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Fire PRA Methods Enhancements

Additions, Clarifications, and Refinements to EPRI 1019189

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Interim Report, December 2008

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PRODUCT DESCRIPTION

This report describes research on fire probabilistic risk assessment (PRA) methods. The fire PRA methods presented in this report provide additions, clarifications, and refinements to the methods proposed in 2005 by the Electric Power Research Institute (EPRI) and the U.S. Nuclear Regulatory Commission (NRC) in *EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities* (EPRI 1011989/NUREG/CR-6850). The purpose of the current report is to provide the most current, state-of-the-art information in order to support the many fire PRAs under development and to improve the framework provided in *EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities* and the National Fire Protection Association (NFPA) standard *Performance-Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants* (NFPA 805). This report incorporates lessons learned from the pilot applications and makes the current model more realistic.

The report is interim because it is expected that additional refinements of the fire PRA methods will occur as more fire PRAs are completed and new lessons are learned.

Results and Findings

This report provides interim methodology and guidance for fire PRA, including the following:

- A re-evaluation of fire ignition frequency trends, revised generic fire ignition frequency estimates, and fire ignition frequency estimation parameters that can be used to develop individual plant frequencies. The new generic frequencies are generally lower than those in *EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities*, but differences vary considerably among ignition bins; in one case, the revised frequency is larger.
- A framework for crediting incipient-fire detection systems in the fire PRA model. The scope of equipment covered is currently limited to lower energy, electrically powered components. Examples indicate a potential benefit from the use of incipient-fire detection systems in these types of applications.
- A more detailed approach to the treatment of large oil fires caused by main feedwater (MFW) pump oil leaks based on the experiential data involving such fires. A significant reduction—approximately one order of magnitude—in the ignition frequency is obtained by using the refined methods for the large MFW pump oil fire frequency.

Challenges and Objectives

The primary objective is to develop fire PRA methodology enhancements that address the issues encountered by the pilot plants during their application of *EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities* and to do so in a timely manner that increases the realism of the fire PRA models, which is essential for the collection of risk insights.

Applications, Value, and Use

A more realistic assessment of fire risks will provide decision makers with additional information regarding what type of corrective measures should be implemented as part of the transition to NFPA 805.

EPRI Perspective

EPRI initiated a program in 1995 to enhance fire PRA technology by providing the technical basis and the engineering tools necessary to support transition to risk-informed/performance-based fire protection (see the EPRI report *Planning and Risk-Informed/Performance-Based Fire Protection at Nuclear Power Plants* [TR-108799]). EPRI has supported fire PRA methodology and data development activities in cooperation with the NRC under a memorandum of understanding (MOU) since 1997 and through earlier cooperative agreements.

In the fire PRA effort, *EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities* is the most recent report to develop and document state-of-the-art tools, data, and methods for the conduct of a fire PRA in a commercial nuclear power plant. Pilot applications of the methods at two nuclear plants yielded lessons learned and highlighted the potential to improve the methods. These improvements generally take the form of additions, clarifications, or refinements that aim to produce a more realistic approach. EPRI has supported technical work on the issues reported herein in order to establish an improved methodology and guidelines in the subject areas. It is envisioned that this effort will continue in the near term and that the fire PRA methods will continue to evolve and involve all aspects of the risk analysis community, including EPRI, NRC Research, utilities, vendors, and owners groups.

Approach

An initial examination of the technical issues was performed through a forum of industry experts and interactions with the NRC under the auspices of the NRC-EPRI MOU. Additional EPRI-supported technical evaluation was performed. The methods used to derive enhanced treatments were consistent with generally accepted methodology from PRA and related statistical applications, and they are documented in the report with supporting references. Because of the urgency of the work and limited time available to support impending regulatory applications, the methodology enhancements were developed with certain limitations, which are also documented in the report. As a result, this report is provided as an interim one.

Keywords

Fire events
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INTRODUCTION

A joint NRC and EPRI effort developed a new set of guidelines and methods for fire PRAs, now documented in NUREG/CR-6850/EPRI TR-1011989 [1] (henceforth referred to as NUREG/CR-6850). This document was intended to establish a new state of practice for fire PRA. NUREG/CR-6850 is currently being used by licensees to develop fire risk studies to support implementation of NFPA-805 [2] under 10 CFR 50.48(c), and other PRA applications. In January 2008 the Nuclear Energy Institute sent a letter [3] to the NRC indicating that the early findings of pilot plants included results that appeared conservative. An examination of those initial results and a closer look at details of NUREG/CR-6850 guidance identified several areas for which the cumulative effects of intentional and inadvertent conservatism impacted the realism of the fire PRA results, in some cases substantially. Subsequently, EPRI and NRC embarked on an effort to expeditiously address the issues identified in the letter (and refined in subsequent public meetings) through the Frequently Asked Question (FAQ) process that had been previously implemented as part of the EPRI-NRC memorandum of understanding [4] and used to clarify aspects of NUREG/CR-6850 for pilot plant applications.

This report documents the technical work done to develop more realistic methodology and guidance for three of the technical issues directly supported by EPRI. These include re-evaluation of fire ignition frequencies, development of guidance on crediting incipient fire detection systems, and enhancing treatment of large oil fires due to main feedwater pump oil leaks. In addition to this introductory section, this report includes three sections that provide technical assessment, basis, and recommendations for enhancing fire PRA methodological treatment for the three technical issues.

- Section 2 provides an evaluation of fire ignition frequency trends, updates generic fire ignition frequency estimates accordingly, and fire ignition frequency estimation parameters that can be used to develop individual plant frequencies. Appendix A and B provide supporting technical information for Section 2.
- Section 3 addresses an issue that was not included in the NUREG/CR-6850 guidance on treatment of fire detection systems. This section describes the technology and PRA application methodology for incipient fire detection systems. Appendix C provides supporting technical information for Section 3.
- Section 4 provides guidance on the treatment of large oil fires due to main feedwater pump oil leaks. NUREG/CR-6850 had provided a simplified treatment, similar to a screening analysis, applicable to all sizes of pumps. The approach and methodology provided herein was designed specifically for main feedwater pumps, and while still relatively simple in nature, it removes some conservatisms of the original treatment.

A summary and recommendations section is provided for the three technical discussions. This section summarizes the proposals and identifies certain technical issues that remain to be resolved in order to more optimally address these issues in future fire PRAs.

2
FIRE IGNITION FREQUENCY

The purpose of this section is to provide a revision to the generic fire ignition frequency values provided in NUREG/CR-6850 / EPRI TR-1011989 [1] taking into account data trends where appropriate. The work includes a limited re-examination of data and a trending analysis from the EPRI Fire Events Data Base report [5] covering the years 1968-2000 to assess whether or not the more recent plant operating experience demonstrates a reduced frequency of fires as compared to older experience. Based on the analysis outcome, fire frequency estimates for the fire frequency ignition source bins were updated.

2.1 Methodology and Approach

The information provided below is a summary of the overall methodology and results. The work was divided into two principal analyses. The first was to determine if the fire events data had statistically valid declining trends as are apparent from a visual scan of the annual frequency of fire events. The second was to update the bin ignition frequencies, as appropriate, using current practice and methodology. These steps included a reexamination of the EPRI Fire Events Data Base (FEDB) trending and frequency estimation results reported in Reference 2, updated using methods consistent with the NRC's Handbook of Parameter Estimation for Probabilistic Risk Assessment [6]. These methods are used extensively in NUREG/CR-6928 [7] for the NRC's initiating event frequency estimations, along with trend evaluations similar to those used in this work. With one exception (discussed later) the reanalysis was limited to data available for the years 1968-2000, since at the time of this work, an updated and quality assurance reviewed FEDB was not available. However, a preliminary update to the data base was examined to determine if noticeable contradictory indications were present as discussed later in this section.

The data used in the analysis was obtained from the updated FEDB and included several additional events and slightly revised binning since References 1 and 5 were published. This primarily affects bin 15 (electrical cabinets, designated 15.1 for this analysis) and bin 16 (High Energy Arcing Faults - HEAF). HEAF events from bin 15 were removed and a new bin for electrical cabinets with HEAF created, bin 15.2, consistent with the current FEDB. Bin 16 was reconstituted in two parts as bus ducts (bin 16.1) and iso-phase bus ducts (bin 16.2). The entire data set was further screened to include only incidents reported after a plant's commercial operation date and before the decommission date, as appropriate. The total reactor years at power and not at power were also updated based on NRC reported operating hours [8, 9].

Consistent with NUREG/CR-6850, data classified with a severity of "potentially challenging" were counted as 1.0 event, while undetermined severity events were counted as 0.5 event and non-challenging events were given 0 event credit. Bin definitions and reactor power applicability were treated consistent with NUREG/CR-6850 including fractional treatment of events with undetermined power conditions based on plant availability. Specifically, if an analysis was to consider events at power only and the reactor mode was not known for some event, the event's count was multiplied by the availability factor of the specific plant, if known, or by a general availability factor using total plant experience by decade as follows:

- 1968-1980: 0.78
- 1981-1990: 0.71
- 1991-2000: 0.802

For example, an undetermined severity event occurring at unknown reactor mode in 1987 would be credited as 0.5 * 0.71 = 0.355 event in the count of events at power, and as 0.145 in the count of events at non-power. Availability data was obtained from NRC' s web site [8].

2.2 Fire Event Trends

The trending analyses examined both power and non-power reactor operating modes and ignition source bins combined for applicable power conditions (all modes and at power only) as identified in NUREG/CR-6850 (see Table 6-2). Analyses also evaluated trends for all severity classifications in the FEDB (Challenging, Undetermined, and Not Challenging). Several statistical tests were employed including: the Laplace test (or "centroid test"), Fisher's exact test, and the chi-square test. A discussion of statistical methods used is provided in Appendix A.

Statistically significant trends were identified for all data aggregated, potentially challenging events only, and potentially challenging plus undetermined events for reactors at power and all modes combined. These trends indicated reduced frequencies in the post-1990 period when compared to the period 1968-1990. Data from the 1990s were found to be statistically different than pre-1991 data for each of the associated data sets. Figure 2-1 shows some typical plots indicating trends. This is a case in which at power data only was analyzed. Note that after 1990 all frequencies are below 0.2/Rx-Yr with an average of about 0.14/Rx-Yr. In the pre-1991 period, for 20 out of 23 years the frequencies are above 0.2/Rx-Yr with an average of about 0.29/Rx-Yr. Provided in Figure 2-2 is a cumulative trend plot which shows two distinct trend lines intersecting at about 1990. They indicate a noticeable inflection point indicative of a sharp change in frequency. These visual observations were supported by quantitative statistical tests described in Appendix A with null hypothesis (no trend), two sided P values less than 0.05. Similar results were obtained for all data aggregated, potentially challenging events only, and potentially challenging plus undetermined events. Analyses were performed for reactors at power and all modes combined. The implications are that there is a statistically significant difference between pre- and post-1990 data.

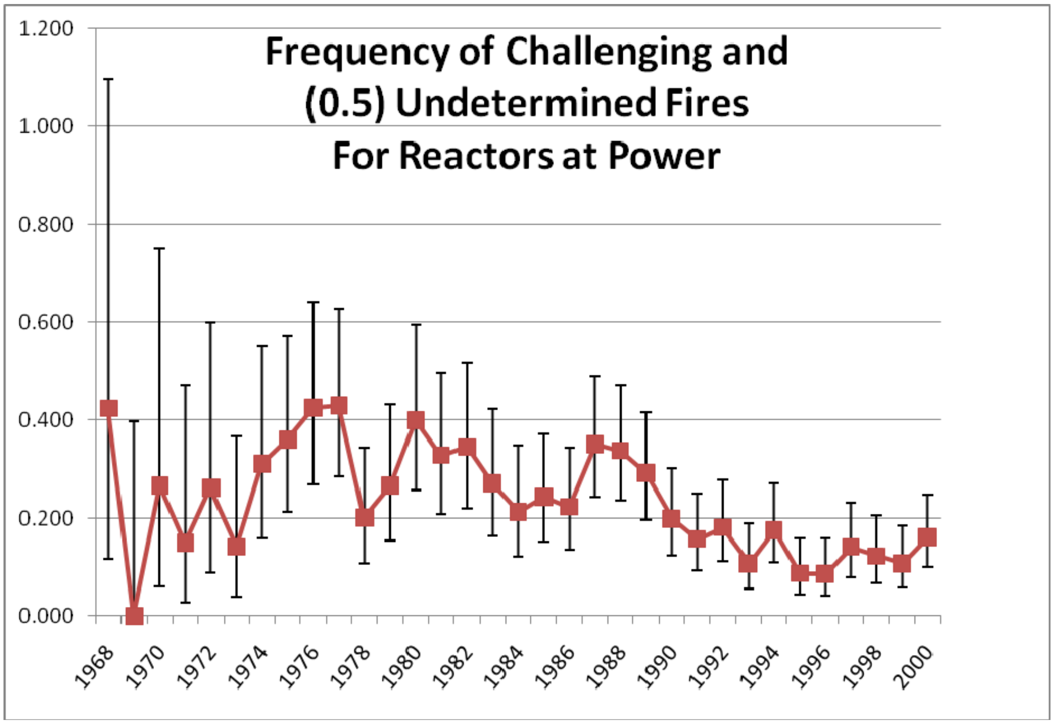

Figure 2-1
Trend indications for potentially challenging and undetermined fires: annual frequencies and 90% confidence intervals shown as error bars

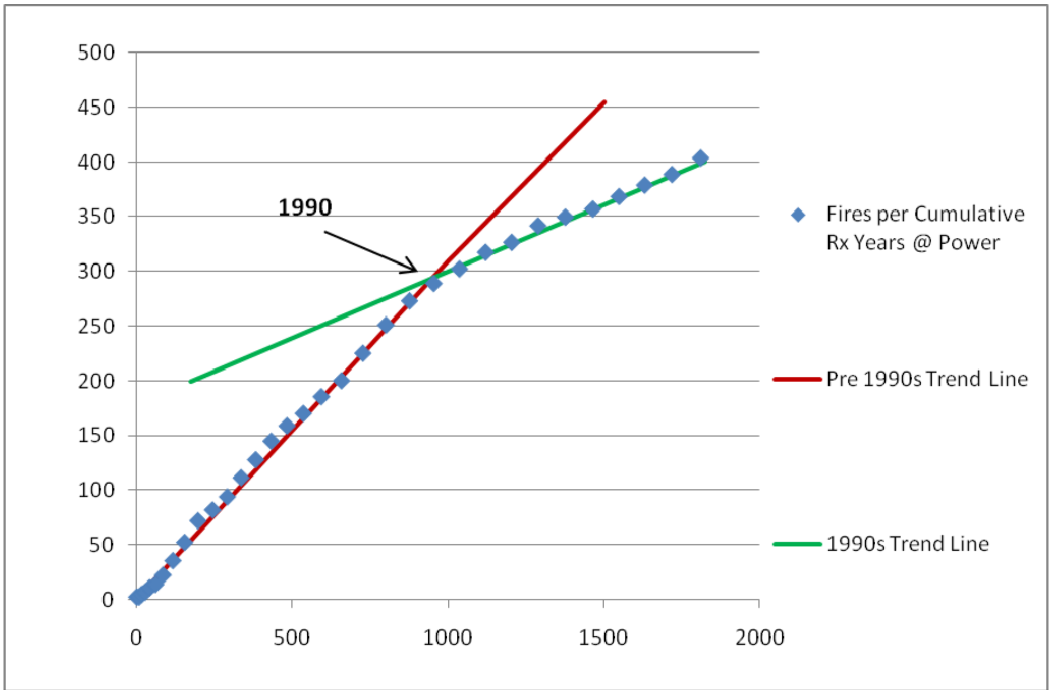

Figure 2-2
Trend indications for potentially challenging and (0.5) undetermined fires: cumulative plot and trend lines

Trends and results for potentially challenging events presented in Figure 2-1 are very similar to NRC public web results [8] for “severe” fire events (shown in Figure 2-3). The NRC results indicate that overall frequencies are about constant or declining for several years from the early 1990s to a date beyond the limit of this analysis. As a point of reference, the NUREG/CR-6850 total (all bins) frequency average from 1968-2000 is also shown in Figure 2-3.

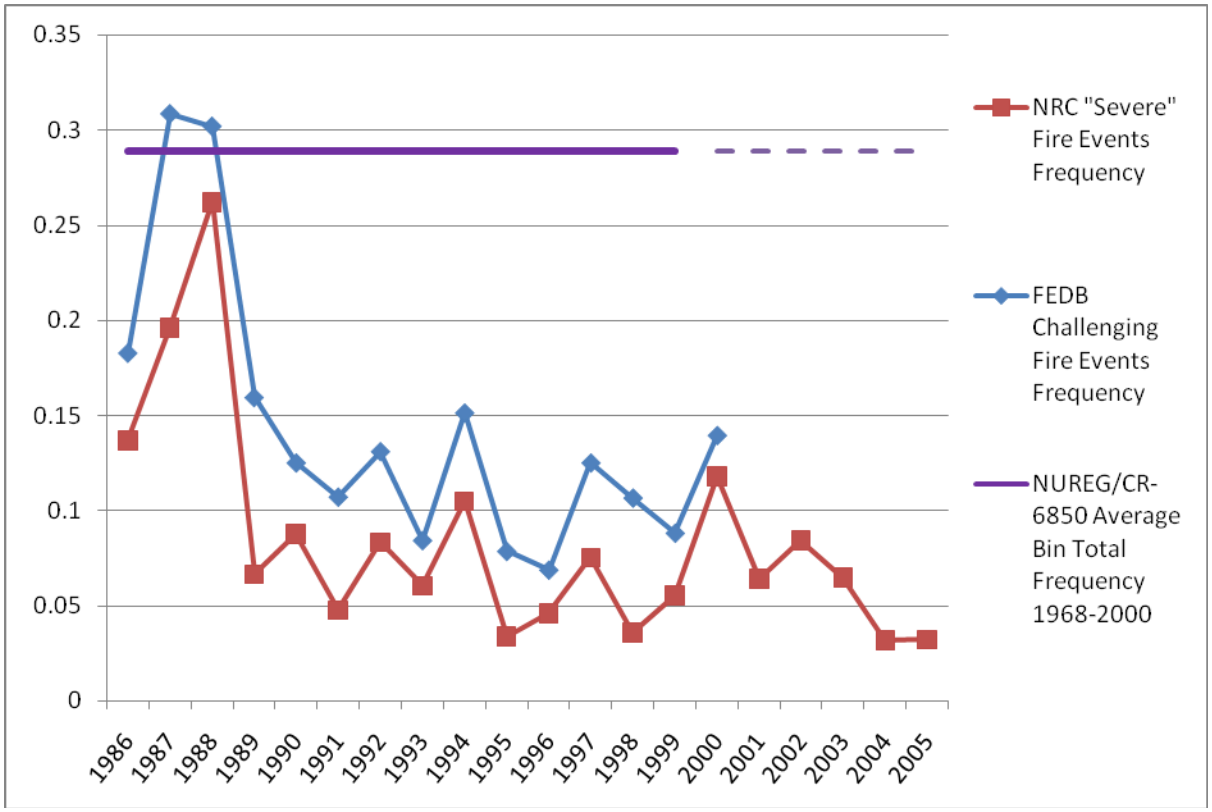

Figure 2-3
Comparison of NRC web and FEDB fire events frequencies

Recently obtained data from Nuclear Electric Insurers Limited (NEIL) has been added to the FEDB to provide a preliminary update of event data through April 2008. This updated data has had some preliminary analysis performed to get a rough indication of consistency with the trends observed though 2000. In this dataset there are 188 fire incidents that occurred at a nuclear plant “inside the fence” from January 2001 through April 2008. The preliminary classification of these events identified 57 events as potentially challenging and 52 as undetermined severity. The rest were classified as not challenging. A review or validation and verification of the preliminary severity classifications has not been performed. An initial review of the sparse event descriptions did not indicate significant fires (magnitude or damage).

