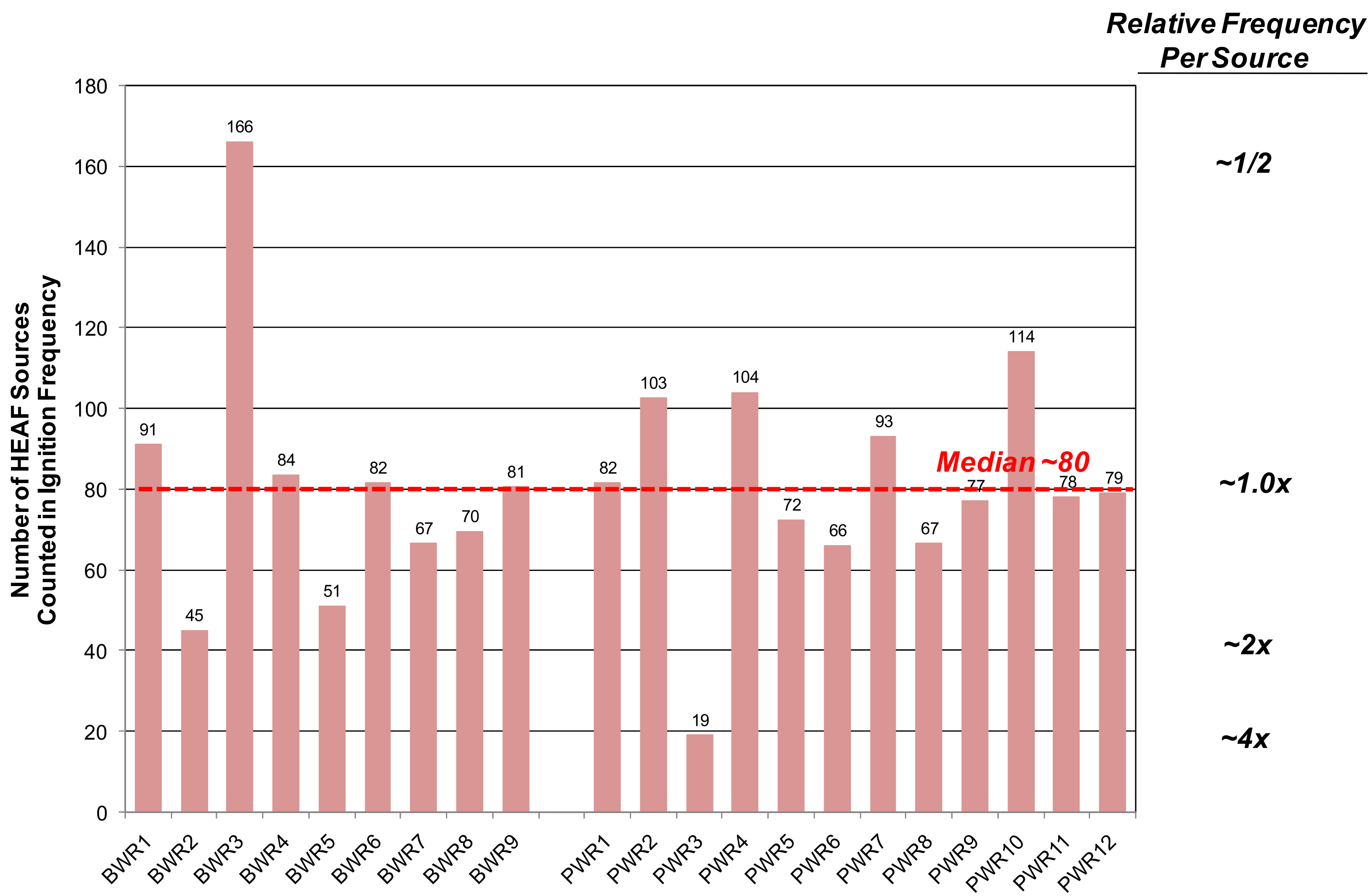
Finally, the disaggregation of fire events into 40 bins provides a challenge to depict the frequency and character of fire ignition source bins where small data sets, some containing just one event, may exist. A fresh look at how to organize, characterize, and analyze this data in light of the scenarios for which they are being applied is needed.

Figure 3-2
Electrical Cabinet Counts for Various Plants



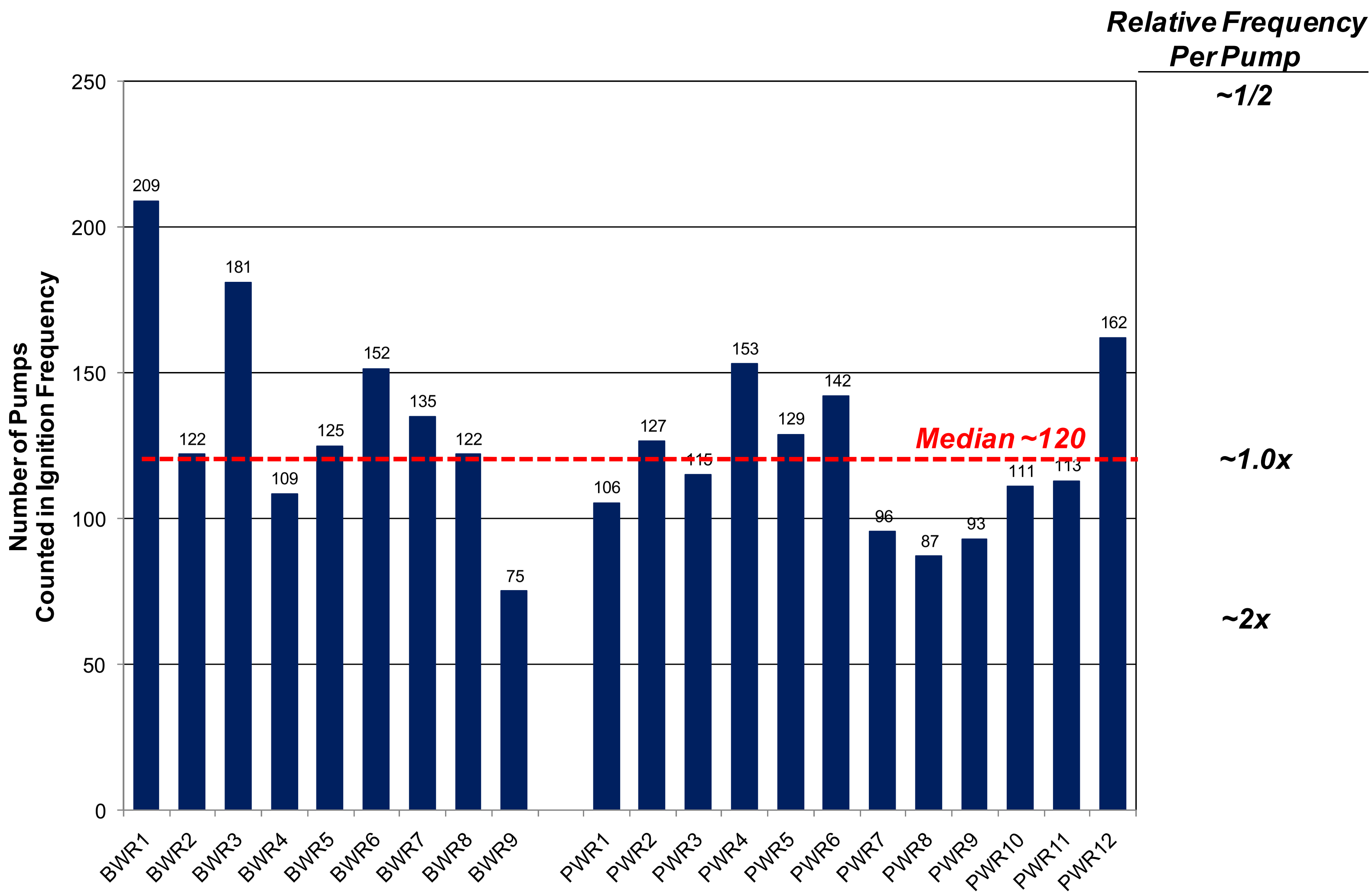
* Draft information (unverified)

Figure 3-3
HEAF Source Counts for Various Plants



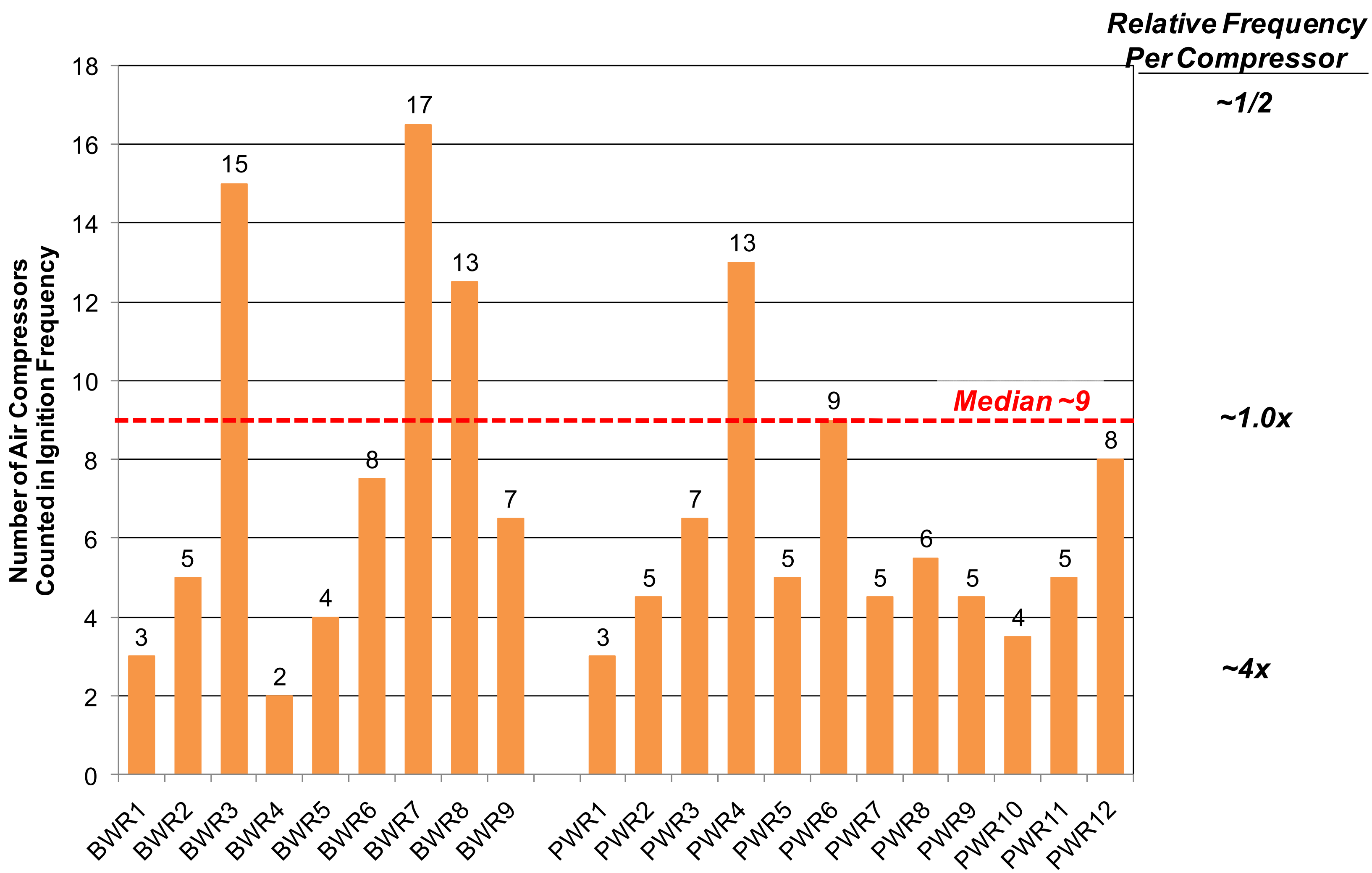
** Draft information (unverified)*

Figure 3-4
Pump Counts for Various Plants



* Draft information (unverified)

Figure 3-5
Air Compressor Counts for Various Plants



* Draft information (unverified)

3.1.2 Fire Severity Characterization

The next significant area in need of additional realism is the treatment of fire severity. This is not limited to the treatment of the incipient fire growth in electrical cabinets, but also the treatment of oil fires. A key disconnect in the NUREG/CR-6850 treatment is that the events from the FEDB are treated as being in the t^2 growth phase, even though the majority are suppressed or controlled before external damage occurs. This means that each fire in the FEDB is treated as if it will grow at a specified rate to a fully developed fire. In the case of electrical cabinets, this timeframe is 12 minutes. As discussed in Section 3.2.1, the derivation of this 12 minute interval is based on fire tests that bear little resemblance to real plant fires.

The treatment of oil fire severity is relatively simplistic and, for the diesel generator case, does not compare well with the events in the FEDB that are driving the ignition frequency. FAQ 08-0044 adjusted treatment for MFW pump oil fires, but other components need a similar update:

- Pumps
- Transformers
- Diesel generators

The Owners' Groups are coordinating with EPRI on the development of an improved approach on oil fires for these component types.

In addition, the improved FEDB is expected to provide a significant amount of data upon which an improved treatment of fire severity could be enhanced. Consequently, this research area must be coordinated with the FEDB development and analysis activities.

3.1.3 Credit for Incipient Detection

The original NUREG/CR-6850 methodology did not provide any guidance regarding credit for incipient fire detection systems. FAQ 07-0046 provides an improved approach for certain applications. Additional development is needed for the use of incipient detection systems outside of electrical cabinets and additional technical bases are needed to assure consistent application of this credit. Here again, the data collected in the FEDB effort will provide additional information on incipient fire development.

In addition, the NRC has plans to perform tests on incipient fire detection systems. These tests could provide valuable input to the treatment of a spectrum of incipient detection systems.

3.1.4 Fire Suppression and Control

The treatment of fire suppression in NUREG/CR-6850 relies on a relatively weak data set extracted from the original FEDB. This data limits ability to address suppression realistically. The improved data collection being undertaken in the development of the new EPRI FEDB will provide a much more robust basis for crediting fire suppression and control.

Control of fires is not explicitly addressed in NUREG/CR-6850. Experience shows that significant fires are often initially controlled rather than suppressed. In some instances, the fire response is to control the fire and manage the heat load on surrounding equipment until the fire can be extinguished or fuel is expended. Anecdotal examples include events that were not declared suppressed for 90 minutes, but no surrounding equipment was damaged.

This activity will be coordinated with the development of the updated FEDB.

3.2 Category 2: Fire Damage Assessment

This category of activities involves the development of the fire from initial flame to peak heat release rate and extinguishment, including the assessment of fire damage through fire modeling.

3.2.1 Fire Growth Assumptions

Fire growth, particularly in electrical cabinets, is an important input to the realistic quantification of fire risks. As with other aspects of NUREG/CR-6850, the treatment of electrical fire growth rates is very coarse and does not address many condition-specific factors that could influence the development rate and peak heat release rate. One example is the influence of ventilation-limited conditions.

The fires in the FEDB do not appear to evolve in the t^2 development phase for some time after event initiation. Nevertheless, NUREG/CR-6850 conservatively assumes a fire growth rate for electrical cabinets (Bin 15) of 12 minutes from the initiating of the fire to peak HRR. This short time artificially limits the benefit of intervention actions such as control or suppression and is a potentially major factor in the overstatement of electrical cabinet fire risks. While the improved FEDB should provide better basis for fire growth assumptions, it is clear that reference basis for the existing treatment has little connection with real plant conditions. It is also important to note that the assumption of a 12 minute growth to peak HRR indirectly applies to other ignition sources beyond Bin 15. For example, pump motor fire, battery chargers and other electrical-based fires all rely on the same growth rate assumption.

One primary input to the assignment of electrical cabinet fire growth rates is NUREG/CR-4527 [Ref. 10]. This purpose of this research was to characterize the development and effects of internally ignited cabinet fires in nuclear power plants. The tests described in NUREG/CR-4527 form the primary basis for 12 minute fire growth rate assumption for electrical cabinets.

In order to ignite cables in the cabinets, these tests utilized a “transient” ignition source comprised of a polyethylene bucket containing:

- 1 quart of acetone
- 1 lb of kimwipes

The flame height from the bucket was described as approximately 3ft and the contents of the bucket burned for approximately 35 minutes. In the early scoping testing it was learned that, the cables had to be positioned to the flame and the cable bundles had to be physically separated in order to sustain burning.

The heat release rate trace for the ignition source only is shown in Figure 3-6. The fire in the polyethylene bucket grew to a peak heat release of approximately 30 kW over a period of approximately 12 minutes. In Figure 3-7, this same trace is overlaid on the results of several other tests from NUREG/CR-4527. This shows that tests ST-1 and ST-2, which did not ignite and propagate to the cables, had similar heat release rates. Furthermore, this trace and the data provided in Figure 3-8 indicates that the peak HRRs used in NUREG/CR-6850 did not subtract the HRR contribution from the ignition source. For example, in Figure 3-8, the results for test ST5 shows a peak of 132 kW. This is the same value as the trace on Figure 3-7, which appears to be the total HRR.

Figures 3-8 and 3-9 include many tests that involve unqualified cables and with the cabinet doors open to maximize the flow of air for combustion. One test, PCT5 actually used 15 gallons of heptane as an ignition source.

What is more significant is that all of the fires grow to a peak that is generally coincident with the growth rate for the acetone and kimwipes. As shown in Table 3-1 (also Table G-2 of NUREG/CR-6850) the growth to peak heat release is quite consistent and fairly tightly grouped around 12 minutes. Interestingly, tests ST1 and ST2, in which the cables were not successfully ignited, are included in this table summarizing the fire growth rates. Further, there is no apparent investigation of the effects of the ignition source on fire growth rates. Thus, it is not at all clear that the 12 minutes used in NUREG/CR-6850 to reflect the growth of fires in electrical cabinets has any relationship with real fires. In fact, the data indicates, at least indirectly, that the growth rate is strongly influenced by the ignition source.

Finally, Figure 3-10 includes an extract from the NUREG/CR-4527 results and conclusions and identifies that there are significant differences in the development of fires in qualified and unqualified cables and that ventilation effects can also be significant.

The application of this data in NUREG/CR-6850 leads to potentially significant overstatement of fire growth rate and damage due to the following:

- The tests were designed to cause damage and relied upon significant ignition sources to start and sustain the fires
- All fires treated as if propagation is possible
- Fire growth rate set by “transient” ignition source (acetone & kimwipes)
- Tests with 10-15 gal of heptane as ignition source are included in the experimental base
- Most tests were with open or no doors
- Many tests were with unqualified cables
- Benchboard and vertical cabinets treated the same

Consequently, the damage rate and damage potential to be used in the FPRA appears overstated and the short growth time reduces potential for intervention by plant personnel to control or suppress the fire, e.g., operations or brigade. This treatment needs to be informed by better experience, data, and more mechanistic treatment of cabinet parameters, e.g., ventilation limited fires, qualified/unqualified cables, cabinet type.