The preliminary results of the initial classification review of the 188 reported fire events, with 57 of these events identified as potentially as challenging, compares with 266 events captured in the FEDB for the seven year period 1994-2000 inclusive. This comparison is for approximately equal reactor years in the two periods. Of the 266 events in the earlier period, 85 events were classified as potentially challenging and 47 as undetermined. The rest were not challenging. While this comparison cannot be used as the sole basis to support a continuation of the earlier trend, it supports the premise that the reduced fire frequencies of the 1990s have been sustained.

Qualitatively, there are many reasons for the apparent significant decline in fire events over time. Some potential reasons for the fire event decrease in the post-1990 period include the many changes in the physical plant as well as the many program implemented by the nuclear plants in the US. These include:

1. On-going post-Generic Letter 81-12 implementation of modified designs and fire protection plans/practices to meet 10 CFR 50.48 and Appendix R. The changes to the fire protection plans in support of implementation of Appendix R include:
   - Training of personnel with fire detection and suppression duties
   - Improved plant procedures associated with treatment of fire events
   - Limits on combustible materials
   - Fire watches
   - Availability of portable fire extinguishers and other manual firefighting equipment;
2. Increased on-line maintenance that improves the reliability of fixed ignition sources such as panels and pumps;
3. The cultural issues such as decreased smoking on-site including the elimination of smoking within most facilities and restricting smoking on-site to designated smoking areas often located away from structures
4. Improved plant housekeeping practices.

Moreover, during the mid-1980s the NRC's Maintenance Rule became effective, the NRC program for systematic assessment of licensee performance (SALP) was implemented, and safety performance indicators were developed and used in SALP. During the 1990s, a sensitivity to risk was increased as the first individual plant examination (IPE) PRAs were developed then followed by the IPEs for external events (IPEEE) which for the first time included a systematic examination of fire risk at all operating nuclear power plants.

Collectively these design, maintenance and operational changes represent a significant improvement in the current nuclear fleet as operated negating much of the pre-1990 data as not relevant to the current as-built and as-operated plant. In addition, other data sources such as those associated with internal initiating events, component reliability, common cause failures, and accident sequence precursors show similar declining trends consistent with the qualitative observations on improved plant operations.

2.3 Individual Bin Fire Event Frequencies

In Section 2.2, trends are analyzed and presented as averages across all fire event bins.In this section individual bin frequency analyses are performed for the 39 fire ignition source bins (component and location) based on the current FEDB breakdown. Table 2-1 provides bin identification information. The bins are defined consistent with NUREG/CR-6850 except for modifications made to the original bins 15 (electrical cabinets) and 16 (HEAF) to be consistent with more current classifications that have been used in the FAQ process. The high energy fire ignition events associated with electrical cabinets have been removed from bin 15, now designated bin 15.1, to a new bin, designated 15.2, electrical cabinets-HEAF. In addition, bin 16 was split into segmented bus duct events as bin 16.1 and iso-phase bus duct events as bin 16.2 in accordance with the FAQ process. More recently the fire events classified as applicable to bins 16.1 and 16.2 were re-examined as part of the FAQ process with changes being made to both bins. As part of this re-examination, the data set for iso-phase bus faults was extended to June of 2004 to capture a more recent potentially challenging event for this bin. The data used in this report reflects those bin data set modifications.

Additional bin identification information provided in Table 2-1 includes the applicable power mode(s) for which FEDB data should be used for bin fire ignition frequency estimation and reactor type applicability. Both of these bin classification characteristics are consistent with NUREG/CR-6850.

Several bins with similar design and/or operational characteristics relevant to fire ignition likelihood were identified as candidates for combination to better assess trend and frequency estimation statistics. These combined bins are indicated in Table 2-1 in the combined bins column, the rightmost column.

Generic fire ignition frequencies were derived using both the Jeffreys non-informative prior distribution and a constrained non-informative prior distribution as described in Reference 6. The original and revised bin frequencies are presented in Figure 2-2 and the process is described below.

Table 2-1
Ignition source bin identification

6850 Bin #	Ignition Component	Location	6850 RX Mode	RX Type	Combined Bins
1	Batteries	Battery Room	All	All	
2	Reactor Coolant Pump	Containment (PWR)	Power	PWR	
3	Transients and Hotwork	Containment (PWR)	Power	PWR	
4	Main control board	Control Room	All	All	
5	Cable fires caused by welding and cutting	Control/Aux/Reactor Building	Power	All	Cable Fire W&C
6	Transient fires caused by welding and cutting	Control/Aux/Reactor Building	Power	All	Transient W&C
7	Transients	Control/Aux/Reactor Building	Power	All	Transients
8	Diesel generators	Diesel Generator Room	All	All	
9	Air Compressors	Plant-Wide Components	All	All	
10	Battery Chargers	Plant-Wide Components	All	All	
11	Cable fires caused by welding and cutting	Plant-Wide Components	Power	All	Cable Fire W&C
12	Cable run	Plant-Wide Components	All	All	
13	Dryers	Plant-Wide Components	All	All	
14	Electric motors	Plant-Wide Components	All	All	Electrical 1
15.1	Electrical Cabinets Non-HEAF	Plant-Wide Components	All	All	
15.2	Electrical Cabinets-HEAF	Plant-Wide Components	All	All	
16.1[1]	Bus Duct	Plant-Wide Components	All	All	
16.2[1]	Iso-phase Ducts	Plant-Wide Components	All	All	

Table 2-1 (continued)
Ignition source bin identification

6850 Bin #	Ignition Component	Location	6850 RX Mode	RX Type	Combined Bins
17	Hydrogen Tanks	Plant-Wide Components	All	All	Misc H2
18	Junction box	Plant-Wide Components	All	All	
19	Misc. Hydrogen Fires	Plant-Wide Components	All	All	Misc H2
20	Off-gas/H2 Recombiner (BWR)	Plant-Wide Components	Power	BWR	
21	Pumps	Plant-Wide Components	All	All	
22	RPS MG sets	Plant-Wide Components	Power	All	Electrical 1
23	Transformers	Plant-Wide Components	All	All	
24	Transient fires caused by welding and cutting	Plant-Wide Components	Power	All	Transient W&C
25	Transients	Plant-Wide Components	Power	All	Transients
26	Ventilation Subsystems	Plant-Wide Components	All	All	
27	Transformer - Catastrophic	Transformer Yard	Power	All	
28	Transformer - NonCatastrophic	Transformer Yard	Power	All	
29	Yard transformers (Others)	Transformer Yard	Power	All	
30	Boiler	Turbine Building	All	All	
31	Cable fires caused by welding and cutting	Turbine Building	Power	All	Cable Fire W&C
32	Main Feedwater Pumps	Turbine Building	Power	All	
33	T/G Excitor	Turbine Building	Power	All	Turbine
34	T/G Hydrogen	Turbine Building	Power	All	Turbine

Table 2-1 (continued)
Ignition source bin identification

6850 Bin #	Ignition Component	Location	6850 RX Mode	RX Type	Combined Bins
35	T/G Oil	Turbine Building	Power	All	Turbine
36	Transient fires caused by welding and cutting	Turbine Building	Power	All	Transient W&C
37	Transients	Turbine Building	Power	All	Transients

Footnote 1. Bin 16.1 and 16.2 replace former bin 16 (high energy arcing faults) from NUREG/CR-6850

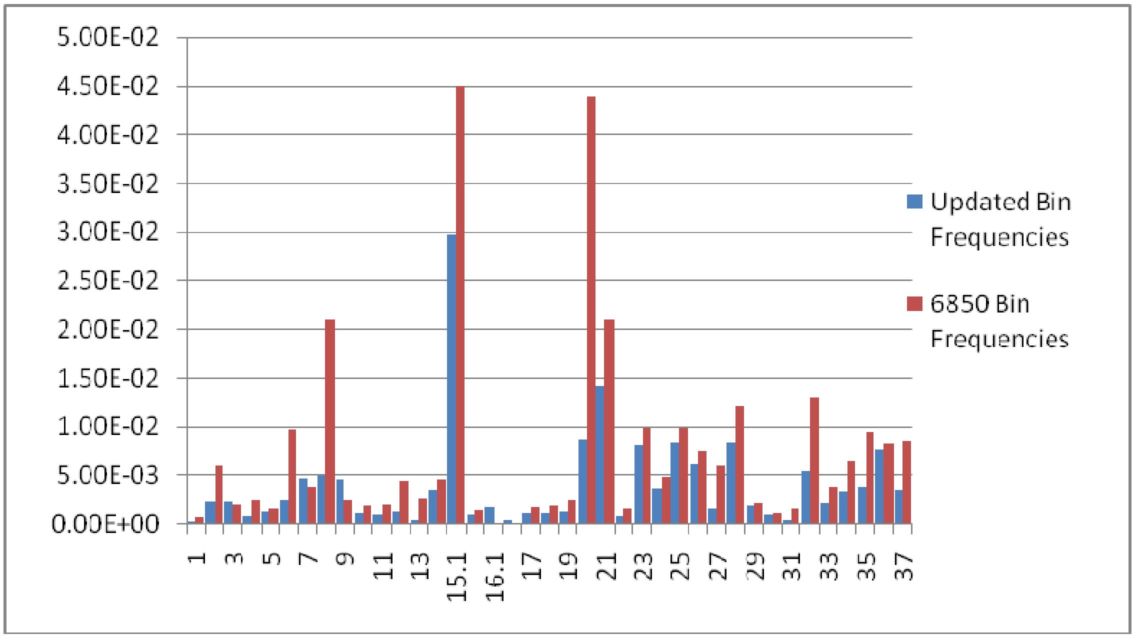

Figure 2-4
Updated bin and NUREG/CR-6850 bin frequency comparisons

Given that a trend was present in the dataset, and this trend indicated an inflection in approximately 1990, a method to treat the pre-1990 data was needed. Several approaches were considered since the 1968-1990 data could not be given equal weight with the later data but should have some level of influence over the post 1990 data. The Jeffreys non-informative prior was considered for use with the post-1990 data, but this method is non-informed and therefore ignores the pre-1990 data. Another method, the constrained noninformative (CNI) prior was considered for use. In the constrained noninformative prior, a diffuse distribution with mean determined from 1968-1990 period, was deemed to be a suitable compromise, using the early data but down-weighting it. The data from the period 1968-1990 was used to set the constrained noninformative prior parameters. In addition, a hierarchical Bayesian analysis was performed for the bins with the largest post 1990 data populations to allow for plant to plant variability. Other bins with lower data density did not have sufficient data to detect plant to plant variability. These and similar methods are used in NUREG/CR-6928, along with trend evaluations similar to those used in this work, in the estimation of initiating event frequencies. A more thorough discussion of the Bayesian update methodology is provided in Appendix A.

The CNI prior was used in all but the specific bin updates identified below as the best prior for estimating updated bin frequencies. The results for Jeffreys and CNI priors are similar and consistent. There was fairly strong indication of an increase in the frequency for the post-1990 period for air compressors (bin 9). There was no qualitative underlying cause identified for this indication which is contrary to all other bin results and the overall fire incident trends. For this case, the more conservative Jeffreys non-informative prior was used to update the post-1990 data. The only bin for which plant to plant variability was detected was bin 15.1, the most densely populated bin. For this bin, a more diffuse prior distribution consistent with those from NUREG/CR-6850 was used and a hierarchical Bayesian analysis was performed.

The updated results for all bins with comparison to the original NUREG/CR-6850 values are shown in Figure 2-4. Individual bin results varied with a few bins showing increases over NUREG/CR-6850 values and most showing about a factor of 2 or more decrease from NUREG/CR-6850 recommended generic frequencies.

The primary reason the updated frequencies are generally smaller than the original frequencies is that the updated frequencies use the post-1990 data, with the earlier data strongly down-weighted. Given that the overall trend in fire ignition frequency is downward in the post-1990 period, the revised frequencies are expected to be lower. It should be noted that the FEDB data plotted in Figure 2-3 are based on only the potentially challenging events, while the updated bin frequencies with an average factor of 2 decrease include the undetermined events as well and are therefore more conservative (higher) than the potentially challenging event frequencies. Also, the revised frequencies are higher, and potentially more conservative, than the most current NRC "severe" fire event frequencies due to the inclusion of the undetermined events. Therefore, the updated bin frequencies represent a reduction from the NUREG/CR-6850 frequencies, but they remain higher (more conservative) than the latest severe fire event frequencies published on the NRC website

The updated frequency distributions are of the form gamma (α, β). It should be noted that for bin 15.1, the gamma posterior distribution was derived as a weighted average of log-normals that were obtained from the hierarchical Bayes analysis (values shown, highlighted in Table 2-2). A very large sample from this distribution was produced, and a gamma distribution was fitted to the sample by matching the medians and the 95th percentiles. The revised generic fire ignition frequencies and associated statistical parameters are provided in Table 2-2. As a point of comparison, the combined bin results are provided in Table 2-3; however, their validity and potential use was not further examined.

The total mean fire frequency for the 1991-2000 period derived by combining all updated individual bin frequencies from Table 2-2 is about 0.15/Rx-Yr. This is above the mean but within the 95% upper bound of the fire frequency derived from the data for the same period when analyzed in total as an aggregate. This indicates both a reasonableness of the combined bin fire frequency and a slightly conservative bias in the individual bin estimated frequencies, which reflects uncertainty at the individual bin level.

Table 2-2
Updated bin frequencies and statistical parameters (individual bins)

Bin #	Mean Frequencies	5% Bound	95% Bound	Alpha	Beta
1	3.26E-04	1.28E-06	1.25E-03	0.5	1534
2	2.35E-03	2.75E-04	6.11E-03	1.5	639
3	2.34E-03	3.20E-04	5.89E-03	1.655	708.4
4	8.24E-04	4.23E-05	2.47E-03	1	1212.9
5	1.25E-03	2.64E-04	2.83E-03	2.32	1856.4
6	2.46E-03	5.00E-04	5.65E-03	2.235	906.73
7	4.81E-03	1.90E-03	8.80E-03	5.03	1045.1

Table 2-2 (continued)
Updated bin frequencies and statistical parameters (individual bins)

Bin #	Mean Frequencies	5% Bound	95% Bound	Alpha	Beta
8	5.04E-03	2.10E-03	9.02E-03	5.5	1091.1
9	4.65E-03	1.83E-03	8.51E-03	0.5	1075.3
10	1.18E-03	1.38E-04	3.07E-03	1.5	1271.9
11	9.43E-04	4.84E-05	2.82E-03	1	1060.5
12	1.32E-03	1.55E-04	3.43E-03	1.5	1137.8
13	4.20E-04	1.65E-06	1.61E-03	0.5	1189.9
14	3.41E-03	1.16E-03	6.61E-03	4	1173.6
15.1	2.36E-02	5.36E-04	9.40E-02	0.453	19.16
15.2	1.06E-03	1.24E-04	2.75E-03	1.5	1419.3
16.1	1.27E-03	1.49E-04	3.31E-03	1.5	1200.4
16.2	8.24E-04	9.66E-05	2.15E-03	1.5	1820.0
17	1.18E-03	1.38E-04	3.07E-03	1.5	1271.9
18	1.11E-03	1.30E-04	2.89E-03	1.5	1350.5
19	1.24E-03	1.45E-04	3.22E-03	1.5	1212.9
20	8.83E-03	2.02E-03	1.95E-02	2.5	283.19
21	1.42E-02	8.81E-03	2.06E-02	15.5	1094.4
22	9.33E-04	3.85E-05	2.88E-03	0.92	985.87
23	8.02E-03	4.18E-03	1.29E-02	9	1122.7
24	3.65E-03	1.11E-03	7.38E-03	3.425	938.34
25	8.28E-03	4.08E-03	1.37E-02	7.815	944.14
26	6.12E-03	2.87E-03	1.04E-02	7	1144.1
27	1.62E-03	1.90E-04	4.21E-03	1.5	927.84
28	8.38E-03	4.06E-03	1.40E-02	7.5	894.67
29	1.89E-03	5.84E-04	3.79E-03	3.5	1856.4
30	9.78E-04	1.15E-04	2.55E-03	1.5	1534
31	4.50E-04	1.77E-06	1.73E-03	0.5	1110.2
32	5.44E-03	2.12E-03	1.00E-02	4.901	901.31
33	2.10E-03	3.73E-04	4.98E-03	2	951.96
34	3.23E-03	8.81E-04	6.79E-03	3	927.84
35	3.89E-03	1.20E-03	7.82E-03	3.5	899.78
36	7.55E-03	3.52E-03	1.28E-02	6.91	915.35
37	3.41E-03	9.71E-04	7.07E-03	3.15	922.51

Log-Normals	mean	5%	median	95%
15.1	2.9E-02	5.6E-04	9.8E-03	9.4E-02

Table 2-3
Frequencies and statistical parameters for combined bins

Bin #	Combined Bin	Mean Frequencies	Alpha	Beta
5,11,31	Cable fires caused by W&C	9.53E-04	2.8	2958
6,24,36	Transient fires caused by W&C	4.38E-03	11.6	2641
7,25,37	Transients	5.61E-03	15	2674
17,19	Misc. H2 Fires	1.08E-03	2.5	2323
14,22	Electrical 1	2.16E-03	4.4	2050
33,34,35	Turbine Generator	2.26E-03	6	2659

3

CREDITING INCIPIENT FIRE DETECTION SYSTEMS IN FPRA QUANTIFICATION

This section develops an approach and supporting basis to apply quantitative credit in fire PRAs for the use of incipient fire detection for low voltage electrical components. The methods contained in this report section supplement the methodology provided in NUREG/CR-6850 and EPRI 1011989 [1] Appendix P, since the treatment of these types of fire detection systems was not included in that report. The applicability and scope of circumstances potentially covered by incipient fire detection systems is also discussed.

3.1 Incipient Detection

Incipient fire detection systems (IFDS) refer to fire detection hardware that is able to detect precursor conditions that are characteristic of conditions that may develop into fires, such that they can be corrected or controlled before any actual ignition (fire) occurs, thereby significantly limiting potential damage. Typically, these systems are based on air sampling which can detect very small concentrations of decomposition products prior to the appearance of visible smoke. They commonly use aspiration smoke detectors (ASD) as a principal element of Very Early Warning Fire Detection Systems (VEWFDS) as described in NFPA 76 [10].

A simplified representation is provided in Figures 3-1 and 3-2. Aspirating Smoke Detection systems use an aspirator to draw the sample back to the detector through a network of tubes and inlet ports, located and sized for specific applications. The detectors typically use cloud chamber or laser technology to detect minute traces of combustion products. Their sensitivity provides the ability to detect the earliest incipient stages of a fire, typically in two minutes or less per specifications. A more detailed discussion of VEWFDS applicability and capabilities is provided in Appendix C.

3.1.1 Incipient vs. Traditional Detection

Traditional fire detection generally relies on heat or smoke concentrations representative of a smoldering or free burning fire to activate alarms. Based on the timing, there may already be equipment damage beyond the ignition source before the fire response, either manual or automatic, is able to control the fire. Very Early Warning Fire Detection Systems (VEWFDS) are able to provide significantly more time for fire protection personnel to investigate alarmed conditions and, if warranted, initiate fire brigade response prior to any noticeable smoke or actual fire for non-energetic fire initiators. VEWFD is obtained by detecting a fire threat in the incipient, or overheating, stage of a fire.