Figure 3-6
Ignition Source Heat Release Rate from NUREG/CR-4527

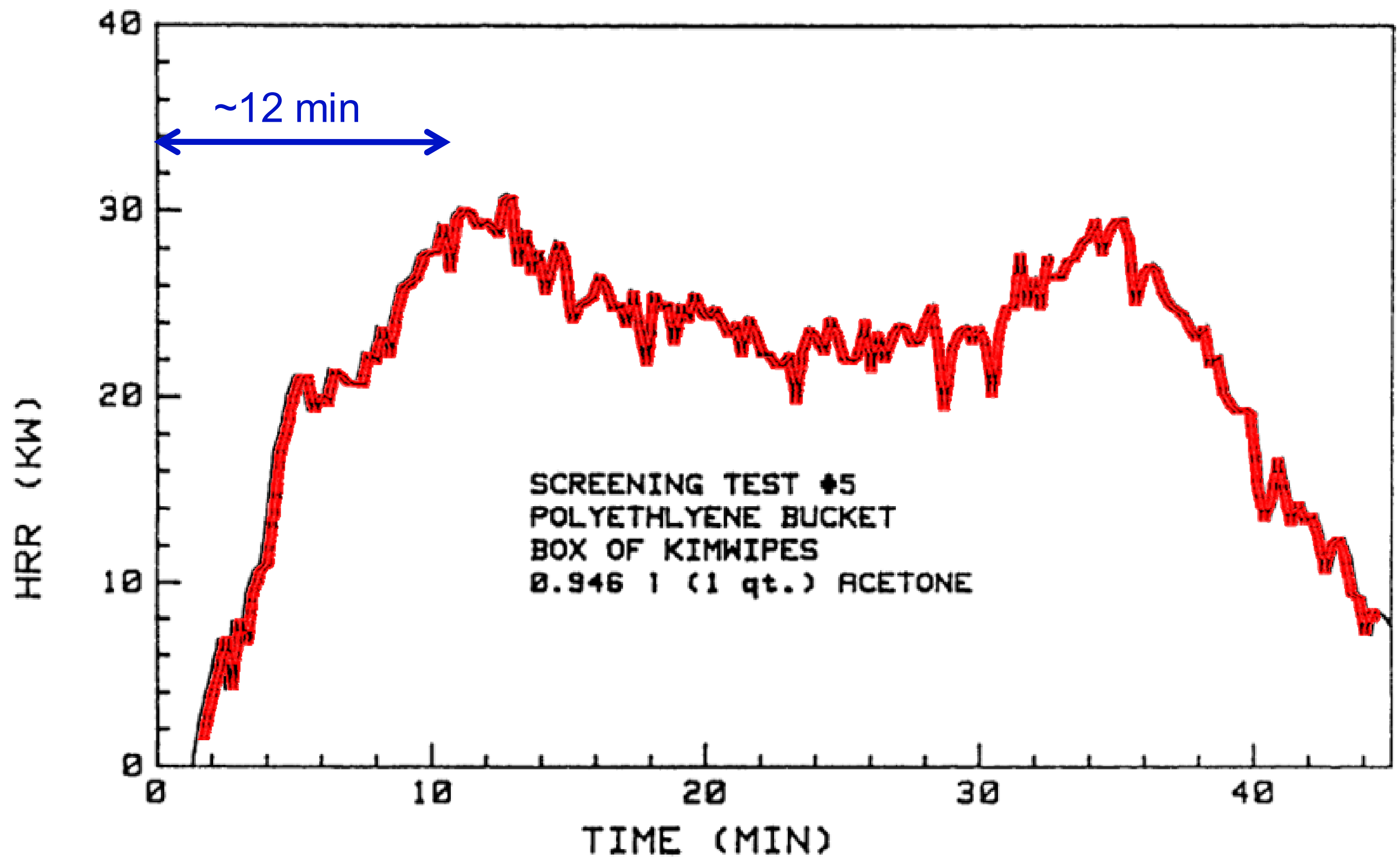


Figure 6. Heat Release Rate for the Transient Ignition Source; Screening Test #5

Figure 3-7
Screening Test Results from NUREG/CR-4527

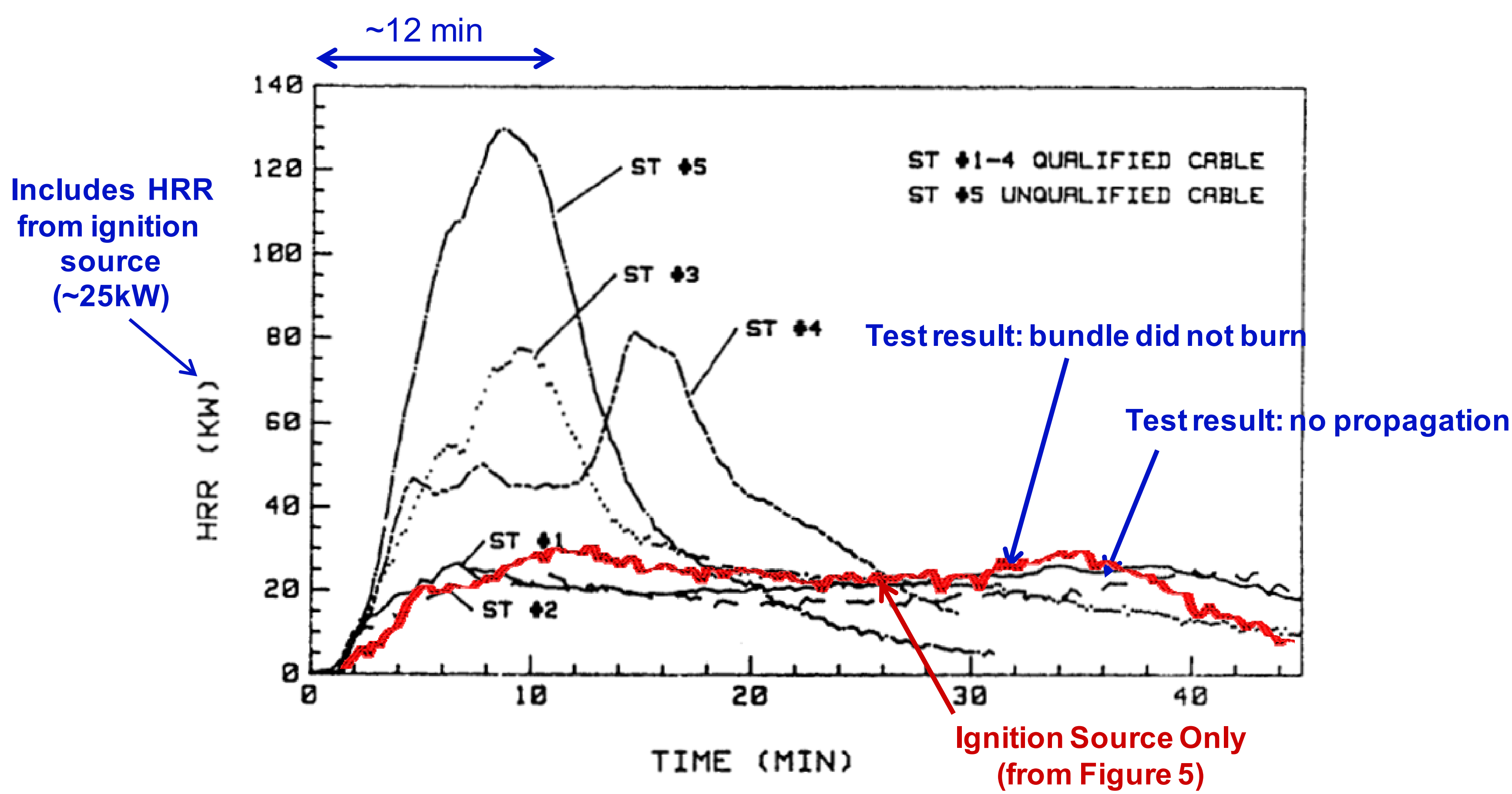


Figure 8. Heat Release Rate Plots for Scoping Tests #1 through 5

Figure 3-8
Summary of Scoping Test Results from NUREG/CR-4527

Test #[a]	Cable Type	Amount of In Situ Fuels[b,c] (KJ)	Cabinet[d] Ventilation Method	Peak HRR (KW)	Intense Burn Duration (min)	Test Result
ST1	Q	117,000	No doors	24	15	Bundle did not burn
ST2	Q	117,000	No doors	27	17	No propagation
ST3	Q	117,000	No doors	77	18	Entire bundle consumed
ST4	Q	117,000	No doors	82	17	Almost entire bundle consumed
ST5	UQ	117,000	No doors	132	17	Entire bundle consumed
ST6	Q	348,500	No doors	82	25	No propagation
ST7	Q	348,500	Doors closed	95	25	No propagation
ST8	Q	582,875	Doors closed	93	30	No propagation
ST9 barriers	Q	234,990	Doors open	74	20	No propagation
ST10	UQ	611,530	Doors closed	280	30	Propagated All burned
ST11	UQ	611,530	Door open	506	20	Propagated All burned

No Significant Damage

Figure 3-9
Summary of Preliminary Cabinet Tests from NUREG/CR-4527

Table 4

Matrix of Preliminary Cabinet Tests

TEST #	IGNITION FUEL	CABINET TYPE	CABINET VENTILATION	IN SITU FUEL TYPE	IN SITU FUEL AMOUNT (KJ) [BTU]
PCT 1	Transient	Vertical	Vent Grills on Doors	UQ	7.283×10^5 [6.90×10^5]
PCT 2	Transient	Vertical	Doors Open	UQ	1.051×10^6 [1×10^6]
PCT 3	Transient	Vertical	Doors Open	Q	1.055×10^6 [1×10^6]
PCT 4	Heptane	Vertical	Doors Open	Heptane	56.78 ℓ (.929 m^2 pan) [15 gal (10 ft^2 pan)]
PCT 5	Electrical	Benchboard	Door Open Front Grill	UQ	1.519×10^6 [1.44×10^6]
PCT 6	Transient	Benchboard	Door Open Front Grill	Q	1.551×10^6 [1.47×10^6]

Table 3-1
NUREG/CR-6850 Summary of Time to Peak HRR (From Table G-2 of NUREG/CR-6850)

Test	Time to Peak	Steady Burning	Time to Decay	Ignition Source	Cable	Ventilation
ST1	7	8	15	Transient	Qualified	Open
ST2	6	11	17	Transient	Qualified	Open
ST3	10	8	18	Transient	Qualified	Open
ST4	14	3	17	Transient	Qualified	Open
ST5	8	9	17	Transient	Unqualified	Open
ST6	8	17	25	Transient	Qualified	Open
ST7	18	7	25	Transient	Qualified	Closed
ST8	10	20	30	Transient	Qualified	Closed
ST9	10	10	20	Transient	Qualified	Open
ST10	10	20	30	Transient	Unqualified	Closed
ST11	18	2	20	Transient	Unqualified	Open
PCT1	11	10	21	Transient	Unqualified	Closed
PCT2	12	2	14	Transient	Unqualified	Open
PCT3	13	14	27	Transient	Qualified	Open
PCT4a	16	0	16	Heptane Pool	Unqualified	Open
PCT4c	16	0	16	Heptane Pool	Unqualified	Open
PCT5	17	0	17	Electrical	Unqualified	Open
PCT6	11	0	11	Transient	Qualified	Open
Test 21	4	14	18	Gas Burner	Unqualified	Open
Test 22	9	2	11	Gas Burner	Unqualified	Open
Test 23	10	0	10	Transient	Qualified	Open
Test 24	12	0	12	Electrical	Qualified	Open
Average	**11.4**	**7.1**	**19**			

Figure 3-10
Excerpts from Conclusions Section of NUREG/CR-4527

"A number of conclusions can be made as a result of the Scoping Tasks that give insight into cabinet fire development and input into the Preliminary Cabinet Tests. The conclusions are as follows:

- There is a "critical" amount of "ignition source fuel" that is necessary to ignite a cable bundle, particularly qualified cable.
- Qualified cable fires (with the selected cable and ignition source) in vertical cabinets do not spread throughout the cabinet.
- Unqualified cable in vertical cabinets will easily ignite (with the selected ignition source) and propagate a fire in a single cabinet.
- Burning rate (as measured by the HRR) is affected by the ventilation method (i.e., closed or open cabinet door) in tests using unqualified cable. Closed cabinet doors appear to result in higher cabinet temperature but also cause oxygen deprivation that appears to limit the burning rate.
- Smoke obscuration in the test enclosure occurs within eight minutes in unqualified cable cabinet fires in the configurations tested.
- The thermal environment in the enclosure does not become severe enough to cause melting of components or result in flashover.

Furthermore, an important observation made during the tests was that when comparing the test cabinets loaded with in situ fuel (loadings are based on survey information) to pictures of actual nuclear power plant cabinets, the fuel load appears to be small. As a result of the Scoping Tests, it appears that cabinet fires with qualified cable do not propagate significantly. However, cabinet fires with unqualified cable may be a real threat to the safety of a nuclear power plant, from the standpoint of fire spread, and control room habitability, given the "critical" conditions and configurations."

3.2.2 Peak Heat Release Rates

As discussed in Section 2, peak HRRs are an important factor in defining the damage caused by an ignition source. The assumptions related to peak heat release rates should be investigated and improved where possible for electrical cabinets, transient ignition sources, hot work, and electrical fires from pumps and fans.

<u>Electrical Cabinets</u>

As discussed in Section 2.3, electrical cabinet fires are a major contributor to fire CDF in current FPRAs. The observed damage from operating experience does not align with the damage computed using fire models based on the assumed peak HRR inputs and the damage does not align with actual operating experience. This results in an overstatement of the effects of fires and has potential to confound risk-informed decision-making, as described in Section 2.5.

The basis for the assignment of peak HRR distributions has little documentation. This makes justification for deviation from the postulated peak HRRs very difficult. Without knowing the basis, the analyst is left without a basis to adopt a different basis. The expert judgment applied is essentially inscrutable and does not meet the requirements of the ASME/ANS PRA Standard.

The peak HRRs assumed for electrical cabinets are binned very simply. As shown in Figure 3-10, there are only 5 bins for electrical cabinets and these do not align well with the test conditions. In fact, there is a bit of a mix and match of test conditions used to assign peak HRRs. For example, some of the values for cabinets with qualified cables refer to tests with unqualified cables. Many results are from tests with open cabinets but there is no bin for open cabinets, so all cabinets have those results applied.

EPRI has a research task underway to develop a more refined approach to the assignment of peak HRRs in electrical cabinets.

<u>Transient Ignition Sources</u>

In NUREG/CR-6850, transient ignition sources are evaluated in three separate categories with specified frequencies (Bins 7, 25, and 37). The source for the assumed peak HRR is from tests performed on trash bags. However, the events in the FEDB are primarily events involving transient ignition sources such as space heaters, extension cords, scaffolding, etc. In fact, only one FEDB event involved a trash receptacle. Once again, there is a disconnect between the events that are being used to define the frequency and the assumptions related to damage.

<u>Hot Work</u>

Similar to the transient ignition sources, a disconnect exists between the hot work event freqencies and the applicable operating experience. In this case, the majority of hot work events in FEDB are pre-Appendix R. The new FEDB needs to inform with the type of events that actually occur during hot work under current fire protection requirements. An alternative treatment might tie the peak HRR to the types of hot work that has involved fires, rather than an arbitrary HRR from a transient source.

Other Sources

There are a variety of issues associated with the assignment of peak HRRs. As the key items such as electrical cabinets are made more realistic, it is expected that additional simplifications/assumptions on peak HRRs will be identified for improvement. One example involves electrical fires from pumps and fans. As shown in Figure 3-12, Table G-1 of NUREG/CR-6850 says that the data used to assign peak HRRs for pumps and fans are from electrical cabinet fire tests and it is "considered conservative". On a plant-specific basis, these contributors can be significant. Another interesting aspect of the treatment of pump fires is that all pumps greater than 5 hp are considered using the same peak HRR. This means that electrical fires in small radwaste transfer pumps are treated the same as electrical fires in very large circulating water pumps.

Figure 3-11
Electrical Cabinet Peak Heat Release Rates (from Table G-1 of NUREG/CR-6850)

Tests of Cabinets with Unqualified Cables

Average of Benchboard Tests with Open Doors

Table G-1
Recommended HRR Values for Electrical Fires

Ignition Source	HRR kW (Btu/s)		Gamma Distribution	
	75th	98th	α	β
Vertical cabinets with qualified cable, fire limited to one cable bundle	69 [1] (65)	211 [2] (200)	0.84 (0.83)	59.3 (56.6)
Vertical cabinets with qualified cable, fire in more than one cable bundle	211 [2] (200)	702 [3] (665)	0.7 (0.7)	216 (204)
Vertical cabinets with unqualified cable, fire limited to one cable bundle	90 [4] (85)	211 [2] (200)	1.6 (1.6)	41.5 (39.5)
Vertical cabinets with unqualified cable, fire in more than one cable bundle closed doors	232 [5] (220)	464 [6] (440)	2.6 (2.6)	67.8 (64.3)
Vertical cabinets with unqualified cable, fire in more than one cable bundle open doors	232 [5] (220)	1002 [7] (950)	0.46 (0.45)	386 (366)

Figure 3-12
Peak Heat Release Rates for Other Fixed Ignition Sources (from Table G-1 of NUREG/CR-6850)

Table G-1
Recommended HRR Values for Electrical Fires

Ignition Source	HRR kW (Btu/s)		Gamma Distribution	
	75th	98th	α	β
Vertical cabinets with qualified cable, fire limited to one cable bundle	69 [1] (65)	211 [2] (200)	0.84 (0.83)	59.3 (56.6)
Vertical cabinets with qualified cable, fire in more than one cable bundle	211 [2] (200)	702 [3] (665)	0.7 (0.7)	216 (204)
Vertical cabinets with unqualified cable, fire limited to one cable bundle	90 [4] (85)	211 [2] (200)	1.6 (1.6)	41.5 (39.5)
Vertical cabinets with unqualified cable, fire in more than one cable bundle closed doors	232 [5] (220)	464 [6] (440)	2.6 (2.6)	67.8 (64.3)
Vertical cabinets with unqualified cable, fire in more than one cable bundle open doors	232 [5] (220)	1002 [7] (950)	0.46 (0.45)	386 (366)
Pumps (electrical fires) [8]	69 (65)	211 [2] (200)	0.84 (0.83)	59.3 (56.6)
Motors [8]	32 (30)	69 (65)	2.0 (2.0)	11.7 (11.1)
Transient Combustibles [9]	142 (135)	317 (300)	1.8 (1.9)	57.4 (53.7)

See Note 8: No basis

Note 2: Vertical Cabinet Test

Figure 3-12
Peak Heat Release Rates for Other Fixed Ignition Sources
(Continued)

Notes for Table G-1

1. Ref. G.2: Sandia experiments, average of vertical cabinet fire intensities with qualified cable.
2. Ref. G.3: VTT experiments with control cabinets.
3. Ref. G.2: Sandia experiments, average of two bench-board cabinet experiments with qualified cable.
4. The value is based on expert judgment. The expert panel assumes that the type of cable will only affect the ability of the cable to ignite. Therefore, once ignited, a single cable bundle is assumed to burn with similar intensity regardless of the cable qualification. A value of 85 BTU/s was selected as a conservative estimate for unqualified cables to represent a higher intensity at the 75th percentile when compared to qualified cable.
5. Ref. G.2: Sandia experiments, average of two vertical cabinet experiments with unqualified cable and closed doors.
6. Twice the intensity selected for the 75th percentile.
7. Ref. G.2: Sandia experiments, the highest heat release rate observed in cabinets with open door and unqualified cable.
8. No experimental evidence is available for assessing fire intensities for electrical fires in equipment other than electrical cabinets (or panels). Recommended values are considered conservative and are based on electrical cabinet (panel) fires experiments.
9. Distribution estimated based on the range of the tested transient fuel packages summarized in table G-7.