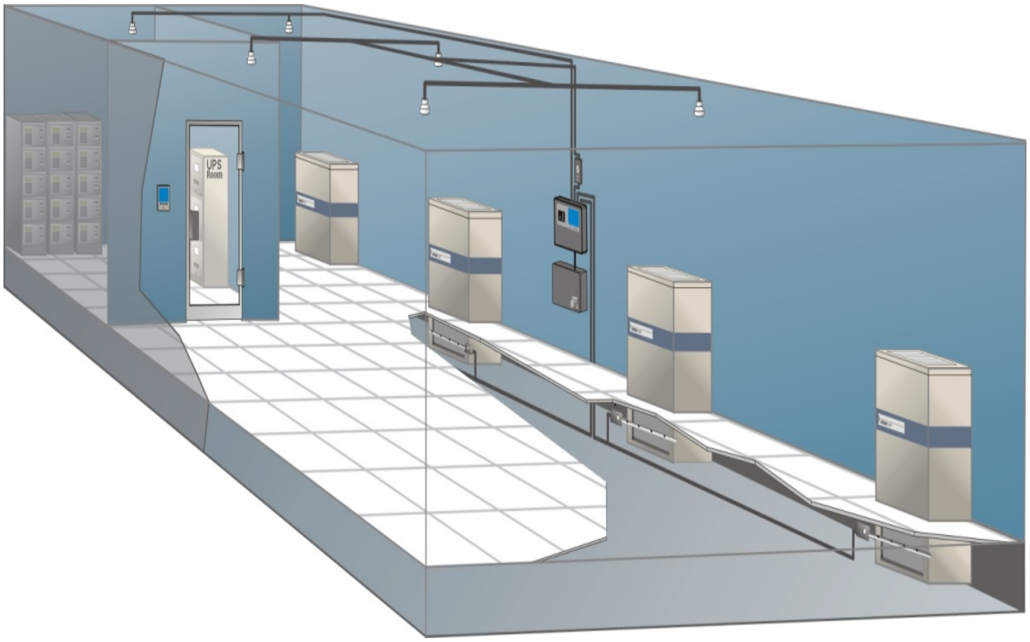

Figure 3-1
Aspirating smoke detection (ASD) system
Courtesy of Safe Fire Detection (http://www.safefiredetection.com)

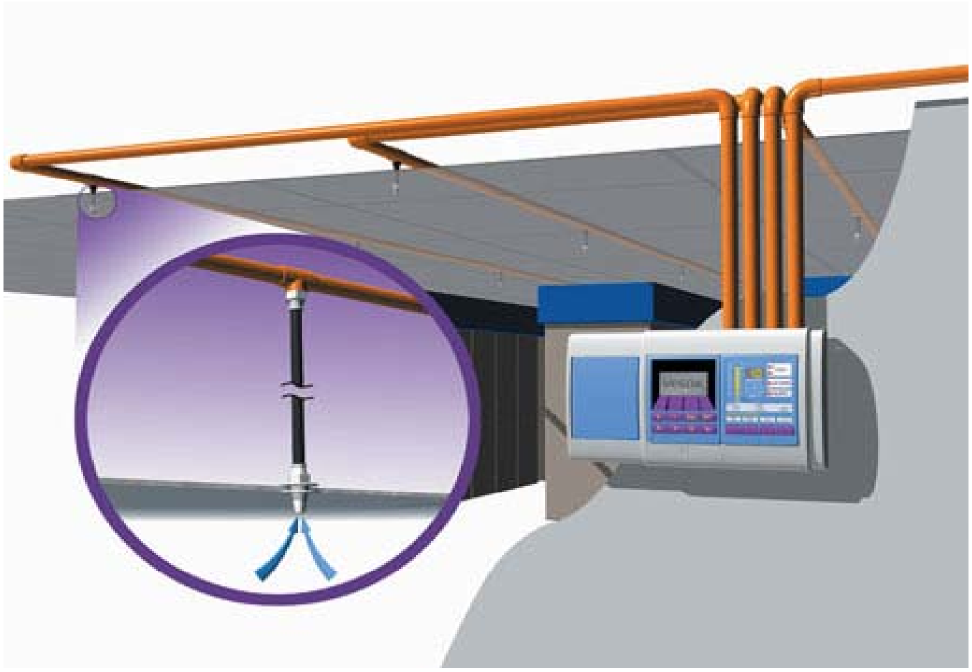

Figure 3-2
Aspirating smoke detector and sampling tubes
Courtesy of Xtralis (http://www.Xtralis.com)

3.1.2 Timing and Response

Generally, early incipient fire stages are characterized as overheating with lack of visible smoke or fire and can evolve over a period of tens of minutes to more typically hours, days, or longer. Later incipient fire growth stages that involve some smoking, smoldering, or even limited flaming more typically occur over a period of many minutes or even hours for non-flaming conditions. Fire growth stages and timing are discussed in more detail in Appendix C.

Field experience provides evidence that most electrical fires start due to some kind of insulation degradation, with subsequent overheating ultimately leading to electrical shorting (faults) which could then result in ignition of nearby combustible materials such as cable insulation. Qualified electrical cabling is generally resistant to burning and will normally not propagate if the ignition source is removed (de-energized). However, given enough heat and oxygen, a cable fire can develop. This is generally a function of the energy provided by the ignition source. It is possible for high voltage sources to experience a fault that produces an arc with sufficient energy to quickly ignite cables such that the detection would be considered prompt but not necessarily incipient (e.g., when a circuit breaker incompletely opens and forms an arc). It is also possible for high voltage sources to experience "hot spots" due to gradual degradation, such as from a loose-bolted connection carrying current. It may also be possible to detect the effects of hot spots heating nearby insulating materials before the hot spot leads to a thermal runaway condition hot enough to ignite the nearby insulating material. For lower energy sources, however, the initial faults that could lead to a fire generally occur long before any actual fire, significant heating, or secondary cable ignition occurs.

Given this understanding of incipient fire growth timing, Figure 3-3 was developed to provide a perspective on the approximate time relationships of incipient fire growth and detection, suppression, and equipment damage. It was developed for fires originating in electrical cabinets and panels, but provides approximate relationships for other fire ignition sources. The figure shows that the detection of incipient fire conditions is expected to occur long before damaging smoke or flaming conditions occur, allowing substantial time for fire protection technicians to identify and suppress the fire ignition source. This characterization is in accordance with objectives stated in NFPA 76 for VEWFDS. The more traditional fire detection systems credited in NUREG/CR-6850 and EPRI 1011989 are not sufficiently sensitive or capable of providing such early warning to responders, leaving only minutes to successfully mitigate fires that have progressed beyond the later incipient stages.

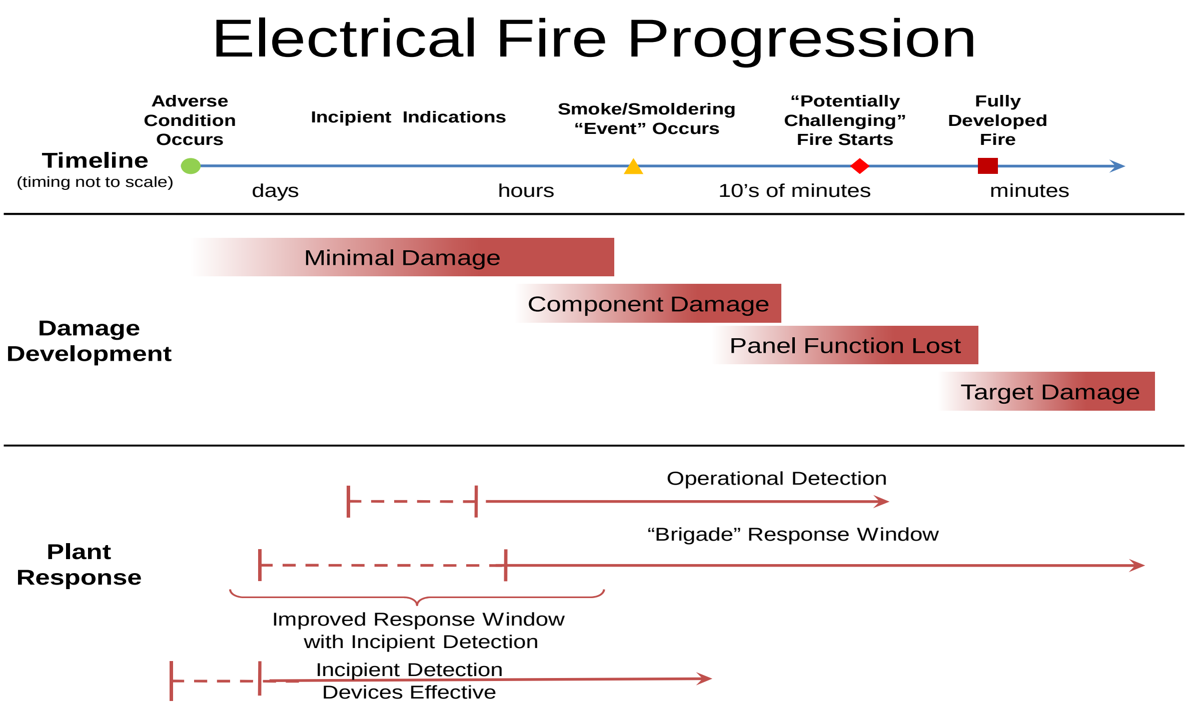

Figure 3-3
Electrical fire progression diagram

3.2 Incipient Detection Model and Fire Ignition Frequency Assumptions

As described above, the installation of VEWFDS proves the capability of detecting and suppressing potential fires induced by non-energetic causes. This has significant implications for adjustments to the fire ignition frequency as derived in accordance with the methodology provided in NUREG/CR-6850 and EPRI 1011989 without crediting VEWFDS. The following discussion provides a model by which incipient fire detection and suppression can be incorporated into a fire PRA. It applies to plants with fire detection systems that are designed, installed, operated, and maintained in accordance with the guidelines of NFPA 76 for VEWFDS.

The fire ignition frequency as derived in accordance with the methodology provided in NUREG/CR-6850 and EPRI 1019189 without crediting VEWFDS may be adjusted by: (1) multiplying the location weighted ignition frequency by the fraction of ignition source J components in location L that are effectively covered by the VEWFDS; (2) accounting for the availability of the VEWFDS; and (3) the pre-emptive suppression probability associated with very early detection and fire brigade response. This revised ignition frequency is represented on the incipient fire event tree as depicted in Figure 3-4. The original ignition frequency without credit for VEWFDS is $\lambda\omega$, calculated as described in Section 6 of NUREG/CR-6850. The ignition frequency adjusted to account for VEWFDS would be:

$$\lambda\omega_{\text{VEWFDS}} = \lambda\omega(1-\mu RP)$$

where: μ is the fraction of ignition source J components in location L that are effectively detected by VEWFDS in the pre-combustion stage

R is the reliability of the VEWFDS in location L (where $R = 1-\underline{R}$)

P is the pre-emptive response effectiveness of the fire alarm responders

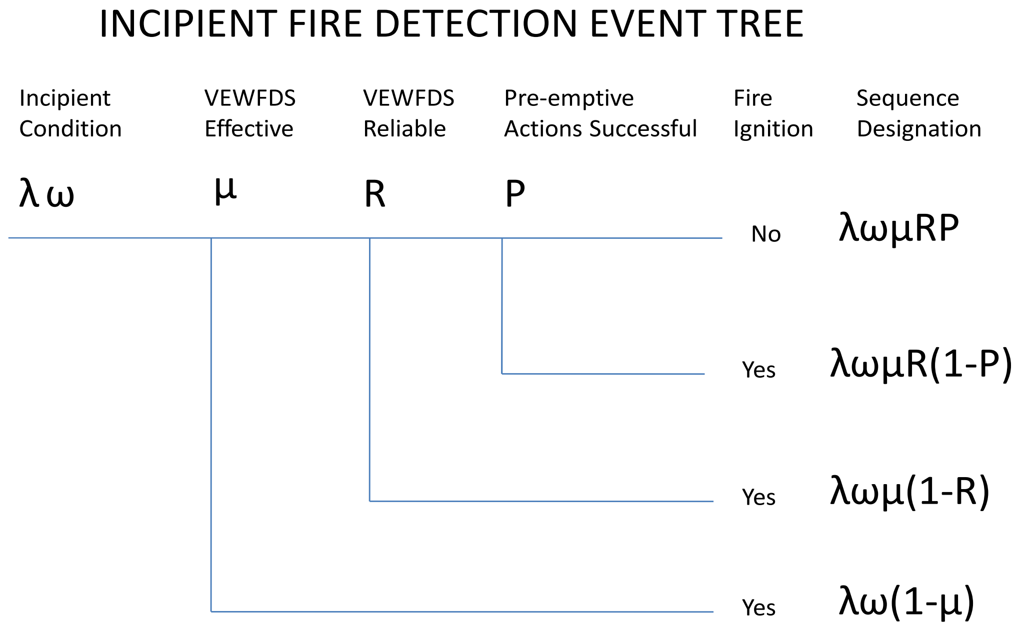

Figure 3-4
Incipient fire detection event tree

The adjusted fire ignition frequency has three subsequences (see Figure 3-4) with two different treatments. The first subsequence, designated $\lambda\omega\mu R(1\text{-}P)$, is the frequency of incipient fires that are detected, but are not preemptively suppressed and are assumed to grow to challenging fires in accordance with fire modeling guidance in Section 8 and 11 of NUREG/CR-6850. However, a fire watch can be assumed to be present, allowing for supplemental mitigation actions in accordance with modeling guidance in Appendix P of NUREG/CR-6850. The next subsequence, designated $\lambda\omega\mu(1\text{-}R)$, represents the ignition frequency for the fraction of time the VEWFDS is unreliable. If the fraction is significant, analysis of these sequences should be conducted without IFD, but at the reduced apparent frequency. The last subsequence, designated $\lambda\omega(1\text{-}\mu)$, is the ignition frequency of the fraction of components of type J that are not effectively detected in the incipient stage due to limitations assumed in the VEWFDS capability (e.g., higher voltage and/or energetic ignition sources attributed to instantaneously developing fires). However, the analysis of this set can take credit for prompt detection at the time of ignition and with normal detector delay and normal fire brigade suppression response.

3.3 Components Effectively Covered by VEWFDS

Credit for reduction of ignition frequency may be taken in fire zones that have VEWFDS installed for the following components that are effectively covered by the system.

- Components of 250V or less: batteries and battery chargers (bins 1 and 10), electrical cabinets and panels (bins 4 and 15), and air compressors (bin 9)
- Components of 480V or less: cable runs (bin 11), junction boxes (bin 18), electric motors (bin 14), pumps (bin 21), and RPS MG Sets (bin 22)

The above components are considered to be effectively covered by the VEWFDS, meaning pre-combustion indications are expected to alarm the VEWFDS well before a challenging fire would develop, allowing for preemptive actions by plant fire protection and fire brigade members. These components are to be used in computing their respective bin fraction for μ. Examples of events from the EPRI FEDB that would be expected to be mitigated by VEWFDS are provided in Appendix C.

3.4 Suppression and Preemptive Action Effectiveness in Limiting Incipient Fire Growth

Properly maintained and monitored VEWFDS are generally capable of detecting pre-combustion products long before the smoke, flaming and fire growth and propagation stages occur for non-energetic fire scenarios. Time frames on the order of hours and possibly days longer are expected between the time the overheating incipient stage begins and when the smoke stage begins to emit detectable pre-combustion products. Both of these stages typically occur much longer before significant flaming occurs. Appropriate response procedures, training of response personnel, and application of supplemental detection equipment to locate specific incipient fire locations and source equipment, provide a high degree of assurance that incipient fire conditions, if detected early, will not be allowed to progress to the more challenging fire states. This level of early detection is dependent on the type of detection technology used.

The preemptive response effectiveness, P, is determined based on the following assumptions:

- Alarms will indicate incipient fire conditions, normally before smoke or smoldering conditions develop, and up to a hour or more before ignition occurs (based on manufacturers' claims, NFPA 76 objectives, and technical discussion in Appendix C).
- Prompt response by fire protection technicians (typically 15 minutes or less) is assumed to respond/arrive at the alarm indicated location and implement preventive/corrective measures (based on plant specific procedures).
- Plant fire protection procedures direct appropriately trained response staff to take prompt and preemptive actions to locate and suppress the incipient fire condition.
- Response to an alarm will continue until positive indication that the incipient condition has been found or determined to be a false alarm. False alarms must be positively identified before response may be terminated.

- Responders will be trained and have procedures on the use of supplemental local incipient detection equipment (e.g., thermography meters). New portable CCD air sampling detectors are able to detect the incipient particulate released prior to smoke, and are not affected by dirt or dust drawn into the detector.
- In consideration of the training of technicians and specialized incipient fire detection equipment and/or procedures that may be employed, the control room suppression curve may be used as a surrogate for incipient detection suppression and/or preemptive action effectiveness. (This is based on the expectation that specifically trained technicians will promptly arrive at the site of the alarm indication before ignition conditions are reached and systematically evaluate the situation. Thus, it is more akin to a control room response than a typical fire watch response. A different approach to evaluating suppression effectiveness may be used based on plant specific operator response time, operating experience, or appropriate manufacturer's data.)
- Assumes incipient condition will be identified and prevented from achieving ignition for up to 99.9% or more of true incipient conditions. (This value is based on using the control room suppression curve for 15 minutes or greater time to suppress with minimum non-suppression limited to 0.001. A different value may be used based on plant specific operator response time, operating experience, or manufacturer's data.)

For in-cabinet installations, it is expected that the conditions would be resolved prior to any noticeable fire damage of the ignition source (this could be days). Even for wide area room overage, the VEWFD systems are very effective at detecting low concentrations of smoke. This is the basis for VEWFD use in the telecommunication and clean room facilities: fast detection of incipient fire scenarios. Manufacturers have product-specific software packages to design systems and sensitivity levels to provide the performance desired for different applications. For area monitoring, some fire damage to the ignition source might be expected. This may be avoided or reduced by considering factors identified in Table C-1 of Appendix C for specific applications. Therefore, fire damage associated with sources that are effectively covered by incipient fire detection should be treated as follows:

- For in-cabinet installations, assume fire damage is localized to the ignition component and that circuits associated with the ignition source will be de-energized for troubleshooting purposes. Spurious operations do not need to be postulated due to the localized and limited nature of the damage.
- For area monitoring installations, assume that the ignition source is damaged, but there is no propagation of fire damage effects to targets located in the local area of the source and that circuits associated with the ignition source will be de-energized for troubleshooting purposes. Spurious operations may be postulated due to damage within the ignition source (cabinet).

For all other fire ignition sources of type J in location L that have VEWFDS coverage, prompt detection may be assumed to occur at the time ignition occurs as follows:

- Assume fire ignition is detected at t=0 + alarm delay time (typically a maximum of 2 minutes).
- Assume fire brigade response and suppression time consistent with plant experience and apply appropriate suppression curve from NUREG/CR-6850.
- Assume fire damage, propagation, and circuit effects consistent with NUREG/CR-6850.

3.5 Nuclear Power Plant Operating Experience

While installation of incipient fire detection systems at operating nuclear power plants is limited, recent experience over the past 5-10 years has been very positive. An informal survey of commercial U.S. nuclear power plants with IFDS installed has indicated high reliability, very few nuisance alarms, some cases where incipient conditions were detected as expected, and no cases where fires occurred in areas and for equipment covered by IFDS. The survey is summarized in Table 3-1. Also, extensive application of VEWFDS has been reported at Bruce Power Station in Canada as a principal preventive measure for fire protection [11].