3.2.3 Fire Damage Assessment

NUREG/CR-6850 includes various assumptions related to the damage caused by fires. For example, high energy arcing faults in switchgear and bus ducts, as well as damage to sensitive electronic equipment.

Switchgear and Bus Duct HEAF

The current treatment of HEAF events in switchgear is another simplification in method that inappropriately bounds many conditions, especially for low voltage conditions, and may be applicable for certain switchgear. If the treatment of electrical cabinet fires is refined, then HEAF events would become the dominant fire risk contributor. Thus, this treatment should be informed by more comprehensive review of switchgear HEAF events.

The treatment of bus duct HEAFs was refined in a prior FAQ 007-0035, but retains some conservatism. Like switchgear HEAFs, this treatment should be informed by more comprehensive review of bus duct HEAF events.

Damage to Sensitive Electronic Equipment

Currently, there is no guidance for the treatment of potentially sensitive electronic equipment. There is not even an adequate definition of the applicable circumstances, equipment, damage, and failure modes. Consequently, it is conservatively assumed that such components fail at t=0. This overstates the contribution from such failures.

3.2.4 Fire Propagation

Electrical cabinet fires are always assumed to generate significant heat release and cause damage within the cabinet. Operating experience does not support this assumption.

A proposed treatment of fire propagation from a sealed, but not ‘well-sealed’, low voltage cabinet/MCC fires was in the original FAQ 08-00043. However, it was removed by the NRC staff in the final version. As the FEDB effort continues, the insights from the improved data could be used to inform the treatment and justify a probability of non-propagation.

3.2.5 Fire Modeling

Fire modeling is an essential element of a realistic fire PRA. Current fire modeling tools have various limitations that merit additional guidance. EPRI and NRC collaborated on a draft guidance document (NUREG-1934). The initial version of this document received significant industry comments which are being addressed in the re-write.

Even with improved guidance, various fire model uncertainties could impact application of fire modeling results. An integrated approach to addressing fire modeling uncertainties is expected to be required in order to avoid the use of unduly bounding assumptions.

3.3 Category 3: Plant Impact, Fire PRA Scenarios and Quantification

This category of activities involves the translation of fire damage into effects that can be modeled in the fire PRA model.

3.3.1 Treatment of Hot Shorts

The treatment of hot shorts in AC and DC circuits is an important aspect of a FPRA. The current approaches to hot shorts are evolving as test data is received and evaluated. For example, recent DC circuit testing may allow the refinement of the duration of DC hot shorts. Currently, analysts are required to assume that all DC hot shorts occur and remain for infinite duration. Since DC circuits control many important components, such as PWR PORVs and BWR SRVs, these assumptions can dramatically affect the accident scenarios analyzed, e.g., LOCA vs. no LOCA. There is a need to properly apply results and insights from these tests to assure realistic methods are available for incorporation into the FPRA.

3.3.2 Human Reliability

NUREG/CR-6850 provides little guidance on the treatment and quantification of human failure events and essentially defaults to bounding HEPs=1.0. A draft NUREG-1921 was issued for public comment last year and received substantial comments from industry and proposed an onerous screening process that was of little value. The revision of NUREG-1921 is underway now and must be completed in order to provide a realistic means to incorporate human action in the FPRA. Control room fires are a special case of fires involving human actions to suppress and respond to a fire, up to and including in some cases, the abandonment of the control room.

3.3.3 Modeling of Control Room Fires

Control room fires may become a significant risk contributor as realism is added in other parts of the FPRA. Control room fires involve complex spatial challenges in a critical plant area that is continuously manned. This makes the treatment of control room fires distinct from most other electrical cabinet fires. The opportunity for detection and intervention can be substantial. EPRI has a research task underway to improve the methods and enhance the treatment of this contributor.

3.3.4 FPRA Model Advancement

As the refinements to the fire modeling inputs are refined, it is expected that additional FPRA model simplifications will need to be addressed. Enhancements are expected to be needed in the treatment of the timing of failures, e.g., cable failures and spurious operations. In addition, there is an implicit assumption in most FPRAs that every fire leads to a plant trip. A preliminary assessment of operating experience indicates that occurrence of a plant trip or significant power reduction varies from area to area in the plant. The average chance of a plant trip or significant power reduction is roughly 1 in 8. Even fires in areas such as switchgear rooms, control rooms, and reactor/auxiliary buildings have relatively modest probabilities of a plant upset. Revision of an assumed likelihood of a plant trip could have significant impact (direct reduction in CDF) for scenarios where the postulated fire damage does not directly cause plant trip.

4.0 CONCLUSIONS & RECOMMENDATIONS

Based on the results and insights from industry fire PRAs, it has been identified that the methods described in NUREG/CR-6850/EPRI TR-1011989 contain excess conservatisms that bias the results and skew insights. While the prior FAQ process made some incremental progress in addressing areas of excessive conservativism, many more remain in need of enhancement.

4.1 Conclusions

The primary source of these issues is the simplified approach taken in defining fire hazards and the bounding assumptions made in characterizing the fire events. The net result is that FPRAs based on NUREG/CR-6850 are not realistic. The conclusions from this review are summarized in Table 4-1.

Table 4-1
Summary of Conclusions and Bases

Conclusion	Selected Bases
Fire characterization does not conform with operating experience	• Over-prediction of number of severe fires • Assumed rate of fire growth & severity, e.g., 12 mins in electrical cabinets, oil fire severity • No credit for control of fires
The level of quantified risk is overstated	• FPRAs based on NUREG/CR-6850 predict high frequency of fires with high CCDPs, but NRC's ASP & ROP have demonstrated this • Predicted frequency of spurious operations not consistent with operating experience
Uneven level of conservatism can mask key risk insights and lead to inappropriate decision-making	• Simplifications result in bounding treatment of "bin" • Overstated fire damage can lead to underestimation of risk increases from plant changes • Assumes plant challenge for all fires, e.g., plant trip • No credit for administrative controls

Realistic FPRAs should be a goal for both the NRC and industry. Conservatively biased PRAs distort decision-making:

- Conservatisms in the results can mask important risk contributors
- Conservatisms in the characterization of fire damage can mask the significance of plant changes, including the risk increase of equipment out of service
- Conservatisms overall can misdirect decision-makers

4.2 Recommended Areas of Industry Research

EPRI initiated the Fire PRA Action Matrix in late 2009 as a means to clarify and coordinate industry activities related to fire PRA methods. The matrix is routinely updated as new issues are identified. The action matrix includes and serves as the coordination point for activities led by EPRI, NEI, PWROG, and BWROG. The industry effort to implement the action matrix reports to NSIAC via an Executive Oversight Group and the technical tasks are coordinated within the NEI FPRATF.

Based on the insights from industry PRAs described in Section 2 and the specific areas in need of additional realism identified in Section 3, EPRI has updated the EPRI Fire PRA Action Matrix to provide a broad, coordinated industry research program with activities targeting the key areas where the level of realism needs to be improved in FPRAs. Table 4-2 below provides an overview of:

- The technical area of needed realism (based on Sections 2 & 3)
- The EPRI research area within each technical area
- The specific EPRI research activity targeting this area
- The industry priority for the activity, i.e., high, medium, low.
- The owner of the research activity, i.e., EPRI, OGs, NRC, or some combination.

Appendix B provides the current schedule for these activities from 2011 to 2014.

Many important Fire PRA activities are already under way within the industry. These activities are focused on the high priority activities that will provide the greatest initial benefit in increasing the level of realism in Fire PRAs. The development of an improved FEDB is a key element to understanding the issues and refining treatment in a number of technical issues, such as manual suppression, incipient fire growth, etc. EPRI is working cooperatively with the NRC staff to ensure that new methods and information can be used in licensing applications.

Table 4-2
Major Industry Research Activities Related to Achieving Realism in Fire PRAs

Area of Needed Realism	EPRI Research Area	EPRI Research Activity	Priority	Owner
Fire event data characterization	1.1 Fire events database	1.1.1 Revise the database structure to fit the current uses in Fire PRAs such as ignition frequency, detection and suppression probability, brigade response, and others	High	EPRI / RES
		1.1.2 Collection fire event information from industry	High	PWROG BWROG
		1.1.3 Define realistic fire event categorization scheme and apply to events	High	EPRI
		1.1.4 Collect component counts and apply to database	High	EPRI / OGs
		1.1.5 Develop Fire Events Database (FEDB) revision 1 and report	High	EPRI
		1.1.6 Transition long-term data collection efforts	High	INPO
	1.2 Fire ignition frequency	1.2.1 Improve methods for ignition frequency calculation	High	EPRI
		1.2.2 Develop Fire Ignition Frequencies	High	EPRI
		1.2.3 Develop component-based ignition frequencies	High	EPRI
		1.2.4 Update ignition frequencies using insights from initial implementation experience	Medium	EPRI

Table 4-2
Major Industry Research Activities Related to Achieving Realism in Fire PRAs

Area of Needed Realism	EPRI Research Area		EPRI Research Activity		Priority	Owner
Fire severity characterization	1.3	Incipient fire growth in electrical cabinets	1.3.1	Utilize information from the FEDB to characterize detection and termination prior to an actual fire event.	Low	EPRI/UMD
	1.4	Oil fire severity	1.4.1	Pumps	High	PWROG
			1.4.2	Transformers	High	PWROG
			1.4.3	Diesel Generators	High	PWROG
Credit for incipient detection	1.5	Credit for incipient detection	1.5.1	Refine FAQ 08-0046	Medium	EPRI
			1.5.2	Incipient fire detector testing (NRC lead)	Low	EPRI / RES
Credit for suppression & Control	1.6	Fire suppression probabilities	1.6.1	Develop recommended approach for non-suppression curves	High	BWROG / GEH
			1.6.2	Refine treatment based on current database	Medium	GEH
			1.6.3	Refine treatment based on updated database	Medium	EPRI