3.6 Estimating IFDS Reliability and Availability

Field experience has shown that modern IFDS that are installed and maintained in accordance with manufacturer recommendations are highly reliable and produce very few nuisance alarms. Therefore, the following approach is proposed for determination of industry generic reliability and availability for use in fire PRAs using NUREG/CR-6850 methods.

Each IFD “system” is comprised of a single aspiration detector with multiple sample lines and sample points. Moreover, each system is normally capable of detecting small changes to the air flow and pressure drop signaling potential blockage of a sample line or port. Thus, the dominant failure modes are associated with detector malfunctions and unavailability for test and maintenance (planned/preventive and unplanned/corrective). Therefore, the reliability of the IFDS is primarily based on that of the detector as determined by preventive maintenance and testing (PMT). Since the IFDS is a continuously operating and monitored system, most malfunctions and support system failures that impact IFD operation are expected to be detected very quickly, typically by alarms.

Since it is a single component system, the IFDS reliability and availability model can be written simply as:

$$Q = 1 - (\underline{R} + \underline{U})$$

Where $\underline{R}$ is the unreliability and $\underline{U}$ is the unavailability. The unreliability is estimated by the following:

$$\underline{R} = \lambda_r T/2$$

Where λ_r is the failure rate derived from failures detected by PMT, and T is the interval between surveillance tests. This accounts for failures of the system that are not self evident without a routine PMT to detect them.

Table 3-1
Incipient detection systems in operating nuclear power plants and operating experience

Plant ID	IFD System ID/#	Type	Date In Service	Locations	Reliability-Time OOS	Alarms	Malfunctions	Fire Events
Palo Verde 1,2,3	VESDA (3) (Xtralis)	Laser	8 + yrs (25 yrs total)	Spent Fuel Storage Interface Shed, SCBA Shop Unit 1, Security Computer Closet, 45 Acre lake pump house	None	A few nuisance alarms - dirt, dust on windy days	None	None
	Protec Mini (SAFE Fire)	Cloud chamber	1 + yr					
TMI 1	Cirrus (SAFE Fire)	Cloud chamber	12/31/1998 (10 yrs)		1 failure during PMT	None	PMT failure due to improper maintenance	2- detected as incipients
Millstone 3	SAFE Fire	Cloud chamber	5 + yrs	Cable spreading room	"very reliable"	1 nuisance-Aux power outside of room	None?	
Robinson	Stratos (AirSense Technology)	Laser	1998 (10 yrs reported)	RTGB Board	1/2 hour per year + 20d in 2002 + 27d in 2006	None in 10 years	Power supply failure in 2002 Battery and processor maint/replace	None?
Clinton Power Station	Cirrus-Protec (SAFE Fire)	Cloud chamber	2001 ?? (7 yrs)	SVC Building	None	None	1- battery failed PMT test, replaced	None?
Hope Creek	SAFE Fire	Cloud chamber	11/2006 (2 yrs)	Service Water Intake Structure monitoring 3 areas	Quarterly PMT OOS time-maintenance-8hrs local hot work- 15hrs	7 during hotwork 3 unknown-possibly dust, nearby brush fire	None	1 incipient-pump overheated in pump bay

The unavailability is estimated by:

$\underline{U} = t/T$

Where t is the time the system is down for testing, preventive maintenance, and corrective maintenance during interval T (the surveillance test interval).

Since IFDS is a continuously operating and monitored system, only pre-existing system failures to function that are detected during PMT are counted in the unreliability estimate. The down time to effectuate repair associated with these failures and down time to repair all other malfunctions that are revealed by continuous monitoring is included in the unplanned unavailability.

In order to derive unreliability and unavailability estimates applicable to nuclear plant operations, an informal survey was conducted of plants with IFDS installed to gather relevant data. The data collected are provided in Table 3-1. From this data an estimate of λ_r can be derived as

$\lambda_{\underline{r}}$ = total number of PMT failures/total operating time summed over all systems

The total number of failures reported as being detected by PMT was 1. The total operating time reported was 54+ system years. Thus the failure rate $\lambda_{\underline{r}}$ based on the maximum likelihood estimator is 1/54 = 0.0185 per year, or 2.1×10^{-6} per hour.

System unreliability is then estimated as a function of the failure rate and PMT interval. For quarterly PMT intervals the unreliability is estimated at 0.0023, and for semiannual PMT intervals the unreliability is estimated at 0.0046. These values represent generic estimates of IFDS unreliability that should be used to evaluate IFDS credit in the fire PRA.

The observed PMT down time was very small, about 0.25-1.0 hour per surveillance period. The repair down time involved several occurrences for the reported operating history. Most are on the order of several hours over the operating life of the system (up to 10 years) and represent a small contributor to overall unavailability. However, one plant reported maintenance and repair down time on the order of 3 to 4 weeks for 2 outage periods. This extended system downtime was attributed to unavailability of spare parts and a lack of urgency due to compensatory measures being in place and other higher priority maintenance tasks at the time. This experience is atypical and not allowed in the current fire protection operating environment. It should be noted that during the time period in which an IFD system is removed from service for planned or unplanned maintenance, compensatory measures are required to maintain adequate fire protection status. The compensatory measure is usually a fire watch.

For quarterly PMT in which the system is unavailable for 1 hour, the PMT unavailability is about 5×10^{-4}. This unavailability value is about a factor of 10 times or more lower than the unreliability experience. Therefore, it is not a significant contributor to the overall unreliability at the reported levels.

For those instances when the system maintenance and repairs were performed in about 8 hours per repair, the industry average unavailability due to corrective maintenance was about $4x10^{-5}$. Another 15 hours of unavailability was reported to allow nearby hotwork, approximately doubling the maintenance and repair unavailability at about $8x10^{-5}$. If the plant with sustained system outage while waiting for repairs and maintenance to be completed is included, the industry average unavailability would be about $2.4x10^{-3}$ and about an order of magnitude higher on a plant specific basis. Indications from the plant with high reported unavailability are that future plant practice will be to limit such instances considerably. As a result, the unavailability performance history for this plant was considered an outlier that should be considered on a plant specific basis. And, as mentioned above, the compensatory measures would further reduce the importance of the unplanned unavailability further.

3.7 Example Fire Ignition Frequency Adjustment for Crediting for IFDS

An estimate of the fire ignition frequency adjustment for crediting IFDS for component J in location L can be made applying the quantitative values derived previously in the equation

$$\lambda\omega_{VEWFDS} = \lambda\omega(1-\mu RP)$$

Two cases are presented below. In the first case the IFDS is assumed to be highly capable of detecting the incipient fire conditions for the ignition component and location. In the second case the IFDS provides a more limited capability. For ASD reliability R = 0.995 (semi-annual PMT) and for P = 0.999 (successful suppression/preemptive action taken with at least 45 minutes before expected ignition), the fire ignition frequency for component J in location L becomes:

Case 1: For $\mu = 1.0$, $\lambda\omega_{VEWFDS} \approx 0.006\lambda\omega$ (the revised ignition frequency) and is composed of:

$\lambda\omega\mu R(1-P) \approx 0.001\lambda\omega$ (incipient fires detected by IFDS, but not suppressed)

$\lambda\omega\mu(1-R) \approx 0.005\ \lambda\omega$ (fires not detected because IFDS unavailable)

$\lambda\omega(1-\mu) \approx 0.0$ (all fires detectable by IFDS)

In this case the fire ignition frequency for components of type J in location L is reduced by more than two orders of magnitude through detection and preemptive/corrective actions taken in response to the incipient indications (alarms). This expectation would be reasonable considering ASD capability and experiential data (see Appendix C) for components identified as within scope (identified in Sections 3.3 and 3.4).

Case 2: For $\mu = 0.5$, $\lambda\omega_{VEWFDS} \approx 0.503\lambda\omega$ (the revised ignition frequency) and is composed of:

> $\lambda\omega\mu R(1-P) \approx 0.0005\lambda\omega$ (incipient fires detected by IFDS, but not suppressed)
>
> $\lambda\omega\mu(1-R) \approx 0.0025\lambda\omega$ (fires not detected because IFDS unavailable)
>
> $\lambda\omega(1-\mu) \approx 0.5\ \lambda\omega$ (fires promptly detected early in fire growth stage, normal fire suppression response after ignition)

In the second case the fire ignition frequency is reduced by 50%. Half the potential fires would be detected and suppressed before any significant damage occurred. This represents very low capability for the kinds of components identified as within scope (Sections 3.3 and 3.4). It could be indicative of a location having a mixture of components of type J with varying degrees of applicability for effective IFDS. An example is a location containing components of both higher and lower power ranges.

The above examples indicate the potential benefit of IFDS in reducing the frequency of damaging fires by prompt detection in the incipient stages and implementation of appropriate pre-emptive and corrective measures. Even those fires detected in the later incipient stages where smoking and ignition have occurred would provide additional suppression response time to fire protection personnel. This is a principal expectation of VEWFDS.

4

REVISED GUIDANCE FOR ESTIMATING LARGE OIL SPILL FIRES FOR MFW PUMPS

This report section contains clarifications and refinements of the NUREG/CR-6850 and EPRI 1011989 [1] guidance on the treatment of large oil spill fires for main feedwater pumps contained in Appendix E, Section E.3. The guidance in Appendix E, Section E.3 for the treatment of large oil spill fires as follows:

The following steps are recommended for assigning the severity factor to scenarios involving oil spill fires.

1. *Determine the amount of oil that can be spilled in the room.*
2. *Assign a severity factor of 0.02 to a scenario consisting of 98% or more of the amount of oil spilled and ignited.*
3. *Assign a severity factor of 0.98 to a scenario consisting of 10% of the amount of oil spilled and ignited.*

This guidance is conservative for Main Feedwater (MFW) pumps in light of number of actual fire events that are captured in the FEDB as well as the general sequence of events captured in these events. The revised guidance proposed below is intended to account for the FEDB experience by the application of severity factors to estimate, more realistically, the impacts MFW pump oil spill fires.

Table C-2 (bin 32) of this report shows that 16.4 events were counted as the basis for the generic fire frequency for Main Feedwater (MFW) Pumps. Review of the FEDB indicates that 14.0 (85%) of all MFW fire events were related to oil fires. A summary of the corresponding fire events from the FEDB is provided in Table 4-1. These MFW pump oil fire events were identified by reviewing the FEDB and including only those events that occurred during power operations and were of challenging or undetermined severity.

Fifteen (15) events were identified with two of the events having undetermined severity factors. The total fire event count is then 14.0 since the two undetermined events were counted as 0.5 each. None of the 15 events involved a substantive volume of oil leakage or significant damage beyond the ignition source.

The data demonstrates that, although an acceptable screening approach, the assumption that 10% of the available oil supply would leak and ignite 98% of the time is a significant overestimate of the frequency based on actual operating experience. Therefore, using the NUREG/CR-6850 assumptions overestimate the occurrence rate of fires that result in at least 10% of the available oil supply spilling and igniting. In the case of the MFW pumps, this volume of oil can be significant and for some facilities can be a controlling assumption with regards to calculated risk.

The data demonstrates that the sequence of events is more likely that some oil leakage occurs and ignites to produce MFW pump oil fires. None of the operating experience indicates that the volume of oil was significant or approached 10% of the available supply. This is not to imply that oil fires involving larger volumes of the oil supply are not possible just that they are less likely than those associated with small oil supply volumes. In addition, the process of assessing the likelihood of fires that would involve higher volumes of oil leakage from the operating experience is relatively straight forward. Using a non-informative prior (which means that the next oil fire event is equally likely to result from significant oil leakage) updated with the current operating experience results in a posterior mean of 0.033 as shown in the equation below. This updating process is described in NUREG/CR-6823 [6]. This is the severity factor that should be applied to the MFW pump fire initiating event frequency to estimate the likelihood that a MFW pump oil fire results from an oil spill and ignition of significant portions of the available oil supply.

$$SF_{\text{Large Oil Fires}} = (0 + 0.5) / (14 + 1) = 0.5/15 = 0.033$$

This likelihood, or additional severity factor, will be applied as a frequency adjustment factor to estimate the frequency of larger oil spill fires for MFW pumps. The adjusted frequency can then be used to assess large oil spill fires for MFW pumps using the partitioning for spill volumes and associated severity factors provided in Appendix E of NUREG/CR-6850.

The guidance provided in Appendix E of NUREG/CR-6850 recommends assuming that for 98% of the postulated fire events 10% of the available combustible fluid inventory is available for combustion. The recommended treatment for the remaining 2% of the oil fire events is to assume that 98% of the available oil inventory is available for combustion. Applying the MFW pump large oil spill severity factor produces the following results:

- 1 – 0.033 = 0.966: Fire affects only the ignition source. No other damage occurs.
- 0.033 x 0.98 = .033: Fire involves 10% of the available oil inventory. The fire is assumed to remain confined to the MFW pump skid/pedestal.
- 0.033 x 0.02 = 6.7E-04: Fire involves 98% of available oil inventory. The fire cannot be assumed to remain confined to MFW pump skid/pedestal.

The factors above do not take into account the 85% condition noted above, which represents the portion of all MFW pump fires that are due to oil ignition. Applying that condition results in the following factors that should be used to estimate the frequency of MFP oil fires for these three categories:

- 0.966 x 0.85 = 0.82 Fire only affects MFW pump.
- 0.033 x 0.85 = 0.028 Fire involves 10% of the available oil inventory. The fire is assumed to remain confined to the MFW pump skid/pedestal.

- 6.7 E-4 x 0.85 = 5.7 E-4 Fire involves 98% of available oil inventory. The fire cannot be assumed to remain confined to MFW pump skid/pedestal.

This approach partitions MFW pump oil fires into three categories rather than the two initially indicated by NUREG/CR-6850. It is more realistic because it reflects the actual operating experience related to MFW pump oil fires. That experience indicates that none of the actual oil fires involved ignition of significant volumes of available oil supplies.

Table 4-1
Main feedwater pump oil spill fires from FEDB

Incident	Description
8	Fire resulted when oil leaking from a pump-motor reservoir, through a temporary insulation crack, contacted hot pipe (520 F) and vaporized. This caused flashing when contacting ventilation air.
24	A leak in the oil supply line to the feedwater pump soaked insulation on the feedwater supply line and ignition occurred when oil came in contact with a hot pipe. Fire quickly extinguished with dry chemical. As piping insulation was removed after fire (30 min), several flair-ups occurred which again were quickly extinguished. Fire brigade response was prompt (< 5 min)
201	A smoldering fire resulted from lube oil that leaked from a main turbine shaft-driven feed water pump onto piping insulation.
476	At 2126 hours on June 26, 1985, Waterford 3 Steam Electric Station was 91 percent reactor power when operations personnel received information of a fire in feedwater pump A. At 2131 hours the control room was informed by personnel on the scene that the B feedwater pump, rather than the A pump, was on fire. Since the A pump was already secured, and since the steam generator water levels were decreasing, operation personnel tripped the main turbine and reactor. The fire was extinguished by plant personnel at 2136 hours. The fire was started by a small oil leak, and it was limited to a small portion of the outer wrapping of insulation on the feedwater piping.
477	On June 29, 1985 at 0957 the reactor was manually scrammed and the main turbine manually tripped due to a fire in the reactor feedwater pump 1B, while the remaining reactor feedwater pump was secured for maintenance. The fire was extinguished and the plant shutdown in an orderly fashion.
662	While performing routine rounds, an equipment operator observed smoke emitting from the 2C Reactor Feed Pump (RFP) discharge piping. As it was initially suspected an oil leak was causing the smoke. The fire was extinguished using fire extinguishers and fire water.
737	As a result of maintenance activities, oil soaked lagging and paper was ignited by the hot surface of Feed Water Pump "A" Suction pipe.
739	Walking by Steam Generator Feedwater Pump A, plant personnel noticed smoke rising from the outboard pump bearing area, and he immediately contacted the control room. The fire brigade commenced attack from the feed pump platform, but were unable to determine the effectiveness of the attack due to the steam rising from the pump casing. They redirected their attack from the bottom of the feed pump, putting the fire out in its incipient stage.
824	A fire was reported at the "B" reactor feed pump; the cause may have been due to oil-soaked insulation; the fire was extinguished in about 15 minutes.

Table 4-1 (continued)
Main feedwater pump oil spill fires from FEDB

Incident	Description
961	Event occurred on August 11, 1991. At approximately 08:55 a fire was reported in the Turbine building. The plant was at power operation. The fire was reported to be approximately 18 minutes in duration. The fire was detected and extinguished by the fire brigade. This fire was extinguished by using water and carbon dioxide. The fire apparently originated from oil-soaked insulation resulting from a lubrication oil leak. The root cause of this event was turbine bearing lube oil leaking from the flange gasket of the ground brush assembly. This saturated the surrounding insulation with oil which fueled the fire once ignited. A ground wire was pinched between the gasket and the flange creating a leak path.
1482*	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 successfully completed surveillance testing. RAC# 2-86-043.
2388	Ref. SOS 93-2116
2422	Residual lubrication oil caught fire on the B reactor feed pump. The fire was in the area of the outboard pump bearing. The fire was controlled with portable extinguishers and completely extinguished using less than 200 gallons of water from a hose line.

* This description is a duplicate of the entry in the FEDB for Incident #1483. All other parts of this entry are different and are associated with a different plant and date. Therefore, it is included in the counts for MFW pump oil fires even though the exact description of the event is not available.

5
SUMMARY AND RECOMMENDATIONS

The initial applications of current fire PRA (FPRA) methods, as described in NUREG/CR-6850/ EPRI TR-101989 and EPRI 101989 have identified a number of conservatisms. These conservatisms are not unexpected as the fire PRA methods are expected to evolve as they are applied. However, the conservatisms can impact the ability to apply the resulting PRA to the spectrum of risk informed applications including the transition to risk informed performance based fire protection (i.e., 10 CFR 50.48(c) or NFPA 805).

This report is one of the efforts to improve the methods for fire PRA presented in NUREG/CR-6850 and EPRI 1011989 through the addition, refinement or clarification of the guidance contained in these documents.

This document is an interim report that provides refinements, or alternatives, to fire PRA methods for three technical aspects. These include:

1. Fire Ignition Frequency Re-Evaluation
2. Method for Crediting Incipient Fire Detection Systems
3. Main Feedwater Oil Fire Treatment

This work provides interim refinements in the selected areas and may be considered for use in fire PRAs while more extensive methodology updates are undertaken, as necessary. The refinements and follow-on work recommendations for each of these areas are discussed below.

5.1 Fire Ignition Frequency Re-Evaluation

5.1.1 Summary

Section 2 provides an evaluation of fire ignition frequency trends, updates generic fire ignition frequency estimates accordingly, and fire ignition frequency estimation parameters that can be used to develop individual plant frequencies. The new generic frequencies are about a factor of 2 lower than those originally developed in NUREG/CR-6850, but differences vary considerably between individual bins, and in one case, the revised bin frequency is larger. The frequency changes are due to statistically significant reductions in fire events in the post-1990 period and are consistent with fire protection and general plant safety program improvements since the mid-1980s. The generic frequencies and associated Bayesian parameters are provided as an alternative to current NUREG/CR-6850 estimated values and parameters.

5.1.2 Recommendation for Follow-On Work

There are several aspects of Fire Ignition Frequency Re-Evaluation that could benefit from additional follow-on activities. These include:

- Update the FEDB to more current time frame in content with additional quality for post-1990 data
- Re-evaluate the definition/criteria for events classified as “potentially challenging” and “undetermined” including event counting “assumptions”
- Examine updated data to establish an individual component level fire ignition frequency as an alternative to a plant level component fire ignition frequency
- Update generic fire ignition frequency estimates and computational parameters to reflect post-1990 data and revised data quality per items above

These additional methodology enhancements would need to consider the connection to the rest of the PRA modeling assumptions related to fire growth, severity, detection, and suppression to more realistically assess the likelihood of severe fires in future fire PRA applications.

5.2 Method for Crediting Incipient Fire Detection Systems

5.2.1 Summary

Section 3 addresses an issue that is not included in the NUREG/CR-6850 guidance on treatment of fire detection systems. This section describes the technology and PRA application methodology for incipient fire detection systems. Following the discussion of the characteristics of incipient fire growth and technical basis incipient fire detection systems, an event tree methodology is provided as a framework for crediting incipient fire detection systems in the fire PRA model. The scope of equipment covered is currently limited to lower energy electrically powered components. Examples indicate the potential benefit of incipient fire detection systems in these kinds of applications.

5.2.2 Recommendation for Follow-On Work

There are two aspects of the methodology for crediting incipient fire detection systems that could benefit from additional investigation. These are:

- Develop a supplemental technical basis for incipient fire growth characteristics and associated incipient fire detection lead time;
- Expand the technical basis for incipient fire detection to a larger scope of fire ignition components including higher voltage and non-electrical elements.

It may be necessary to expend some effort in the first area achieve benefit in the second. Additionally, it may be useful to expand the experimental basis in a mutually advantageous working arrangement with IFD vendors and utilities with an abiding interest in IFD applications.

5.3 Main Feedwater Oil Fire Treatment

5.3.1 Summary

Section 4 provides guidance on the treatment of large oil fires due to main feedwater pump oil leaks. In Section E.3 of Appendix E of NUREG/CR-6850, guidance is provided regarding recommended methods of accounting for the severity of potential fire events involving ignition of oil leaking from equipment. The guidance assumes that, for all equipment containing oil, there is a 98% probability that at least 10% of the available oil will ignite and a 2% probability that at least 98% of the available oil will ignite. No basis for the selection of those two choices is provided. As noted in Section 4, review of the operating experience does not support such a pessimistic this treatment. All of the MFW pump oil spill fires had significantly less oil spilled than assumed in the current method. A more realistic approach was developed based on the actual events involving MFW pump fires associated with oil leakage. This produces about an order of magnitude reduction in the large MFW pump oil fire frequency.

5.3.2 Recommendation for Follow-On Work

The current basis for the current MFW pump oil fire leak severity assumptions, and, in fact, all pump oil spill fires, is not documented. There are two aspects of pump oil fire treatment that would benefit greatly from additional methodology development. These include:

- Developing a more mechanistic, but operational experience data driven model of oil leak frequency and magnitude, coupled with a fire ignition probability model
- Expand the oil fire treatment to a spectrum of pump sizes and types, and possibly a more diverse set of components

Utilizing available data it should be possible more realistic treatment of oil fires consisting of three groups:

1. Small fires relating to minor oil leaks
2. Fires limited to ignition of a small portion of the available oil.
3. Large fires involving ignition of a significant portion of the available oil

In addition, it should be possible to include a degree of component size and type discrimination in the methodology.

6
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A

STATISTICAL METHODS

This appendix describes the most important statistical methods used in this report, and illustrates the methods with a typical data set. In the development of the fire ignition frequencies, many subsets of the data were examined, both large and small. Some of these examinations are preliminary, and are not described in this report. However, the methods described here are valid for any of the data subsets, unless it is stated otherwise.

The primary purpose of the analysis was to use past data on fire frequencies to estimate current fire frequencies. The two main elements of the analysis were: (1) to choose a well-fitting model to fit the data; and (2) to estimate the resulting parameter(s). The process of choosing a model involved considering possible models and examining them using both graphical tools and formal goodness-of-fit tests. The final estimation involves using appropriate diffuse prior distributions plus the data to obtain Bayesian estimates.

A.1 Choosing a Model

A.1.1 Graphical Methods

Graphical plots can show qualitative patterns, sometimes unanticipated, and thereby guide the later selection of a model. For data such as fires ignition frequencies (events per year), two useful plots are described here.

One type of plot is a side-by-side plot of annual frequencies, as described in Section 6.2.3.2.1 of Reference A-1. In this plot, the simple estimated frequency, number of fires divided by number of reactor years, is plotted for each year. Such a graph often shows considerable irregularity or scatter. Therefore, it is very helpful to include error bars for each plotted point, such as a 90% confidence interval for the frequency for each year. Figure A-1 shows such a plot. The data for this plot uses all challenging fires plus assigns half of an event to those fires that are listed as undetermined severity. The data includes only the history at power, because an examination of the data showed that the fire frequencies with the reactor up or the reactor down are significantly different for the “at power” only bins. This plot shows some evidence of lower frequency in recent years than in early years.

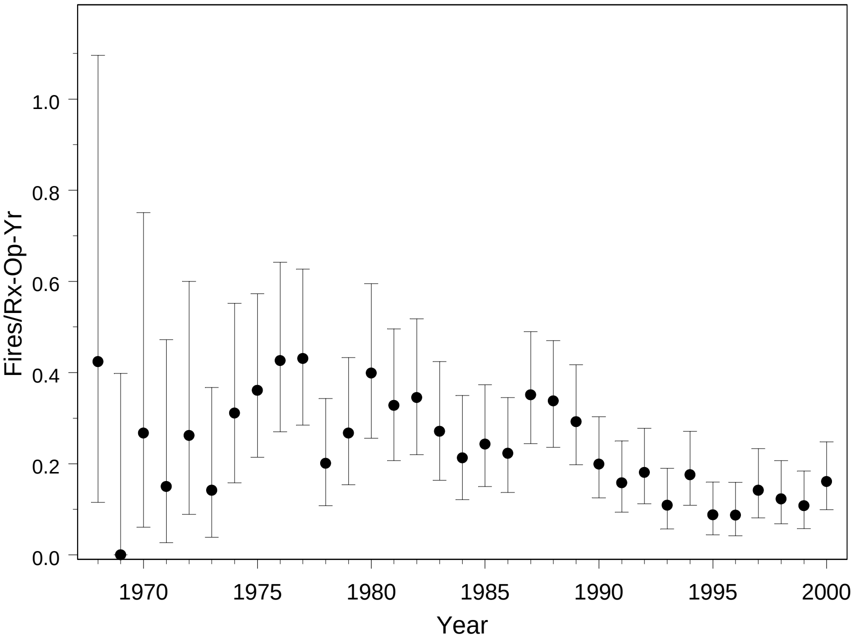


Figure A-1
Frequency of fires (challenging fires plus half the fires of unknown severity) with the reactor at power

The second useful plot is a cumulative plot of events, as also described in the above-mentioned section of Reference A-1. The horizontal axis shows the cumulative number of reactor years (e.g., at the end of each calendar year) and the vertical axis shows the cumulative total number of fires that occurred up to that point. This plot often shows less year-to-year variation, because the eye can average a low year with an adjacent high year and view the larger overall pattern. The slope of this cumulative plot is the number of events divided by the number of reactor years, and so the slope estimates the event frequency. If the plotted points are rising steeply (large slope) in one portion of the plot, the estimated frequency is large there. If the points rise more slowly (smaller slope) in another portion of the plot, the estimated frequency is smaller there. Figure A-2 shows the cumulative plot corresponding to the data for Figure A-1. This plot shows that not only is the frequency decreasing (steeper slope on the left than on the right), but it seems to have changed in one step, being approximately constant before 1990 and being a smaller constant after 1990. Figure A-3 emphasizes this visual impression by inserting two fitting lines.

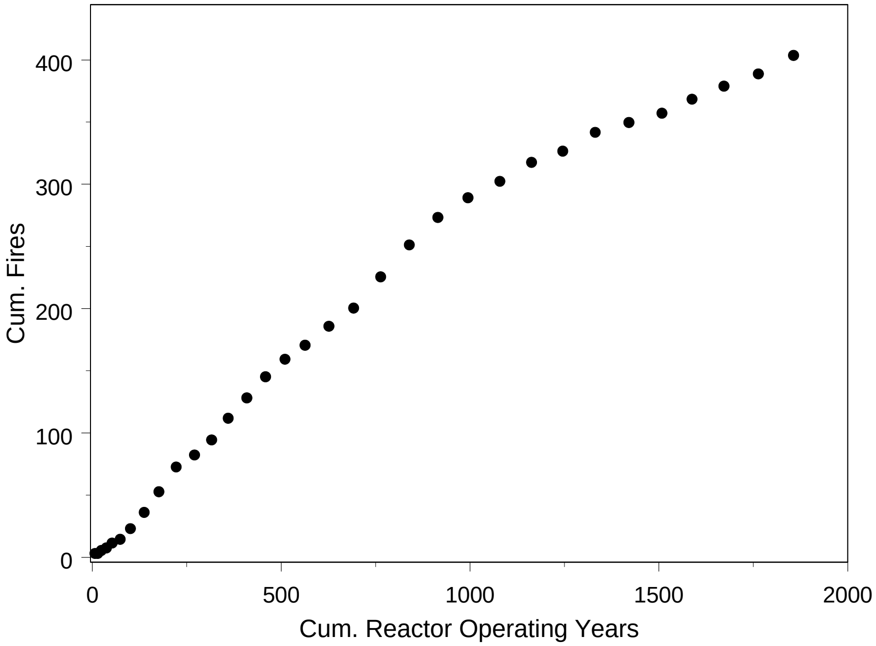


Figure A-2
Cumulative plot of fires, with same data as Figure A-2

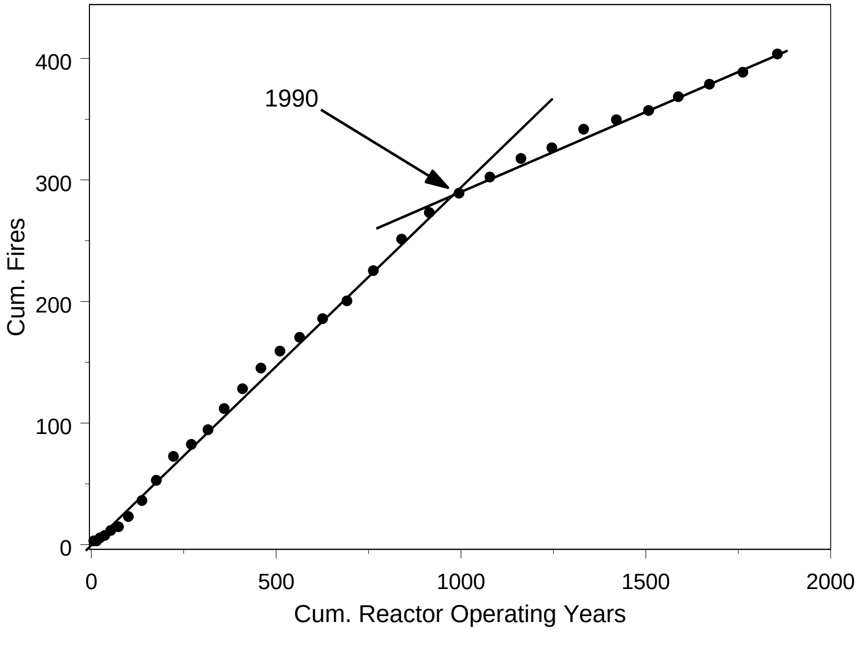


Figure A-3
Figure A-2 with straight fitting lines added

The bend is not sharp at exactly 1990. With various subsets of the data, the bend might be better placed at 1989 or 1991. However, unless the data subset was very small, the change from one constant fire frequency to a smaller one seemed to be the typical pattern, with the dividing line in the late 1980s or early 1990s.

Once a pattern is seen, possible explanations of the engineering causes should be sought. A convincing engineering explanation puts a proposed model on much firmer footing than if only statistical evidence can be found. Some engineering reasons for the bend in Figure A-2 are given in the body of this report, near the end of Section 2.2.

A.1.2 Statistical Tests

Three useful tests are described here. Two of the tests ask if the data in a single interval are consistent with a constant event frequency throughout the interval. The third considers two different time intervals, assumes that the event frequencies are constant in each individual interval, and asks if the data are consistent with one single frequency that applies to both intervals.

Consider first a single interval, consisting of a number of calendar years. A widely used test for homogeneity is the Pearson chi-squared test, described in Section 6.2.3.1.2 of Reference A-1. This test looks at the scatter of the estimated frequencies from the different years. If this scatter is too large, the test rejects the hypothesis of a constant event frequency. This test is not focused on finding trends, but instead looks for any kind of large variation from year to year. It uses the chi-squared distribution, which is a valid approximation when the number of events is not too small, say, more events than years.

The second test for homogeneity within an interval is the centroid test, called the Laplace test in Section 6.2.3.2.2 of Reference A-1. This test is focused on discovering trends, not just scatter. It does this by determining whether the events tend to pile up at one end of the interval or the other. If the mean occurrence time for all the fires is far from the middle of the interval, the test rejects the hypothesis of a constant frequency in favor of the alternative of an increasing or decreasing frequency. This test uses an approximation that is valid when at least 3 events occur. To be fully correct, the mean should be calculated based on each event's exact occurrence time from the beginning of the interval, measured, say, in cumulative reactor-years,. In this report, only the total reactor-years for each calendar year were used, and each fire was treated as if it occurred at the midpoint of the year. The use of mid-year times in this report means that more than 3 events are needed, and the number is not known.

The final test supposes that homogeneity has been accepted within each of two intervals, and asks if the data are consistent with a single frequency that applies to both intervals. The chi-squared test can be used if the data set is moderately large. An exact test, valid even for small data sets, is constructed as follows. Suppose that n events have occurred in the total data set, and we hypothesize that the same event frequency applies to both intervals. The reactor years are counted in each of the two intervals. If Interval A contains a fraction p of all the reactor years, the number of events in Interval A should be binomial(n, p). If the actual number in Interval A is much larger or smaller than expected, the test rejects the hypothesis of a common frequency for both intervals.

A number of variables can lower the level of precision in results obtained from all of the above tests. A small count of fires can make the asymptotic approximations very rough for the chi-squared and centroid tests. The use of midpoints instead of exact dates also makes the centroid test only rough. Finally, the event counts are not known exactly—the conclusions of this report are based on counting the "challenging" fires plus half of the fires of undetermined severity. In addition, if an analysis is restricted to a particular reactor mode, such as operation at power, and an event occurred with no mode recorded, the event is prorated, with a fractional count assigned to each reactor mode. As a result, the data sets typically have fractional counts of events. This affects all three tests in unknown ways. As a result, test conclusions must not be taken as definitive but only as rough indications, especially with small data sets.

The above tests were applied as follows in the analysis for this report. Various time intervals were considered, starting at various calendar years but all ending at the year 2000. In each case the centroid test was applied to determine if the frequency WITHIN the interval appeared to be constant. The test was applied with a two-sided alternative, because for at least one data subset the frequency appeared to be increasing, although for most the frequency appeared to be decreasing. Strong enough evidence of either kind of trend would cause the centroid test to reject the hypothesis of constant frequency. When the centroid test was applied to the data set of Figures A-1 through A-3, the test accepted a constant frequency within any time interval starting in 1990 or later—the p-value (level at which the hypothesis of constant frequency could be rejected) was 0.17 or more for each such interval. For the interval 1990-2000, the p-value was 0.19. However, when a larger time interval was considered, the test rejected the hypothesis of constant frequency. For example, for the interval 1989-2000 the p-value was 0.009, and for intervals starting earlier the p-value was even smaller.

One could then apply the chi-squared test to investigate in a second way whether the frequency is constant. This test looks for variation from year to year, not for events concentrated at one end. For the time period 1990-2000 the p-value is 0.59, so the test emphatically finds no evidence of non-constancy. Similarly, for the period 1968-1989, the p-value is 0.66, so again the test finds no evidence of non-constancy.

As a side comment, Figure A-1 might lead some viewers to think that the scatter is greater in the earlier years. The two chi-squared analyses just given shows that neither interval has more random scatter than would be expected from Poisson counts. The apparent large variability in the early years is simply a consequence of having few reactors, yielding small amounts of data.

As a final check, it can be asked if the two time periods have frequencies that differ from each other by a statistically significant amount. The estimated frequencies are 0.30 for 1968-1989 and 0.14 for 1990-2000, and a chi-squared test rejects equality of the two frequencies with p-value 1.4E−13. Thus, the test declares that the two frequencies are unquestionably different. The test based on the binomial distribution would give a similar result, but there is no need for it when the sample contains hundreds of fires.

In summary, the above investigation concludes that, when considering fires while the reactor is at power, the fire frequency can be modeled as constant from 1968 through 1989, and as a different constant from 1990 through 2000. Similar investigations were performed for many subsets of the data, although not all of the results are reported.

A.2 Estimating the Parameters

The analyses of this report, though performed on many data sets, typically found that the fire frequency could be modeled as a constant from 1968 to some year around 1990, and as a different constant from about 1990 through 2000. The very best dividing year was not always the same, but for simplicity the division was always taken to be between 1990 and 1991. This was adequate in every case.

To obtain a Bayesian estimate for the frequency in 2000, we updated a diffuse prior with the data from 1991-2000. The discussion below considers the choice of an appropriate prior. Three options were considered:

1. Use the Jeffreys noninformative prior, gamma(0.5, 0).
2. Use a fully informative prior reflecting the early period, such as the result of updating the Jeffreys prior by the 1968-1990 data.
3. Use a constrained noninformative prior, a gamma distribution with shape parameter 0.5 and mean equal to the mean from option 2. This distribution is described in Section 6.2.2.5.3 of Reference A-1 and, at a more mathematical level in Reference A-2.

The Jeffreys prior is diffuse, but conservative. For example, its mean is either undefined or infinite, depending on which words are used to describe it.

Use of the 1968-1990 data to construct a fully informative prior for the 1991-2000 data is equivalent to pooling all the data from 1968 through 2000, which earlier the graphs and tests showed is incorrect. However, the mean of this prior distribution does give a rough, reasonable starting point. A diffuse distribution with that mean could be used as a prior, to be updated by the 1991-2000 data. Denote the mean by $\mu_{68\text{-}90}$.

The constrained noninformative (CNI) prior with mean $\mu_{68\text{-}90}$ is gamma(0.5, $1/(2\mu_{68\text{-}90})$). This is the prior distribution that was used throughout this report.

In every case, a gamma prior with parameters α_{prior} and β_{prior} is updated with data consisting of x fires in t years (normally reactor-operating years or reactor-calendar years). The result is the following posterior distribution for the fire frequency: gamma with parameters

$\alpha_{posterior} = \alpha_{prior} + x$, and

$\beta_{posterior} = \beta_{prior} + t$.

Use of the CNI prior is illustrated here (see Figure A-4) for a hypothetical data set with an early period of 2.11 fires in 641.2 reactor-years, followed by a more recent period with 1.155 fires in 585.6 reactor-years.