Table 4-2
Major Industry Research Activities Related to Achieving Realism in Fire PRAs

Area of Needed Realism	EPRI Research Area		EPRI Research Activity		Priority	Owner
Fire growth assumptions	2.1	Fire growth and comparison with data	2.1.1	Review of data to distinguish factors impacting fire growth rate (qualified vs. non-qualified, ventilation, etc.)	Medium	EPRI
			2.1.2	Refine treatment based on updated database	Medium	EPRI
Peak heat release rates	2.2	Electrical cabinet peak heat release rate (HRR)	2.2.1	Review of available data	High	EPRI
			2.2.2	Treatment for ventilation limited cabinets	High	EPRI
			2.2.3	Testing plan, as needed	Low	EPRI / RES
	2.3	Transient ignition source HRR	2.3.1	Review of database and development of revised treatment	Medium	EPRI
	2.4	Hot work HRR	2.4.1	Review of database and development of revised treatment	Medium	EPRI
	2.5	Other HRRs	2.5.1	Review of database and development of revised treatment	Medium	EPRI
Damage assessment	2.6	Switchgear HEAF zone of influence (ZOI)	2.6.1	Review of data from switchgear events	Medium	EPRI
			2.6.2	Formulation of revised treatment for medium voltage switchgear	Low	EPRI
			2.6.3	Formulation of revised treatment for low voltage switchgear	Low	EPRI
	2.7	Bus duct HEAF ZOI	2.7.1	Review of data from bus duct events and formulation of revised treatment	Low	EPRI

Table 4-2
Major Industry Research Activities Related to Achieving Realism in Fire PRAs

Area of Needed Realism	EPRI Research Area		EPRI Research Activity		Priority	Owner
	2.8	Damage to sensitive electronic equipment	2.8.1	Formulation of revised treatment to avoid assumption of failure for all	Low	EPRI
Fire propagation	2.9	Electrical cabinet propagation	2.9.1	Review of database and development of revised treatment based on cabinet-specific factors	Medium	GEH
Fire modeling	2.10	Fire modeling guidance	2.10.1	Completion of Fire Modeling Users Guide (FMUG)	High	EPRI / RES
			2.10.2	Update FMUG to address propagation of modeling uncertainty in the PRA	Low	EPRI
Treatment of hot shorts	3.1	AC circuits hot short probability and duration	3.1.1	Review of test results and development of revised treatment to enhance FAQ 08-0051	Medium	EPRI
	3.2	DC circuits hot short probability and duration	3.2.1	Review of test results and development of revised treatment	Medium	EPRI / RES
			3.2.2	Conduct phenomena identification and ranking table (PIRT) panel	Medium	EPRI / RES
			3.3.3	Peer review of results	Medium	EPRI / RES
			3.3.4	Issue report	Medium	EPRI / RES
Human Reliability	3.3	Human reliability analysis (HRA) methods and performance shaping factors for fire PRAs	3.3.1	Update of NUREG-1921	High	EPRI / RES
			3.3.2	Refinement of EPRI HRA report, as needed	Low	EPRI

Table 4-2
Major Industry Research Activities Related to Achieving Realism in Fire PRAs

Area of Needed Realism	EPRI Research Area		EPRI Research Activity		Priority	Owner
Modeling of control room fires	3.4	Control room modeling and treatment in the fire PRA	3.4.1	Refinement of treatment	Medium	EPRI
PRA model advancement	3.5	Address unrealistic model simplifications	3.5.1	Address assumption that there is always a plant trip following each fire event	Medium	EPRI
			3.5.2	Address assumption that failed ventilation causes immediate failure of equipment	Low	EPRI

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APPENDIX A

FIRE EVENT SUMMARIES FOR DIESEL GENERATOR FIRES (BIN 8)

Table A-1

Summary of Diesel Fire Events

Event No.	Year	Description	Characterization
50	1974	During testing of the emergency diesel generator while the reactor was at 2535 Mwt, a small fire occurred in the logging around the diesel engine exhaust gas inlet. The fire resulted from a small amount of oil leakage from an engine inspection cover plate joint which had ignited from heat. The fire was extinguished. No damage occurred. The bolts were checked. temporary oil deflectors were fabricated and installed to keep the oil off the exhaust manifold.	Exhaust manifold
54	1975	The diesel generator appeared to have overheated which caused a back pressure in the exhaust manifold with a subsequent explosion in the crankcase. An air filter door blew open and gaskets burned. Oil leaked from several locations and the exhaust manifold was red hot.	Crankcase explosion
63	1975	Fire in a diesel exhaust manifold.	Exhaust manifold
67	1975	Maintenance employees decided to change the oil in the emergency diesel generator air intake filter. The filter contains 20 gal. of 50 wt. oil in a reservoir at the bottom with calrods electrically heated. A 3-position switch controls the calrods from the control room. The switch was left in the auto position when the draining began. As the oil drained, the calrods became exposed. Heat built up and the oil ignited, starting the filter on fire. A thermistor wire above in a cable tray detected the fire and opened the start-up transformer deluge valve. This action held the fire in check. At 13:25 the deluge valve was closed and dry chemical fire extinguishers, fire brigade and employees extinguished the blaze. The interior screen portion of the filter was destroyed and 20 gal. of 50 wt. oil were lost as a result of the incident. The diesel generator itself was not protected by sprinklers. It was determined that the employees had been cleared to work on the diesel generator, but not the filter.	Lube oil leak

Table A-1

Summary of Diesel Fire Events

Event No.	Year	Description	Characterization
68	1975	A small fire occurred on the surface of the exhaust manifold during a test of the standby diesel generator. Oil leakage from the diesel front cover plate was absorbed by the exhaust manifold insulation. Operation ignited the oil soaked insulation.	Exhaust manifold
2374	1975	DR75-0067	na
73	1976	Cause-leaking flange gasket. The flange gasket leaked exhaust gases with traces of oil onto the exterior of the flange. The oil was ignited by exhaust heat. (Oil leaking onto diesel-exhaust manifold caught fire.)	Exhaust manifold
75	1976	While performing a surveillance test run of the 13U diesel generator, a small fire occurred on the exhaust manifold on the control end of the engine. An operator in the diesel room secured the engine and extinguished the fire. The 13U diesel was declared inoperable and surveillance testing completed per tech spec 3.8.1.A. Fire was due to lube and fuel oil which had accumulated under the insulation at one point on the exhaust manifold. There was also an injector leak in the vicinity of the fire.	Exhaust manifold
79	1976	Oil leaked onto diesel exhaust manifold and caught fire.	Exhaust manifold/oil leak
85	1976	A small fire occurred on the exhaust manifold on the control end of the engine. The fire was due to an accumulation of lube and fuel oil under the insulation on the exhaust manifold. There was also an injector leak in the vicinity of the fire.	Exhaust manifold
86	1976	An operator disconnected DC tie breaker, losing DC power during a battery charge. A reactor tripped and a safety injection occurred. The main generator was overloaded and fire resulted.	na
87	1976	During testing, a fire was discovered in the exhaust of emergency diesel generator. Apparently, the turbo-charger was replaced.	Exhaust manifold

Table A-1

Summary of Diesel Fire Events

Event No.	Year	Description	Characterization
89	1976	During testing, a fire broke out on DG 16-21. A hairline fracture in a fuel line fitting caused fuel to spray out and be ignited by heat from the exhaust header.	Fuel line leak
115	1977	During a test run to verify operability of diesel generator 11 after preventative maintenance work, a small fire developed when lube oil sprayed from the lube oil strainer and ignited on contact with the exhaust manifold. The D/G was shut down and the fire quickly extinguished. The O-ring gasket in the oil strainer failed at its glued joint due to the normal pressure buildup. The joint had not been glued properly. No damage occurred to the D/G. Pre-action system tripped by heat detectors but insufficient heat to open heads.	Lube oil leak
1151	1977		na
134	1978	During a test of diesel generator 2, the generator was manually tripped due to abnormal indications. Fire from exhaust stack, then smoke alarm was noted. Fire inside turbocharger was found. The fire team applied a fine water spray to the turbo exterior and the fire was contained. Probable cause of the fire was failure of the bearing between the air inlet blading and exhaust turbine blading of the diesel engine turbocharger. The subsequent failure of bearing oil seal allowed lubricating oil into the turbocharger.	Turbocharger
144	1978	The operator noticed smoke emitting from the DG control cabinet and shut down the DG.	Cabinet
150	1978	Fire in a diesel exhaust manifold during a test.	Exhaust manifold
166	1979	Fire involving exciter control cabinet of DG. It was discovered while operating diesel generator for trouble-shooting.	Cabinet

Table A-1

Summary of Diesel Fire Events

Event No.	Year	Description	Characterization
172	1979	During a special DG test, a diesel turbocharger failed which resulted in a fire within the engine's exhaust system, and eventually caused the engine to shut down. The heat from the internal fire also caused some of the painted external surfaces of the exhaust system to ignite. The external fire was quickly extinguished using portable equipment. The cause of the fire was the failure of the turbocharger on the GM Electro-Motive Diesel Engine. (Fire smoldered during two hours. After several attempts with CO2 and dry chemical, the decision was finally made to use water which quickly extinguished the fire.)	Exhaust manifold
186	1980	During surveillance test of diesel generator bearing overheated and ignited lube oil. The result was a broken shaft assembly.	Lube oil leak
204	1980	Fire involving generator exciter cubicle located in the DGB. Discovered while conducting 24-hour performance test.	Cabinet
215	1980	Fire in turbocharger.	Turbocharger
222	1980	Cause-turbocharger failure. While testing diesel generator 1-2 the operator noted a surging in the engine. He then detected smoke and upon scanning the engine discovered the turbocharger casing glowing red. DG 1-2 was immediately tripped, and the fire brigade was called. The fire was contained in the exhaust piping and was extinguished as soon as the diesel stopped. The turbocharger failed releasing lubricating oil into the exhaust chamber of the unit. The high exhaust temperature ignited the oil causing a fire inside the exhaust pipe. The turbocharger and after-coolers were replaced.	Turbocharger
887	1980	During surveilance testing of an emergency diesel generator, excessive smoking from the turbo charger exhaust flange was observed. Inspection revealed that loose flange bolts had allowed hot exhaust gasses to come in contact	Exhaust manifold