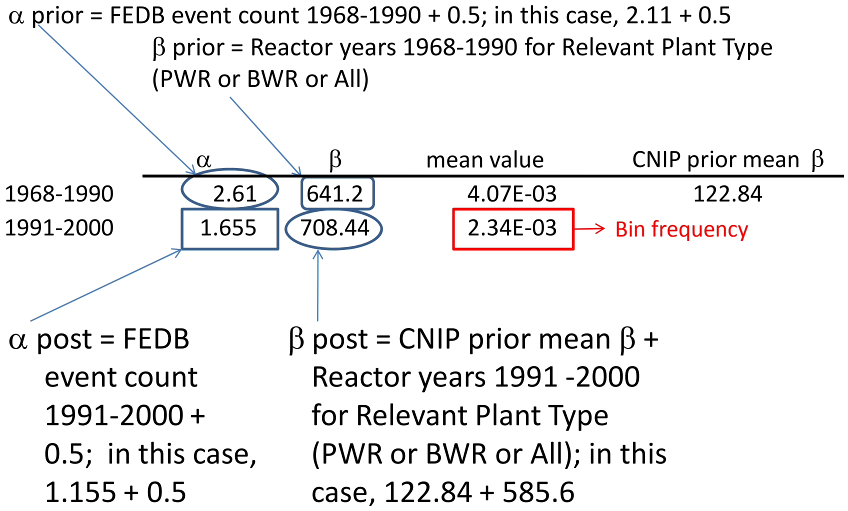


Figure A-4
Calculations with constrained noninformative prior and hypothetical data

When the three priors are applied to the data used for illustration in Section A.1, the following results are obtained:

> First, the 1968-1990 period had 289.10 fires in 994.90 reactor-operating-years. The fractional number comes from fires of unknown severity and/or fires occurring when the reactor mode is not known. Updating the Jeffreys prior with this data set yields a gamma(289.60, 994.90) distribution for the fire frequency. The mean of this distribution, $\mu_{68\text{-}90}$, is 289.60/994.90 = 0.291 fires per reactor-operating-year.
>
> The 1991-2000 period has 114.52 fires in 861.51 reactor-operating-years. The constrained non-informative prior is gamma(0.5, 1/ $\mu_{68\text{-}90}$) = gamma(0.5, 1.72), and the posterior distribution is gamma(115.02, 863.23) fires per reactor-operating-year. The mean is 0.133. The Bayes 90% credible interval is (0.113. 0.154).

For comparison, the results from using the three options for a prior are shown in Table A-1. All the distributions are of the form gamma(α, β), and the term rcry stands for "reactor critical years," which has been called "reactor-operating-years" elsewhere in this report.

Table A-1
Results using three possible priors for the 1990-2000 data on fires with reactor at power

Prior Gamma(α, β)	Jeffreys	Constr. Non-Inform.	Fully Informative
Prior α	0.5	0.5	273.19
Prior β (rcry)	0	1.67	914.95
Prior mean (1/rcry)	undef. ("infinite")	0.299	0.299
Posterior α	130.52	130.52	404.11
Posterior β (rcry)	941.46	943.13	1856.41
Posterior mean (1/rcry)	0.139	0.139	0.218
Posterior 5th %ile	0.120	0.119	0.200
Posterior 95th %ile	0.160	0.159	0.236

This table illustrates that a large 1991-2000 data set can overwhelm any diffuse prior, whether it is Jeffreys or constrained noninformative. However, the constrained noninformative prior has the psychological advantage of making some use of the early data rather than discarding it altogether. Numerically, using one noninformative prior or the other makes essentially no difference in this example. However, with the sparser data seen for single bins, the median ratio of the posterior means was 1.1, and the most extreme case (from a data set with only two fires) had a ratio of over 2.

A fully informative prior, on the other hand, makes a big difference in nearly every case. In the example considered here, it results in a compromise between the 1968-1990 frequency and the 1991-2000 frequency, which is correct for neither time interval, and certainly not correct for the year 2000. For this reason, it is not used at any place in this report.

For individual bins, one could compare the early and late periods, using the exact test given in Section A-1.2 based on the binomial distribution. If they show a statistically significant difference, the recent time period, 1991-2000, could be analyzed using the Jeffreys prior or the constrained noninformative prior. If they do not, then another possibility is to pool the data from 1968-2000. The decision of whether to treat the two time periods as different or not was complicated by borderline cases. To avoid subjectivity in judgment, it was decided to almost always use the CNI prior based on 1968-1990, and to update it with the 1991-2000 data.

Two exceptions were made to this decision, as discussed in Section 2.3. First, one bin seemed to show an increase during the recent years, not the decrease typically seen. To be conservative, the Jeffreys prior was used with the 1991-2000 data, for this one bin.

The other exception was for a bin with so many fires that between-plant variability could be seen. In this case the between-plant variation was modeled using the hierarchical Bayes methods described in Section 8.3 of Reference A-1. The between-plant variability was assumed to be log-normal, and the median and error factor were assigned diffuse priors used in NUREG/CR-6850.

The program WinBUGS (Ref. A-3) generated a very large sample from the posterior distribution. A gamma distribution was fitted to this sample by matching the medians and the 95th percentiles. Only the 1991-2000 data were used in this case.

References:

A-1 Atwood, C.L., et al., *Handbook of Parameter Estimation for Probabilistic Risk Assessment*, NUREG/CR-6823, 2003.

A-2 Atwood, C.L., "Constrained Noninformative Priors in Risk Assessment," *Reliability Engineering and System Safety*, 1996, v. 53, pp. 37-46.

A-3 Lunn D.J. et al., WinBUGS — A Bayesian modelling framework: concepts, structure, and extensibility. *Statistics and Computing*, v. 10, 2000, pp. 325-337. Program can be downloaded from http://mathstat.helsinki.fi/openbugs/.

B

FIRE IGNITION FREQUENCY DATA AND RESULTS DETAILS

This appendix provides data tabulations for fire frequency analyses and parameter estimations. The tabulations are as follows:

- Table B-1 provides an updated tabulation of reactor years correcting values originally used in NUREG/CR-6850 that were based on industry average capacity factors. This tabulation was derived from References B-1 and B-2. The table provides a compilation for at power and all operating modes from which industry average availability factors have been calculated.
- Table B-2 provides a tabulation of FEDB counts used in the trending analyses for at power and Table B-3 provides similar tabulations for all operating modes analyses. Adjusted counts were derived in accordance with NUREG/CR-6850 counting procedures for fire severity (potentially challenging, undetermined, not challenging) and power level undetermined.
- Figures B-1 and B-2 provide supplemental plots of cumulative numbers of fire events versus reactor years. Laplace test (centroid) values are in the range of -5 to -12 (p values << 0.05) in each case, providing strong indication of declining fire incident trends over the interval. For these cases no adjustments were made to counts for undetermined event severity or for instances where reactor operating state was unknown.
- Table B-4 provides a compilation of the adjusted bin counts and applicable reactor years for the periods 1968-1990 and 1991-2000 (with exception noted) used to estimate individual bin fire ignition frequencies. Adjusted counts was derived in accordance with NUREG/CR-6850 counting procedures for fire severity (potentially challenging, undetermined, not challenging) and power level undetermined.
- Table B-5 provides a compilation of bin counts, calculated frequencies, and related data for both NUREG/CR-6850 parameter estimates and updates performed for this study.

References:

B-1 NRC web site http://nrcoe.inel.gov/results/index.cfm.

B-2 *Development of Transient Initiating Event Frequencies for Use in Probabilistic Risk Assessment*, NUREG/CR-3862, U.S. Nuclear Regulatory Commission, May 1985.

Table B-1
Summary reactor year and availability data

Plant type, Op. Mode	Applicable Period				Period	Availability
	1968-1990	1991-2000	1968-2000			
All modes all plants	1376.2	1075.3	2451.5		1968-1980	0.777
Power, all plants	994.9	861.5	1856.4		1981-1990	0.709
PWR at power	641.2	585.6	1226.8		1991-2000	0.802
BWR at power	347.8	275.9	623.7			

Year	Reactor Critical Years			Reactor Years All Modes All RxYrs	Average Annual Availability
	PWR-All	BWR-All	Total+HTGR		
1968	4.3	2.7	7.1	7.9	0.892
1969	4.7	2.8	7.5	8.2	0.916
1970	4.4	5.0	9.4	12.1	0.777
1971	7.0	6.4	13.4	16.3	0.819
1972	7.4	7.8	15.3	19.6	0.780
1973	10.5	10.6	21.1	28.1	0.750
1974	15.9	11.4	27.3	35.7	0.766
1975	22.1	14.2	36.4	48.1	0.757
1976	22.7	16.4	39.1	53.7	0.728
1977	28.5	17.4	45.9	59.4	0.773
1978	29.8	18.8	48.6	62.3	0.779
1979	26.4	18.0	44.9	64.5	0.697
1980	26.4	16.9	43.8	65.8	0.666
1981	32.0	17.4	49.8	68.2	0.730
1982	31.2	17.6	49.3	71.5	0.688
1983	34.8	16.4	51.7	73.3	0.705
1984	37.3	15.8	53.2	78.7	0.675
1985	43.9	18.9	62.8	85.9	0.731
1986	45.0	19.9	65.7	94.2	0.697
1987	48.6	21.8	71.4	98.9	0.722
1988	52.9	22.3	76.2	105.7	0.721

Table B-1 (continued)
Summary reactor year and availability data

Year	Reactor Critical Years			Reactor Years All Modes All RxYrs	Average Annual Availability
	PWR-All	BWR-All	Total+HTGR		
1989	51.7	22.9	75.3	108.3	0.695
1990	53.8	26.2	80.0	109.7	0.729
1991	57.8	26.2	84.0	110.8	0.758
1992	57.8	26.2	84.0	109.7	0.766
1993	55.3	27.7	83.0	108.0	0.769
1994	59.6	26.4	86.0	108.0	0.796
1995	60.6	28.5	89.1	107.8	0.826
1996	60.7	26.5	87.2	108.3	0.805
1997	54.5	25.4	80.0	107.7	0.743
1998	57.3	27.1	84.4	105.0	0.804
1999	60.4	30.3	90.7	105.0	0.864
2000	61.5	31.7	93.2	105.0	0.888
Totals	1226.8	623.7	1856.4	2451.5	

Table B-2
FEDB counts at power

Year	Challenging	Undetermined	Chall+0.5 Undet	Availability Adjusted Chall+.5 Undet	Not Challenging	Tot All
1968	3	0	3	3	0	3
1969	0	0	0	0	0	0
1970	2	1	2.5	2.5	0	3
1971	2	0	2	2	1	3
1972	3	2	4	4	2	7
1973	2	2	3	3	0	4
1974	6	5	8.5	8.5	3	14
1975	8	12	14	13.1	6	26
1976	9	16	17	16.7	1	26
1977	14	12	20	19.8	7	33

Table B-2 (continued)
FEDB counts at power

Year	Challenging	Undetermined	Chall+0.5 Undet	Availability Adjusted Chall+.5 Undet	Not Challenging	Tot All
1978	4	12	10	9.8	10	26
1979	8	8	12	12	5	21
1980	15	5	17.5	17.5	12	32
1981	13	7	16.5	16.4	12	32
1982	16	2	17	17	10	28
1983	13	2	14	14	12	27
1984	10	3	11.5	11.3	7	20
1985	14	4	16	15.3	13	31
1986	12	6	15	14.7	14	32
1987	22	7	25.5	25.0	20	49
1988	23	7	26.5	25.8	29	59
1989	12	24	24	22	13	49
1990	10	14	17	15.9	29	53
1991	9	11	14.5	13.3	20	40
1992	11	10	16	15.2	20	41
1993	7	7	10.5	9.0	26	40
1994	13	7	16.5	15.2	13	33
1995	7	3	8.5	7.8	15	25
1996	6	5	8.5	7.2	9	20
1997	10	3	11.5	11.3	9	22
1998	9	3	10.5	10.4	9	21
1999	8	4	10	9.8	14	26
2000	13	4	15	15	12	29
Totals	314	208	418	403.6	353	875

Table B-3
FEDB counts all modes combined

Year	Challenging	Undetermined	Chall+0.5 Undet	Not Challenging	Tot All
1968	3	0	3	0	3
1969	1	0	1	0	1
1970	4	1	4.5	0	5
1971	3	1	3.5	2	6
1972	5	2	6	3	10
1973	3	2	4	0	5
1974	6	5	8.5	3	14
1975	9	15	16.5	7	31
1976	11	18	20	5	34
1977	18	17	26.5	11	46
1978	8	14	15	13	35
1979	9	11	14.5	5	25
1980	20	11	25.5	21	52
1981	18	9	22.5	27	54
1982	20	10	25	33	63
1983	22	8	26	31	61
1984	15	5	17.5	17	37
1985	20	4	22	22	46
1986	19	13	25.5	20	52
1987	40	15	47.5	40	95
1988	35	20	45	49	104
1989	15	39	34.5	20	74
1990	17	25	29.5	38	80
1991	13	12	19	29	54
1992	15	16	23	34	65
1993	11	13	17.5	35	59
1994	18	16	26	25	59
1995	9	5	11.5	20	34
1996	10	5	12.5	17	32
1997	11	4	13	11	26
1998	10	4	12	13	27
1999	11	7	14.5	24	42
2000	15	5	17.5	24	44
Totals	444	332	609.5	599	1375

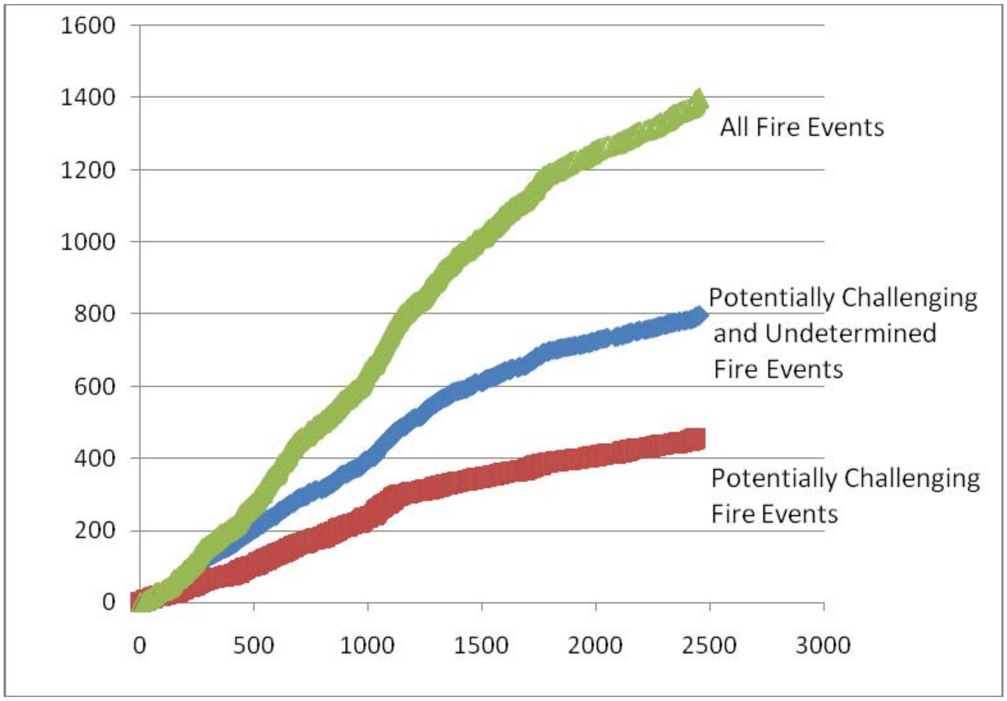


Figure B-1
Cumulative plots of number of fire events versus reactor years for all modes

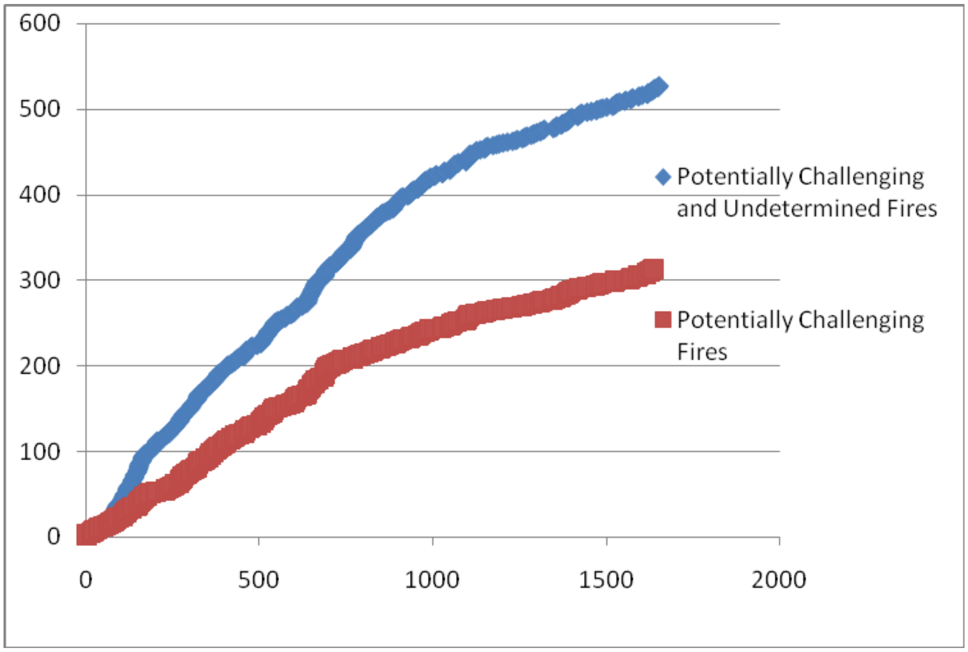


Figure B-2
Cumulative plots of number of fire events versus reactor years for at power

Table B-4
Fire ignition bin adjusted counts and associated reactor years

Bin #	1968-1990		1991-2000	
	Counts	Rx Yrs	Counts	Rx Yrs
1	1.0	1376.2	0.0	1075.3
2	5.5	641.2	1.0	585.6
3	2.1	641.2	1.2	585.6
4	4.5	1376.2	0.5	1075.3
5	0.0	994.9	1.8	861.5
6	10.5	994.9	1.7	861.5
7	2.2	994.9	4.5	861.5
8	43.0	1376.2	5.0	1075.3
9	0.5	1376.2	4.5	1075.3
10	3.0	1376.2	1.0	1075.3
11	2.0	994.9	0.5	861.5
12	10.5	1376.2	1.0	1075.3
13	5.5	1376.2	0.0	1075.3
14	6.5	1376.2	3.5	1075.3
15.1	74.0	1376.2	24.5	1075.3
15.2	1.5	1376.2	1.0	1075.3
16.1	6.0	1376.2	1.0	1075.3
16.2	2.0	1376.2	1.0	1545.3[1]
17	3.0	1376.2	1.0	1075.3
18	2.0	1376.2	1.0	1075.3
19	4.5	1376.2	1.0	1075.3
20	23.5	347.8	2.0	275.9
21	35.5	1376.2	15.0	1075.3
22	3.5	994.9	0.4	861.5
23	14.0	1376.2	8.5	1075.3
24	6.0	994.9	2.9	861.5
25	5.5	994.9	7.3	861.5

Table B-4 (continued)
Fire ignition bin adjusted counts and associated reactor years

Bin #	1968-1990		1991-2000	
	Counts	Rx Yrs	Counts	Rx Yrs
26	9.5	1376.2	6.5	1075.3
27	7.0	994.9	1.0	861.5
28	14.5	994.9	7.0	861.5
29	0.0	994.9	3.0	861.5
30	1.0	1376.2	1.0	1075.3
31	1.5	994.9	0.0	861.5
32	12.0	994.9	4.4	861.5
33	5.0	994.9	1.5	861.5
34	7.0	994.9	2.5	861.5
35	12.5	994.9	3.0	861.5
36	8.7	994.9	6.4	861.5
37	7.7	994.9	2.7	861.5

Footnote 1. Bin 16.2 data set extended to June 2004 with reactor years adjusted accordingly per reference B-1

Table B-5
Bin counts, frequencies, and comparison with NUREG/CR-6850 results

6850 Bin #	Ignition Component	Location	NUREG/CR-6850 Reported Information			CNIP Bayesian Frequencies		
			1968-2000			1991-2000		
			Fire Event Counts	MLE	Bayesian Bin Frequencies	Fire Event Counts: Chal +.5 Undet Adjusted	MLE	Bayesian[1] Bin Frequencies
1	Batteries	Battery Room	1	4.02E-04	7.50E-04	0.0	0.00E+00	3.26E-04
2	Reactor Coolant Pump	Containment (PWR)	6.5	5.97E-03	6.10E-03	1.0	1.71E-03	2.35E-03
3	Transients and hotwork	Containment (PWR)	2.4	2.20E-03	2.00E-03	1.2	1.97E-03	2.34E-03
4	Main control board	Control Room	5.5	2.21E-03	2.50E-03	0.5	4.65E-04	8.24E-04
5	Cable fires caused by welding and cutting	Control/Aux/Reactor Building	2	1.19E-03	1.60E-03	1.8	2.11E-03	1.25E-03
6	Transient fires caused by welding and cutting	Control/Aux/Reactor Building	12.6	7.53E-03	9.70E-03	1.7	2.01E-03	2.46E-03
7	Transients	Control/Aux/Reactor Building	6	3.58E-03	3.90E-03	4.5	5.26E-03	4.81E-03
8	Diesel generators	Diesel Generator Room	49.5	1.99E-02	2.10E-02	5.0	4.65E-03	5.04E-03
9	Air Compressors	Plant-Wide Components	5	2.01E-03	2.40E-03	4.5	4.19E-03	4.65E-03

Table B-5 (continued)
Bin counts, frequencies, and comparison with NUREG/CR-6850 results

			6850 Reported Information			CNIP Bayesian Frequencies		
			1968-2000			1991-2000		
6850 Bin #	**Ignition Component**	**Location**	**Fire Event Counts**	**MLE**	**Bayesian Bin Frequencies**	**Fire Event Counts: Chal + .5 Undet Adjusted**	**MLE**	**Bayesian[1] Bin Frequencies**
10	Battery Chargers	Plant-Wide Components	4	1.61E-03	1.80E-03	1.0	9.30E-04	1.18E-03
11	Cable fires caused by welding and cutting	Plant-Wide Components	3	1.79E-03	2.00E-03	0.5	5.80E-04	9.43E-04
12	Cable run	Plant-Wide Components	11.5	4.63E-03	4.40E-03	1.0	9.30E-04	1.32E-03
13	Dryers	Plant-Wide Components	5.5	2.21E-03	2.60E-03	0.0	0.00E+00	4.20E-04
14	Electric motors	Plant-Wide Components	10	4.02E-03	4.60E-03	3.5	3.26E-03	3.41E-03
15.1	Electrical Cabinets Non-HEAF	Plant-Wide Components	109	4.38E-02	4.50E-02	24.5	2.28E-02	2.36E-02
15.2	Electrical Cabinets-HEAF	Plant-Wide Components				1.0	9.30E-04	1.06E-03
16.1	Bus Duct (original HEAF)	Plant-Wide Components	3.5	1.41E-03	1.50E-03	1.0	9.30E-04	1.27E-03
16.2	Iso phase ducts	Plant-Wide Components				1.0	6.47E+04	8.24E-04
17	Hydrogen Tanks	Plant-Wide Components	4	1.61E-03	1.70E-03	1.0	9.30E-04	1.18E-03
18	Junction box	Plant-Wide Components	3	1.21E-03	1.90E-03	1.0	9.30E-04	1.11E-03
19	Misc. Hydrogen Fires	Plant-Wide Components	5.5	2.21E-03	2.50E-03	1.0	9.30E-04	1.24E-03

Table B-5 (continued)
Bin counts, frequencies, and comparison with NUREG/CR-6850 results

			6850 Reported Information			CNIP Bayesian Frequencies		
			1968-2000			1991-2000		
6850 Bin #	**Ignition Component**	**Location**	**Fire Event Counts**	**MLE**	**Bayesian Bin Frequencies**	**Fire Event Counts: Chal + .5 Undet Adjusted**	**MLE**	**Bayesian[1] Bin Frequencies**
20	Off-gas/H2 Recombiner (BWR)	Plant-Wide Components	25.5	4.36E-02	4.40E-02	2.0	7.25E-03	8.83E-03
21	Pumps	Plant-Wide Components	52	2.09E-02	2.10E-02	15.0	1.40E-02	1.42E-02
22	RPS MG sets	Plant-Wide Components	3.7	2.21E-03	1.60E-03	0.4	4.88E-04	9.33E-04
23	Transformers	Plant-Wide Components	23	9.25E-03	9.90E-03	8.5	7.91E-03	8.02E-03
24	Transient fires caused by welding and cutting	Plant-Wide Components	7.3	4.36E-03	4.90E-03	2.9	3.40E-03	3.65E-03
25	Transients	Plant-Wide Components	12.9	7.71E-03	9.90E-03	7.3	8.49E-03	8.28E-03
26	Ventilation Subsystems	Plant-Wide Components	16	6.44E-03	7.40E-03	6.5	6.05E-03	6.12E-03
27	Transformer - Catastrophic	Transformer Yard	10	5.97E-03	6.00E-03	1.0	1.16E-03	1.62E-03
28	Transformer – Non-Catastrophic	Transformer Yard	21.5	1.28E-02	1.20E-02	7.0	8.13E-03	8.38E-03
29	Yard transformers (Others)	Transformer Yard	3	1.79E-03	2.20E-03	3.0	3.48E-03	1.89E-03
30	Boiler	Turbine Building	2	8.05E-04	1.10E-03	1.0	9.30E-04	9.78E-04
31	Cable fires caused by welding and cutting	Turbine Building	1.5	8.96E-04	1.60E-03	0.0	0.00E+00	4.50E-04

Table B-5 (continued)
Bin counts, frequencies, and comparison with NUREG/CR-6850 results

6850 Bin #	Ignition Component	Location	6850 Reported Information			CNIP Bayesian Frequencies		
			1968-2000			1991-2000		
			Fire Event Counts	MLE	Bayesian Bin Frequencies	Fire Event Counts: Chal + .5 Undet Adjusted	MLE	Bayesian[1] Bin Frequencies
32	Main feedwater pumps	Turbine Building	15.5	9.26E-03	1.30E-02	4.4	5.11E-03	5.44E-03
33	T/G Excitor	Turbine Building	6.5	3.88E-03	3.90E-03	1.5	1.74E-03	2.10E-03
34	T/G Hydrogen	Turbine Building	10.5	6.27E-03	6.50E-03	2.5	2.90E-03	3.23E-03
35	T/G Oil	Turbine Building	15.5	9.26E-03	9.50E-03	3.0	3.48E-03	3.89E-03
36	Transient fires caused by welding and cutting	Turbine Building	13	7.77E-03	8.20E-03	6.4	7.44E-03	7.55E-03
37	Transients	Turbine Building	10.5	6.27E-03	8.50E-03	2.7	3.08E-03	3.41E-03

Footnote 1. All updated Bayesian bin frequencies derived from constrained noninformative priors except bin 9 (Jeffreys noninformative prior) and bin 15.1 (Hierarchical Bayes using diffuse log normal prior). Bin 16.2 based on data through June 2004.

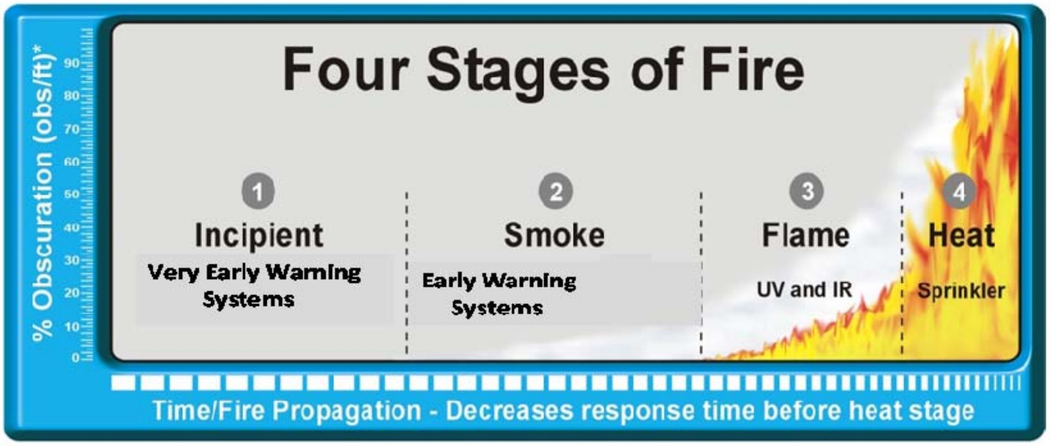
C

SUPPLEMENT FOR CREDITING INCIPIENT FIRE DETECTION IN FPRA QUANTIFICATION

Within the fire protection field, it is commonly acknowledged that aspiration smoke detection (a.k.a. air sampling) provides substantially increased sensitivity in smoke detection compared to conventional spot-type ionization and photoelectric smoke detectors. Aspiration smoke detection is commonly used for very early warning detection in many applications where the detection of incipient fire conditions is a high priority due to the potential for smoke damage regardless of flaming conditions and the need for early response to limit damage and operations interruption. Examples of these applications include clean rooms, data/communication centers and telecommunication facilities. This appendix discusses the technological basis for early warning capabilities of incipient fire detection systems that use aspiration smoke detectors.

C.1 Characterization of Incipient Fire Growth Stages

The figure below presents a schematic characterizing four stages of a fire and the types of detection technologies that can detect the indicated stage. As a material is heated, it will pyrolize (decompose) and give off a range of particles from invisible to visible. The concentration of these incipient particles will be very low at first and will increase with time and heat buildup. As



***Obscuration (obs/ft)** - Percentage of light decrease per foot due to smoke, dirt, dust or pollutants in an environment.

Adapted from Safe Fire Detection web: http://www.safefiredetection.com

Figure C-1
Depiction of fire growth stages

the process continues, smoldering (non-flaming) combustion can occur and the production of smoke will increase. Depending on the fuel and circumstances, the smoldering source can transition into a flaming fire. This may occur after hours or even days of pre-heating and smoldering. Once a flaming fire, the fire can grow, resulting in additional smoke production and more heat. It is during the latter stages of the flaming fire that the greatest thermal and smoke deposition damage can occur. It should be noted that, once a flaming fire condition occurs, the fire will grow slowly for a time period before developing into an exponential growth rate fire. This period of time of early flaming growth can last tens of minutes. Therefore, if a fire can be detected in the smoldering and pre-smoldering incipient stage, personnel can have hours to respond before an exponential flaming fire occurs.

C.2 Very Early Warning Fire Detection Systems

NFPA 76, Standard for the Fire Protection of Telecommunication Facilities (2005), defines Very Early Warning Fire Detection (VEWFD) as one that detects low-energy fires before the fire conditions threaten telecommunications service. Air aspiration detectors are considered VEWFD devices. A main objective in the telecommunications industry is to provide VEWFD so that personnel can respond to the incident before there is a significant fire that would cause an unreasonable degree of life safety for the occupants, and to protect the telecommunications equipment and service continuity. The benefit of VEWFD is reflected in the requirement that states, “Use of VEWFD systems with a Pre-Alarm condition shall provide for an initial response by authorized personnel prior to fire department notification” (8.4.1.3). Figure A.6.5.1 (NFPA 76) provides a depowering decision tree which demonstrates that with a VEWFD alert, technicians can be dispatched to assess the situation prior to dispatching the fire department or considering suppression. On the other hand, the use of Early Warning Fire Detection (EWFD), e.g., conventional spot smoke detectors, would necessitate immediate notification to the fire department. EWFD is defined in NFPA 76 as systems that use smoke, heat, or flame detectors to detect fires before high heat conditions threaten human life or cause significant damage to telecommunications service. The primary difference between VEWFD (e.g., smoke aspiration detection) and EWFD (e.g., conventional spot smoke detectors or heat detectors) is that VEWFD is capable of detecting low-energy fires (such as smoldering or even overheat events) whereas EWFD addresses larger fires that are approaching high heat conditions.

Typical nominal alarm sensitivity levels for spot detectors are one to two orders of magnitude smaller than for VEWFD air aspiration detectors. Sensitivity of typical EWFD or spot type detectors is measured using percent obscuration per foot. Typical manufacturer default alarm settings are approximately 1.3 %/ft for ionization detectors and 2.5%/ft for photoelectric spot detectors. For VEWFD systems, typical alarm values are on the order of 0.03%/ft. The difference in the alarm set points is only partially indicative of the difference in response times. For detectors covering large areas, air aspiration detectors draw air, incipient particulate, and smoke via multiple holes in a pipe network over the entire area. Therefore, the smoke from a given sample point is diluted by the air drawn from the other sample holes. Consequently, for large area coverage, the aspiration detector must have a lower alarm point to respond equivalently to a spot smoke detector at the same location as an aspiration sample point.

However, the different principles of operation of smoke aspiration detectors (VEWFD) enable these detectors to measure much lower concentrations than conventional spot detectors and therefore, they are more sensitive overall. For all things constant, such as the physical conditions of the room, ventilation and detector location, air aspiration detection will respond faster than conventional spot smoke detection. This is particularly true for a situation where a conventional spot detector is compared to a single hole/limited sample area aspiration detector, such as an air sampling detector covering a single electrical cabinet. The VEWFD is more sensitive to detecting small smoldering smoke sources as well as pre-combustion events, such as the overheating of electrical components or wire that can generate both invisible and visible particulate.

C.3 Manufacturers' Cite Technical Performance and Applications for Aspiration Smoke Detectors

The advantage of very early detection by smoke aspiration systems is commonly recognized by the fire protection community. In the Fire Protection Handbook, Custer and Milke state that

> "invisible aerosols are among the earliest appearing fire signatures and are produced at very low energy levels from the fire. Invisible aerosols can be detected through air sampling systems…or incipient fire detection systems. Larger smoke aerosols can be detected by light-scattering, photoelectric, or ionization detectors." (2007)

One aspiration detection manufacturer reports that their system provides the earliest possible warning of an imminent fire hazard, which buys time to investigate a smoke alarm, take action, and avoid the danger, damage and disruption caused by fire (Xtralis, 2008). Another manufacturer reports that aspirating smoke detection is capable of providing a significantly earlier warning of fire compared to other types of detection technologies. The application of very early-warning aspirating detection systems may often result in fire prevention, rather than fire detection, by alarming during the incipient stage of a fire, before visible smoke and flame. This provides the best opportunity to avoid extended damage or disruption of business continuity (AirSense, 2008). A third manufacturer states their VEWFD system detects the invisible particulate (0.0025 μm) created by thermal degradation, during the incipient or overheating stage of a fire, to provide the absolute earliest warning possible of an impending fire threat (Safe, 2008).

C.4 Experimental Performance of Aspiration Smoke Detectors

Although the performance differences are well accepted, there is limited data in the literature that documents the comparative response times of aspiration and spot detectors. One study was conducted by AT&T (1990) in a 61 x 129 ft telephone switching room with a 12 ft high ceiling. Tests were conducted with different ventilation conditions ranging from 0 to 5 ACH recirculation. As stated in the introduction of this report, the work was being conducted to document the performance of VEWFD compared to conventional spot detectors because of a need to detect pre-flaming fires during an overheat condition or a short/arc in power cables or equipment. It was noted that a government report had documented that most telecommunications facilities fires were a result of these types of initiating events. The results of the study showed that the VEWFD air aspiration system had increased sensitivity and was able to detect sources with smoke generation of less than half that of the smallest source that a conventional detector could detect.

The study is described in more detail as follows. Conventional ionization, photoelectric and laser style air aspiration detectors were evaluated at different spacings from the fire, representing coverage of $200ft^2$ and $400ft^2$ per detector. Alarm levels evaluated were typical of how systems are currently installed: 2.5%/ft for photo detectors, 1.2 to 1.5%/ft for ion detectors, and 0.03%/ft and 0.3%/ft for the laser style air sampling system. Sources included heating various materials on a hot plate, including PVC cable and strips, polyethylene (PE) cable and low density PE strips (LDPE), circuit board laminate and circuit board components. Except for the LDPE, these sources were never flaming and represented the early decomposition stages of overheat events. Small newspaper and isopropyl alcohol flaming fires were also tested as benchmarks. These fires were less than a foot tall; the paper fire extended approximately 3 inches above the lip of the container.

The air sampling system provided the earliest time and was the only system that responded to all 24 test fires. The report concluded that an air sampling system would be needed where very early detection of small overheat or fire conditions as was tested are a concern. The results showed that these fires approached were below the lower limit of detection by the conventional spot detectors. The ion detectors did not alarm to any of the non-flaming fires. The photo detectors did not detect the small flaming paper fire and some of the PVC and PE sources and any of the LDPE sources before they transitioned to flaming. In the cases where spot detectors did alarm, the response times for the air sampling system were generally 2 to 8 minutes faster. However, as described above, the photo detectors did not alarm to approximately one-third of the sources and the ions did not alarm to about two-thirds of them. Therefore, it is not possible to know the maximum potential time in early warning that the air sampling detectors provided in these tests; however, as stated earlier, the air sampling detectors were the only detectors to respond to all fire sources and the other detectors did not. The bottom line of these findings is that the air aspiration provided detection of small incipient fires before flaming conditions, and the spot detectors did not alarm at all in many cases. Therefore, based on the type of sources and the response of the systems, the aspiration systems could be providing hours of alarm notification ahead of spot detectors before a flaming condition ever develops. Or, it can be stated directly that the aspiration system detected fire scenarios that were never detected by the spot detectors.

Kushler et al. (1992) conducted a set of tests to evaluate smoke detector responses to low energy fire conditions in two different telecommunication central office facilities. These sites were of variable size with ceiling heights up to 11.5 ft and different ventilation conditions. Spot-type ion, photo and aspiration detection were installed on the ceiling and between rows of electrical cabinets at the height of the cabinet tops. The sources consisted of pyrolizing strips of cable insulation and circuit board material exposed to a radiant heat source of about 350°W. The spot photo detectors were set at 1.0 and 2.5%/ft. Alarm levels for the ion and aspiration detectors were not reported. The conclusions state that the ceiling mounted ion detectors did not detect the smoke from the smoldering sources. One aspiration system consistently alarmed earlier than the photoelectric spot detectors; the time difference ranged from 0.5 to 8 minutes when both alarmed. In a number of the tests, the photo detectors did not alarm and the aspiration system did. These results again show that there are scenarios that will not be detected by conventional spot detectors but will be detected by air aspiration systems. So although there are some scenarios where the difference in detection times may be minutes, the extra lead time for other fire scenarios may be hours or even infinity.

Recent testing by Hughes Associates that included ion and photo detectors from six spot-type manufacturers and an air aspiration smoke detection system evaluated the detection response to two smoldering fire scenarios. The tests were conducted in a 33 by 33 ft room with an 11 ft high ceiling. Both flat and beamed ceiling configurations were evaluated with no ventilation. One test source consisted of smoldering a 12 x 12 x 4 in. block of polyurethane foam with a 250°W heating element inserted in the center. The second source was a bundle of cross-linked polyethylene cable consisting of 5 pieces, each one foot in length. In the middle of the bundle was a 350°W heating element. The smoke detectors and air sampling points were spaced at 250ft^2 per detector. The spot detectors were set to typical alarm sensitivities, 1.2%/ft for ion, 2.5%/ft for photo. The air aspiration system was set to 0.1 %/ft, which is higher than the other studies reported. Smoldering cable tests were conducted for a minimum of 60 minutes. These tests did not transition to flames.

The results demonstrate the higher sensitivity and earlier detection capability of the air sampling system compared to the spot detectors. None of the ionization detectors responded to any of the 13 smoldering fire tests (i.e., the smoldering foam or cables). Only two of the photo detector models responded to the smoldering fires, and one alarmed in only 45% of the tests. The other four photoelectric systems did not alarm at all. Contrarily, the air aspiration system alarmed in all tests, with an average alarm time of 17 minutes from the time of initial heating of the source. For the majority of smoldering cable tests, the air aspiration system provided 43 minutes or more of early warning than the spot photo detectors. Since most of the spot detectors did not alarm at all, the time difference compared to the air aspiration system would be infinity, given that the sources had generally reached a steady-state condition. The 43 minute difference in detection time between the air aspiration system and the spot detectors noted above is limited to this length only because of the selected 60 minute test termination time. If the tests had been conducted longer, then the aspiration system would have provided even greater earlier warning of the fire scenarios.