Table A-1

Summary of Diesel Fire Events

Event No.	Year	Description	Characterization
		with insulation materials	
244	1981	Fire involved exhaust manifold insulation located in the DGB. The fire was discovered while performing a routine test on a diesel generator. The diesel was shut down and placed out of service.	Exhaust manifold
260	1981	During physics testing, while performing monthly surveillance on energy DG #2, a fire developed on the exhaust header of the diesel engine. Oil leaked through the gasket onto insulation. When the temperature reached 1000F, fire ignited on the oil soaked insulation.	Exhaust manifold
262	1981	While conducting a diesel test, lube oil spraying from a cracked instrument line was ignited by the hot exhaust piping above the diesel engine. The fire was extinguished in 8 minutes by the station fire brigade. Instrument line cracked due to fatigue failure caused by vibrating pressure gauge. Diesels were inspected to determine if similar installations exist. All equipment within the fire damage boundary was inspected and repaired or replaced as necessary.	Lube oil leak
263	1981	A small oil fire on 1J emergency diesel generator developed and it was declared inoperable. An oil leak in the exhaust manifold caused the fire. Oil accumulations above the upper piston after stopping the engine drained to the exhaust manifold causing excess oil in exhaust manifold. Leaking exhaust manifold gaskets allowed oil to leak onto the engine. Procedures will be changed to prevent oil accumulations in the exhaust and gaskets will be replaced.	Exhaust manifold
270	1981	While testing the O DG a small fire was observed by an operator near the turbocharger on the diesel. Investigation revealed that the turbocharger lube oil filter canister mounting	Turbocharger

Table A-1

Summary of Diesel Fire Events

Event No.	Year	Description	Characterization
		screw had vibrated loose, allowing lube oil to spray past O-ring seal and onto hot exhaust manifold causing the lube oil to flash.	
286	1981	Several events have occurred involving fuel oil intrusion into the Emergency Diesel Generator (EDG) lube oil system. In one instance, an EDG fire was caused by turbocharger bearing failure due to lube oil containment by diesel fuel oil.	Turbocharger
328	1982	Oil filter gasket leaked oil on to hot turbocharger on "O" diesel generator. Insufficient 1.5 inch hose and insufficient amount of fire protection gear were at the scene.	Lube oil leak
330	1982	Turbocharger oil gasket filter failure sprayed lube oil on hot exhaust manifold and ignited.	Lube oil leak
396	1983	A Div. I D/G fuel line ruptured resulting in a fire near the left bank turbocharger. The engine was secured and an usual event was declared from 1447 hrs. to 1559 hrs. Persons responding to the fire noted that the fire protection deluge valve failed to open. The valve was forced open by a mechanic. Automatic pre-action system failed to operate. The fire was reported out approximately 25 minutes after starting.	Turbocharger
397	1983	During surveillance testing of E-3 diesel, operators noted output power was swinging and exhaust temperature was high. Investigation revealed that there was a fire in the exhaust. It was determined that one Elliott turbocharger had failed causing a power reduction. The governor increased the fuel flow as a result. Excess fuel ignited in the exhaust.	Exhaust manifold
902	1983	During a routine test of a diesel generator, a smoke detector actuated. Investigation revealed that smoke was coming from the DG turbo charger. The DG was shut down and no damage or open flaming was reported.	Turbocharger
410	1984	During performance of a monthly operability test, DG 'D' experienced a crank case explosion	Crankcase explosion

Table A-1

Summary of Diesel Fire Events

Event No.	Year	Description	Characterization
		that was attributed to an overheating condition in the '2L' cylinder.	
428	1984	Fire in the voltage regulator.	Voltage Regulator
454	1984	During surveillance testing of the #3 emergency DG, a fire occurred in the vicinity of the turbocharger. The engine was shutdown and the fire extinguished when the fixed low pressure carbon dioxide system was activated. The engine was repaired and returned to service on 12-20-84. The fire was caused by a leaking fitting on a fuel injector line which allowed fuel oil to leak into the lube oil. The lube oil became diluted to approximately 40% fuel oil thus changing the viscosity of the oil. As a result, the turbocharger thrust bearings failed and a small crankcase explosion and fire in the turbocharger ensued.	Turbocharger
508	1986	Diesel generator engine exhaust heated oil impregnated insulation to the oil's ignition point.	Exhaust manifold
535	1986	Approximately 2 minutes after starting running the No.2 DG, a fire started in the exhaust manifold. After running for ~13 min the fire still was not out. Exhaust tube was cracked, allowing oil to leak. (Root cause was aging and fatigue failure).	Exhaust manifold
1483	1986	while the unit was at power , during monthly surveillance testing of the #1 emergency diesel generator , a fuel oil leak at the #4 injector allowed fuel oil to splash on to the diesel , which resulted in a fire . the #4 injector was not injecting fuel into the cylinder . fuel was therefore pumped into the clean fuel drain line and was forced out the vented end of the drain pipe , spilling over the diesel . root cause of failure was incorrect installation of injector needle stop gasket . removed and inspected all 24 fuel injectors . reset pressures and replaced the #4 injector and rebuilt two others . the injectors were reinstalled and the diesel	Fuel line leak

Table A-1

Summary of Diesel Fire Events

Event No.	Year	Description	Characterization
		successfully completed surveillance testing . rac# 2-86-043 .	
1485	1986	while the unit was at refueling shutdown , during a surveillance test a fire started in the exhaust header of the 'b' emergency diesel engine . oil was leaking from the manifold gaskets . this was due to the design of the pre-lube system , which allowed too much shrink and swell of the manifold gasket . this allowed oil to leak when the engine was cold and tended to loosen the manifold bolts . the manifold bolts were tightened . rac#2-86-156 .	Exhaust manifold
559	1987	On February 8, 1987, at 1506 hours, the Palo Verde Unit 2 Diesel Generator A started and loaded to 100% for a 24 hour run in support of integrated safeguards testing. At 2031 hours, fire alarms, which monitor DG A were received in the control room. The AO reported a fuel oil fire near the #4 and #5 Right Bank (RB) cylinders. By 2052 hours the fire was extinguished. Initial inspection revealed that the fuel oil line supplying #5 Right Bank had come loose, this caused fuel oil to be sprayed around the general area of #5 RB cylinder, creating the most extensive damage to the #4 RB cylinder head cover. The inspection covers on RB cylinders #4 and #5 were badly charred/ melted.	Fuel line leak
644	1987	Short internal to the starting solenoid caused the air solenoid on air starting motor to burn.	Solenoid
710	1988	Mr. Tinlin of I&C contacted the control room by telephone to report smoke and flames near the diesel exhaust stacks located inside the U-1 119' elev supply room. The supply room was found full of smoke where the diesel exhaust stacks penetrated from the 104' elev up through	Exhaust manifold

Table A-1

Summary of Diesel Fire Events

Event No.	Year	Description	Characterization
		the 140' elev. Upon closer inspection, the fire brigade found smoldering Dow-Corning foam insulation underneath a fire barrier protective boot where the diesel exhaust penetrated.	
736	1988	A small 2x4 board underneath and supporting EDG #1 muffler on the roof of the EDG building caught on fire while EDG #1 was running for its monthly test. Fire alarm was received in control room at 0744 EDT. The fire was extinguished at 0805 EDT.	Transient
765	1988	A fuel oil leak developed on the #1 cylinder of the Emergency D.G	Fuel line leak
831	1988	Smoke from a diesel generator jacket water heater caused a fire alarm; the jacket water pump did not come on when the heater came on due to a damaged temperature sensor.	smoke
808	1989	"During surveillance testing of the diesel generator, oil residue and lagging on the exhaust header caught on fire."	Exhaust manifold
864	1989	"During load testing of the "22" emergency diesel generator, a crankcase explosion occurred."	Crankcase explosion
944	1989	During a 24 hour surveillance test on Deisel generator 'C', a crankcase explosion occurred. This was the second such incident in 3 weeks. Due to excessive smoke in the diesel bay, an operator was unable to get to the local control panel to shutdown the diesel with the emergency stop button. The DG was stopped from the CR.	Crankcase explosion
945	1989	This incident is mentioned briefly in a report which discusses a similar event which occurred three weeks later. During Surveillance testing of the 'B' DG, a crankcase explosion occurred. No other information is provided	Crankcase explosion
875	1990	Oil leaking from the emergency diesel generator during a test run caught fire. The oil leak resulted from slip ring end bearing failure. The bearing design was incorrect and 19 previous oil bearing level problems were not adequately	Lube oil leak

Table A-1

Summary of Diesel Fire Events

Event No.	Year	Description	Characterization
		addressed. The fire was put out in 15 seconds.	
811	1992	Oil leaking from the diesel lube oil strainer caught on fire when it came into contact with the exhaust manifold.	Lube oil leak
1023	1993	LER: 261-93-010 ABSTRACT: This is a voluntary LER. At 1509 hours on August 16, 1993, during the performance of OST-401, "Emergency Diesels Slow Speed Start," and with the H. B. Robinson Unit No. 2 1_/ operating at 100 percent power, a small oil fire occurred on the exhaust manifold of "All Emergency Diesel Generator (EDG). The fire was immediately extinguished by the Operator and the Diesel continued to operate for the period of time required by the OST to declare it operable. At 1519 hours on August 16, 1993, an Alert was declared based on a fire with the potential to affect safety-related equipment. The Alert was downgraded and the emergency terminated at 1637 hours on August 16, 1993. The exhaust manifold gasket was found crimped and has been replaced. The gasket installation procedure will be revised to include more specific guidance on installation. 1_/ H. B. Robinson Unit No. 2 is a Pressurized Water Reactor in commercial operation since March, 1971.	Exhaust manifold
1514	1997	alert declared following d21 engine failure during test run issue description: on 10/9/97 at 2155 the d21 diesel generator was started for the weekly operability run following removal of clearance 97003127. this clearance was for balance work on the flywheel. at 2302 after the diesel had been running fully loaded for approximately 45-50 minutes, the inside eo had just finished his readings for the st when he heard a change of pitch of the engine. no alarms	Exhaust manifold

Table A-1

Summary of Diesel Fire Events

Event No.	Year	Description	Characterization
		were initially received. the eo moved behind the shield wall and observed the high crankcase pressure alarm come in. the eo directed the pro to trip the engine. at about the same time, the outside eo observed 30 to 60 foot flames issue from the exhaust stack of 21. the pro promptly secured the d21 engine per s.92.2.n for emergency shutdown. fire alarms were received in the mcr for d21 and the fire brigade was dispatched per se-8. the eo operating the diesel extinguished flames on the engine with 2 bursts from a purple k drychemical extinguisher.	
1507	1998	On 5/11/98, Crystal River Unit 3 was in the process of running SP-354B, Functional Test of the Emergency Diesel Generator EGDG-1B. This surveillance was scheduled for Friday 15 May 1998, but was moved to Monday 11 May 1998 due to concerns of jacket water expansion tank levels increasing. EGDG-1B was fast started at 19:23. At 19:45 breaker 3210 was closed. At 19:50 excessive smoke was noticed coming from the control side turbocharger. A plant operator immediately requested that the diesel be tripped and reported that the diesel was on fire. EGDG- 1B was tripped. Abnormal Procedure for Fire Protection, AP-880 was entered. At 19:51 the plant operator reported that the fire had been put out with a small amount of dry chemical from a portable fire extinguisher. The fire was minor in nature and did not cause an actuation of the Fire Service Sprinkler System. Coincident with the start of either Emergency Diesel Generator, the associated room ventilation and cooling fans also start. Two fans are provided for each Emergency Diesel Generator and each Auto-starts with the respective EGDG. AHF-22A and B are associated with EGDG-1A and AHF-	Turbocharger

Table A-1

Summary of Diesel Fire Events

Event No.	Year	Description	Characterization
		22C and D are associated with EGDG-1B. Upon the start of EGDG-1B, AHF-22C had operated normally but was apparently unable to be restarted when the fire team leader requested ventilation. AHF-22D was successfully started and used to clear the smoke from the diesel room. Upon further investigation it appears that AHF-22C did restart but the indicator light in the control room did not indicate as such. Maintenance has completed troubleshooting and repaired this deficiency. To prevent restart of the diesel, the fuel racks were tripped and the air start isolation valves were closed. The fire team leader inspected the equipment and reported that there was no potential for reflash of the fire. Walkdowns and inspection of the equipment were performed by operations, mechanical, and electrical maintenance, system engineering, and plant engineering. The results of these inspection revealed the items identified in the Key Observations.	
1508	1998	An explosion in EDG #3 excitation cabinet occurred during scheduled quarterly testing of the EDG. The EDG was manually stopped. Resulted in missing reliability goals of (a)(1) under S-98-0848 and unavailability goal for #3 EDG under S-98-0550. An (a)(1) evaluation was performed, which supercedes the previous evaluations and places all three EDG's in (a)(1) for reliability.	Cabinet
2345	2000	AR22464	na

Table A-2

Summary of Diesel Fire Characterizations (All Diesel Fires)

Characterization	Type	Number
Exhaust manifold	Oil	22
Turbocharger	Oil	9
Lube oil leak	Oil	8
Crankcase explosion	Oil	5
Fuel line leak	Oil	4
Cabinet	Other	4
Voltage Regulator	Other	1
Solenoid	Other	1
Transient	Other	1
Smoke	Other	1
n/a (insufficient info)	Other	4
Total Events =		60

APPENDIX B

EPRI FIRE PRA ACTION MATRIX - SCHEDULE OF ACTIVITIES

Figure B-1
Schedule for Currently Planned Category 1 Activities

EPRI Research Area		EPRI Research Activity		Owner	Dec 2010	Mar 2011	Jun 2011	Sep 2011	Dec 2011	Mar 2012	Jun 2012	Sep 2012	Dec 2012	Mar 2013	Jun 2013	Sep 2013	Dec 2013	Mar 2014	Jun 2014
Category 1: Fire Initiation, Detection, Suppression																			
1.1	Fire events database	1.1.1	Revise the database structure to fit the current uses in Fire PRAs such as ignition frequency, detection and suppression probability, brigade response, and others	EPRI / RES															
		1.1.2	Collection fire event information from industry	PWROG BWROG															
		1.1.3	Define realistic fire event categorization scheme and apply to events	EPRI															
		1.1.4	Collect component counts and apply to database	EPRI / OGs															
		1.1.5	Develop Fire Events Database (FEDB) revision 1 and report	EPRI															
		1.1.6	Transition long-term data collection efforts	INPO															
1.2	Fire ignition frequency	1.2.1	Improve methods for ignition frequency calculation	EPRI															
		1.2.2	Develop Fire Ignition Frequencies	EPRI															
		1.2.3	Develop component-based ignition frequencies	EPRI															
		1.2.4	Update ignition frequencies using insights from initial implementation experience	EPRI															
1.3	Incipient fire growth in electrical cabinets	1.3.1	Utilize information from the FEDB to characterize detection and termination prior to an actual fire event.	EPRI/UMD															
1.4	Oil fire severity	1.4.1	Pumps	PWROG															
		1.4.2	Transformers	PWROG															
		1.4.3	Diesel Generators	PWROG															
1.5	Credit for incipient detection	1.5.1	Refine FAQ 08-0046	EPRI															
		1.5.2	Incipient fire detector testing (NRC lead)	EPRI / RES															
1.6	Fire suppression probabilities	1.6.1	Develop recommended approach for non-suppression Curves	BWROG / GEH															
		1.6.2	Refine treatment based on current database	GEH															
		1.6.3	Refine treatment based on updated database	EPRI															

Note: Colors of bars are only to allow visual distinction.

Figure B-2
Schedule for Currently Planned Category 2 Activities

EPRI Research Area		EPRI Research Activity		Owner	Dec 2010	Mar 2011	Jun 2011	Sep 2011	Dec 2011	Mar 2012	Jun 2012	Sep 2012	Dec 2012	Mar 2013	Jun 2013	Sep 2013	Dec 2013	Mar 2014	Jun 2014
Category 2: Fire Damage Assessment																			
2.1	Fire growth and comparison with data	2.1.1	Review of data to distinguish factors impacting fire growth rate (qualified vs. non-qualified, ventilation, etc.)	EPRI															
		2.1.2	Refine treatment based on updated database	EPRI															
2.2	Electrical cabinet peak heat release rate (HRR)	2.2.1	Review of available data	EPRI															
		2.2.2	Treatment for ventilation limited cabinets	EPRI															
		2.2.3	Testing plan, as needed	EPRI / RES															
2.3	Transient ignition source HRR	2.3.1	Review of database and development of revised treatment	EPRI															
2.4	Hot work HRR	2.4.1	Review of database and development of revised treatment	EPRI															
2.5	Other HRRs	2.5.1	Review of database and development of revised treatment	EPRI															
2.6	Switchgear HEAF zone of influence (ZOI)	2.6.1	Review of data from switchgear events	EPRI															
		2.6.2	Formulation of revised treatment for medium voltage switchgear	EPRI															
		2.6.3	Formulation of revised treatment for low voltage switchgear	EPRI															
2.7	Bus duct HEAF ZOI	2.7.1	Review of data from bus duct events and formulation of revised treatment	EPRI															
2.8	Damage to sensitive electronic equipment	2.8.1	Formulation of revised treatment to avoid assumption of failure for all	EPRI															
2.9	Electrical cabinet propagation	2.9.1	Review of database and development of revised treatment based on cabinet-specific factors	GEH															
2.10	Fire modeling guidance	2.10.1	Completion of Fire Modeling Users Guide (FMUG)	EPRI / RES															
		2.10.2	Update FMUG to address propagation of modeling uncertainty in the PRA	EPRI															

Note: Colors of bars are only to allow visual distinction.

Figure B-3
Schedule for Currently Planned Category 3 Activities

EPRI Research Area		EPRI Research Activity		Owner	Dec 2010	Mar 2011	Jun 2011	Sep 2011	Dec 2011	Mar 2012	Jun 2012	Sep 2012	Dec 2012	Mar 2013	Jun 2013	Sep 2013	Dec 2013	Mar 2014	Jun 2014
Category 3: Plant Impact, Fire PRA Scenarios & Quantification																			
3.1	AC circuits hot short probability and duration	3.1.1	Review of test results and development of revised treatment to enhance FAQ 08-0051	EPRI															
3.2	DC circuits hot short probability and duration	3.2.1	Review of test results and development of revised treatment	EPRI / RES															
		3.2.2	Conduct phenomena identification and ranking table (PIRT) panel	EPRI / RES															
		3.2.3	Peer review of results	EPRI / RES															
		3.2.4	Issue report	EPRI / RES															
3.3	Human reliability Analysis (HRA) methods and performance shaping factors for fire PRAs	3.3.1	Update of NUREG-1921	EPRI / RES															
		3.3.2	Refinement of EPRI HRA report, as needed	EPRI															
3.4	Control room modeling and treatment in the fire PRA	3.4.1	Refinement of treatment	EPRI															
3.5	Address unrealistic model simplifications	3.5.1	Address assumption that there is always a plant trip following each fire event	EPRI															
		3.5.2	Adddress assumption that failed ventillation causes immediate failure of equipment	EPRI															

Note: Colors of bars are only to allow visual distinction.