C.5 Considerations for Application of Aspiration Smoke Detectors

The test results reported above as well as other industry experience demonstrate that air aspiration detection can provide detection of low energy, non-flaming smoke sources. These sources, such as overheating cables, pyrolizing insulation and circuit board materials, are characteristic of incipient stages of electrical fires. The smaller the space, the greater the certainty of detecting the early stages of electrical fires. For example, detection within electrical cabinets or panels can be made at earlier times and with more certainty than detection on overhead ceiling structures above the electrical equipment (Kushler, 1992). Therefore, knowing that aspiration detectors are faster in a room configuration, providing a system with one or two sample ports in an electrical cabinet would be expected to provide even faster detection times than observed in the previous testing reported above.

The fundamentals of the different detection technology types and the way they are deployed strongly affect their performance in ways beyond sensor sensitivity. These differences should also be considered in crediting incipient fire detection in fire PRA. These performance differences are often the result of the attributes of the protected environment. Some of the relevant environmental attributes and the challenges they present to reliable incipient fire detection are listed Table C-1.

The "cumulative effect" has a distinct advantage for ASD because smoke often spreads through large open spaces such as turbine buildings. When smoke enters two or more sampling holes the dilution of the remaining holes is lessened. In effect, the system becomes increasingly sensitive the more the smoke spreads and enters more holes. ASD provides an excellent measure of the size of the original "packet" of smoke released into the protected space. ASD is preferred over point-type smoke detectors here because measurement of the obscuration in the immediate environment of the point is of little value–it is necessary to know how much smoke has been released and diluted in the larger space. It is for this reason that ASD systems perform so well in the large open spaces of power generation facilities they:

- Become more sensitive the more homogenous the smoke
- Generate alarms earlier than point-type smoke detectors
- Maintain a better perspective on the size of the fire risk in the protected environment, and
- Are less susceptible to nuisance alarms (cf point detectors set to very low alarm thresholds)

C.6 Potential Applicability of Aspiration Smoke Detector to Nuclear Plant Fire Incidents

In order to judge the potential for ASD applications in operating nuclear power plants, the EPRI FEDB was reviewed to identify incidents that could reasonably be expected to have been detected by ASD systems. The scope of the review included the following components that are expected to be effectively covered by and ASD system:

- Components of 250V or less: batteries and battery chargers (bins 1 and 10), electrical cabinets and panels (bins 4 and 15), and air compressors (bin 9)
- Components of 480V or less: cable runs (bin 11), junction boxes (bin 18), electric motors (bin 14), pumps (bin 21), and RPS MG Sets (bin 22)

Only lower voltage electrical components and mechanical components that require a lower voltage power source were included at this time to provide added assurance that prompt fire ignition due to high energy ignition phenomena are not likely. Nonetheless, this factor was considered in the database review. A second factor that was considered involved screening events that were caused by human errors which resulted in prompt fire ignition while the technician that caused the event was still working on the component. A compilation of fire events for components within the scope of review with screening for high energy ignition and human error prompt ignition events that could potentially be detected in the early, incipient stage as discussed above is provided in Table C-2.

The counts for the bins in Table C-2 were compared to the totals (including high energy ignition and human error prompt ignition events) for the components within scope to derive a fraction of incidents that could reasonably be covered by ASD systems. The results are provided below:

- Components of 250V or less:
  - batteries (bin 1) – 0 out of 1 = 0.0
  - battery chargers (bin 10) – 3 of 3
  - Main Control Room panels (bin 4) - 3 out of 5 (2 due to technician error, immediately discovered by technician)
  - electrical cabinets (bin 15.1) -34 out of 35
  - air compressors (bin 9) -4 out of 4
- Components of 480V or less:
  - cable runs (bin 11) – 7 of 7
  - junction boxes (bin 18) – 2of 2
  - electric motors (bin 14) – 5 of 5
  - pumps (bin 21) – 7 of 7
  - RPS MG Sets (bin 22) – 5 of 5

These fractions provide a first order estimate on a generic basis of the fraction of fire events with potential for application of ASD systems to detect fires in their early (and later) incipient stage.

References:

C.1 AirSense (2008), *http://www.airsense.us/Presentations/Stratos_Sales_Presentation.pps#506,8,Aspirating Smoke Detection*.

C.2 AT&T, "In Situ Tests of Smoke Detection Systems for Telecommunications Central Office Facilities," Corporate Fire Protection Engineering, Basking Ridge, NJ, October 12, 1990.

C.3 Custer, R.L.P. and Milke, J.A., "Fundamentals of Fire Detection," Section 2, Chaptaer 6, Fire Protection Handbook, 20th ed., National Fire Protection Association, Quincy, Massachusetts, 2007.

C.4 Kushler, B. D., Parks, L. L., and Simpson, J., "Smoke Detector Behavior Under Low Energy Fire Conditions." International Symposium on Fire Protection for the Telecommunications Industry, New Orleans, LA May 14-15, 1992, pp. 1-14.

C.5 NFPA 76, "Standard for the Fire Protection of Telecommunication Facilities," National Fire Protection Association, 2005, Batterymarch Park, MA.

C.6 Safe Fire Detection, "ProX4, Early Warning Aspirating Fire Detector," Cut Sheet Publication Number 6198625, 2008, *http://www.safefiredetection.com/files/Cut_Sheets/ProSeries_Cut_Sheets/ProX4_Cut_Sheet.pdf*.

C.7 Xtralis (2008), *http://www.xtralis.com/opencms/opencms/system/modules/com.vfsportal/default_bodies/apac/int_en/products_fire_whyvesda.html#false*.

Table C-1
Environmental attributes and the challenges they present to reliable incipient fire detection
Courtesy of Xtralis, http://www.xtralis.com

Environmental Attribute	Detection Challenge	Technology Support
Airflow	Dilution towards low levels of homogeneous smoke.	The cumulative sampling of ASD provides fast response, avoidance of nuisance alarms and an excellent measure of the size of the fire risk. High sensitivity of the detector aids faster response.
Ceiling height	High ceilings create large volumes in which smoke is diluted towards low levels of homogeneous smoke. High ceilings allow smoke to lose thermal buoyancy limiting effectiveness of ceiling detection.	The cumulative sampling of aspirating smoke detection provides fast response and an excellent measure of the fire risk. High sensitivity of the detector aids faster response. ASD enables more flexible sampling below the ceiling to penetrate below stratified layers.
Ceiling Type	Beam intrusions and beam pockets create smoke reservoirs in which detection is required.	Lower cost sampling per reservoir is provided by ASD sampling points.
Airborne contaminants and hazardous fluids	Contamination and corrosion of detector entries and detection chambers limits performance, longevity and availability.	The active sampling of ASD overcomes the variable impedances of contaminated insect screens of point-type smoke detectors. Protected optics on some ASD systems allows long service life, lower maintenance costs and higher availability. Use of ASD pre-filtering and sample-conditioning (e.g., gas adsorption) avoids detector destruction and increases availability.
Temperature	Extremes of temperature cause detector failure.	Use of ASD sample-conditioning (e.g., sample air cooling) avoids detector destruction and increases availability.
Occupancy	High occupancy traffic can cause damage to detectors.	Use of ASD capillary sampling allows placement away from sources of traffic damage.
Accessibility to protected area	Inaccessibility to detectors creates high cost of maintenance and risk of detector failure.	Central placement of ASD detector outside of inaccessible protected areas (e.g., high radiation areas) encourages good maintenance and higher availability.
Fire Growth Rate	Fast fire growth requires fast response to any signs of fire.	The active sampling of ASD overcomes the variable delays of smoke entry into the detection chamber experienced by point-type smoke detectors. Point type detectors typically use algorithms to avoid nuisance alarms which delay fast declaration of fast growth fires.

Table C-2
Fire events database incidents with incipient fire detection applicability

Incident Number	Date	Location	Cause Fire	Detection Means	Ignition Component	Ignition Combustible	Description
Air Compressors							
1014	7/13/1994	Rm 319A Diesel Generator Rm			Air Compressor for EDG 2		Belt overheated produced large amount of smoke but no flame. PCAQ 94-0593.
2119	1/23/1996	Service Building	Electrical Malfunction/ Failure	Maintenance/ Operations Personnel	Compressor	Electrical Wiring	
2305	6/7/1998	Service Building	Electrical Malfunction/ Failure	Control Room Indication (other than alarms)	Miscellaneous Motors ('F' VI Compressor Motor)	Electrical Wiring	Received electrical alarms and VI alarms in control room. SRO/ NLO responded to VI area and Determined 'F' VI compressor motor to be smoking. Secured 'F' compressor motor before fire brigade arrived. PIP OC9802057 issued.
2375	2/19/1999	Turbine Building	Electrical Malfunction/ Failure	Maintenance/Operations Personnel	Compressor	Electrical Wiring	
Battery Chargers							
357	11/27/1982	Battery Room (Control Building)	Electrical Failure	Plant Personnel	Capacitor (Battery Charger)	Insulation (Cable)	Routine surveillance on Nov. 27 revealed that the output voltage of the battery charger was off-scale high and that one of the charger capacitors was on fire. The fire was immediately extinguished. At the time, the other Division 2 battery charger, and the entire Division 1 battery system was operable.

Table C-2 (continued)
Fire events database incidents with incipient fire detection applicability

Incident Number	Date	Location	Cause Fire	Detection Means	Ignition Component	Ignition Combustible	Description
Battery Chargers (continued)							
418	4/28/1984	Switchgear Room (Auxiliary Building)	Component Failure, Electrical Failure, Overheated Material	Control Room Observation, Smoke Detectors	Battery Charger	Insulation	Alarms were received from ground on DC bus #1, low voltage on DC bus #1, and zone 7 east switchgear fire alarm. Locally there was a large quantity of smoke and the halon alarm was sounding. Smoke/fire was seen coming from the Battery charger #1.
2228	6/27/1997	Battery Room	Electrical Malfunction/ Failure	Detection System Alarm	Battery Chargers	Electrical Wiring	
Cable Run							
2	2/7/1968	Auxiliary Building	Electrical Failure		Cable (Thermal Overload)	Insulation	On Feb 7, 1968, a fire broke out in the electrical cables leading to a containment sphere electrical penetration canister. The reactor was safely shut down and the fire was promptly extinguished. The outer bulkhead of the penetration had been forced from the canister shell and the electrical cables, including 45 pressurizer heater cables leading to this penetration outside the containment and 11 cables in the cable tray serving an adjacent penetration, had been damaged by the fire. The cable failure was due primarily to thermally overloaded 480V cables in an area of restricted ventilation. Heating due to power losses in the conductors caused the insulation on the conductors to be subjected to elevated temperatures, causing the insulation to age.

Table C-2 (continued)
Fire events database incidents with incipient fire detection applicability

Incident Number	Date	Location	Cause Fire	Detection Means	Ignition Component	Ignition Combustible	Description
Cable Run (continued)							
3	3/9/1968	Auxiliary Building (Switchgear Room)	Electrical Failure, Design/ Fabrication Error	Plant Personnel	Cable		A fire occurred in 3 overhead cable trays in the 480V switchgear room. The cause of the fire was attributed to underrated cables, overloaded trays, and cable bunching.
4	3/12/1968	Auxiliary Building	Electrical Failure, Design/ Fabrication Error	Plant Personnel	Cable Tray (Overheating)	Insulation	On March 12, 1968 an operator noticed erratic readings on control indicators. At the same time another operator noticed smoke coming from the switchgear room cable trays. He called the fire department and plant employees to fight the fire. The fire department laid hose and extinguished the fire with water fog hose lines laid from inside sea water suction. The probable cause of this fire was long term overheating of the insulation.
181	1/21/1980	Turbine Building	Electrical Failure	Plant Personnel	Self Ignited Cable	Cable Insulation	Small smoldering fire in a cable tray beneath the turbine building operating floor.
510	2/1/1986	Chemical Cleaning Building (Swtchgr Rm)	Overheat Material	Plant Personnel	Cable	Insulation (Cable), Terminal Blocks	Cable heated burning cable insulation and terminal blocks.

Table C-2 (continued)
Fire events database incidents with incipient fire detection applicability

Incident Number	Date	Location	Cause Fire	Detection Means	Ignition Component	Ignition Combustible	Description
Cable Run (continued)							
681	3/9/1988	Control Building (Radwaste Building)	Electrical Failure	Plant Personnel	Cable	Insulation (Cable)	A 480 volt cable on top of the radwaste building roof caught on fire due to a short in the cable. This fire did not affect any safety related equipment. At 1442 EST the fire was put out.
908	7/3/1984	Containment (PWR)	Design/ Fabrication Error	Plant Personnel	Cable		While troubleshooting wiring to a containment sump level switch, personnel discovered a overheated section of cable tray. The cable tray had been protected by a fire barrier system and the buildup of heat inside the barrier led to the thermal degradation.
1140	7/15/1990		E	Fire Detection System	Electrical Cable	Cable Insulation	Halon OOS After Fire.
2425	3/1/2000	Turbine Building	Electrical Malfunction/ Failure	Maintenance /Operations Personnel	Electrical Cable/Wiring	Electrical Wiring	
Electric Motors							
223	10/2/1980	Auxiliary Building	Component Failure	Fire Watch	Motor (Valve)		Local observer noticed smoke coming from valve operator of a sample return inlet valve.

Table C-2 (continued)
Fire events database incidents with incipient fire detection applicability

Incident Number	Date	Location	Cause Fire	Detection Means	Ignition Component	Ignition Combustible	Description
Electric Motors (continued)							
347	10/7/1982	Auxiliary Building (Elevator Equipment	Component Failure, Electrical Failure, Overheated Material	Plant Personnel	Motor (Elevator)	Plastic (Motor Windings)	Control room received call of smoke and possible fire in Aux. Building in area of elevator. Apparent cause of smell and smoke was found to be the motor-generation set in elevator penthouse. Subsequent investigation of MG set by electrical shop indicated MC set was burnt up. (No flames, just smoke).
354	11/11/1982	Control Building (Elevator Equipment)	Component Failure, Electrical Failure	Smoke Detectors (Pyrotronics)	Motor (Electric Elevator)	Plastic (Motor Windings)	"Control Building Trouble/Fire" Alarm in control room on fire panel. Fire team responded and de-energized MG set on CC elevator which was smoking heavily. Ventilated penthouse and maintained fire watch until M.G. set was cool to the touch. (No flames, just smoke).
726	6/11/1988	Reactor Building (Penthouse)	Overheated Material, Electrical Failure, Component Failure	Plant Personnel	Motor (Elevator)		Reactor Building elevator motor was smoking. There were no visible flames. No automatic detection/suppression system available in the fire area.

Table C-2 (continued)
Fire events database incidents with incipient fire detection applicability

Incident Number	Date	Location	Cause Fire	Detection Means	Ignition Component	Ignition Combustible	Description
Electric Motors (continued)							
1509	11/23/1998	Reactor Bldg	Electrical Failure	Plant Personnel	CRDM CoolFan	Motor Insul	CRDM cooling fan 1B motor has insulation damage to motor leads. Replace motor--stock # 38301. Cause direct base "motor was determinated during outage and damaged insulation on leads was identified; motor was reterminated for LOSP test and leads were taped as well as possible, when breaker was closed it tripped and fire blew out of motor - motor was replaced. MPFF since terminated damaged leads rather than repairing or replacing them leads damaged from repeated terminated damaged leads without repairing them.”
Electrical Cabinets							
65	11/4/1975	Switchgear Room	Electrical Failure	Control Room Observation	Bus		Fire caused by bus fault in main auxiliary transformer bay.

Table C-2 (continued)
Fire events database incidents with incipient fire detection applicability

Incident Number	Date	Location	Cause Fire	Detection Means	Ignition Component	Ignition Combustible	Description
Electric Cabinets (continued)							
81	5/15/1976	Auxiliary Building	Electrical Failure	Smoke detectors, security guards	Instrumentation		At 01:45 a minor fire occurred in the hot instrument lab. An electrical short ignited a plastic covering on instruments. A security guard detected smoke and contacted the control room. At about the same time, a smoke detector located in a penetration room tripped, sounding an alarm. Employees responded to the alarm and extinguished the blaze with portable dry chemical extinguishers.
82	6/11/1976	Auxiliary Building	Component Failure, Electrical Failure	Plant Personnel	Breaker		An annunciator was received on HPCI valve overload with a loss of control power. A fire was found in GE breaker BMCC6 for valve 23 MOU16. The breaker was deenergized. The apparent cause was overload.
101	4/4/1977	Auxiliary Building	Component Failure, Electrical Failure	Plant Personnel	Breaker		A coil failed by fire in the breaker for an HPCI test valve. The power was removed from the power board, and the coil was replaced. The power was off for 5 min. The failed coil did not disable HPCI. An operator removed the power to locate the coil failure but could have restored power at any time if required.
125	9/15/1977	Auxiliary Building	Personnel Error		Relay		A fire occurred in a relay cabinet. Improper installation of flammable relay contact arm retainers was the cause of the fire.

Table C-2 (continued)
Fire events database incidents with incipient fire detection applicability

Incident Number	Date	Location	Cause Fire	Detection Means	Ignition Component	Ignition Combustible	Description
Electric Cabinets (continued)							
127	12/10/1977	Diesel Generator Building	Electrical Failure	Plant Personnel	Relay (Panel)	Insulation (Cable)	I & C techs saw smoke coming from a 4160V switchgear panel. The called the Control Room and obtained a CO2 extinguisher. When they opened the panel door flames erupted. They extinguished the fire with the CO2 extinguisher. The panel was de-energized. Inspection revealed 2 burned relays.
131	2/10/1978	Reactor Building	Electrical Failure	Plant Personnel	Breaker		Smoke was noticed coming from the supply breaker. The breaker was tripped which extinguished the fire.
177	12/15/1979	Auxiliary Building (Motor Control Cntr	Component Failure, Electrical Failure		Motor Control Center		Fire at Elev 95' Auxiliary Building by the Rad Waste Panel. MCCs were de-energized and then attack fire with water.
192	3/20/1980	Control Building (Elevator Equipment)	Component Failure, Electrical Failure	Smoke Detectors (Pyrotronics)	Relay (Elevator Equipment)		Received fire alarm. Upon investigating found penthouse area full of smoke. Appeared to be coming from relay rack. Upon entry, smoke dissipated and no visible source of fire could be found. Electrical breaker inside door was opened by first person on scene.
214	7/6/1980	Switchgear Room	Component Failure, Electrical Failure	Control Room Observation	Breaker		Fire involving breaker in switchgear room. Out of adjustment contacts not closing completely.

Table C-2 (continued)
Fire events database incidents with incipient fire detection applicability

Incident Number	Date	Location	Cause Fire	Detection Means	Ignition Component	Ignition Combustible	Description
Electric Cabinets (continued)							
236	12/31/1980	Auxiliary Building	Electrical Failure		Motor Control Center		Fire in 480V M.C.C casing. Minor damage to the associated bus work. This M.C.C normally supplied certain emergency safety features including several containment isolation valves, air coolers, and containment spray valves. The M.C.C. was inoperable for 5.5 hours.
324	5/27/1982	Auxiliary Electrical Room	Electrical Failure		Breaker		Core boring by EMD resulted in water dripping into RCL #13.
353	11/9/1982	Auxiliary Building	Electrical Failure	Plant Personnel	Relay		During routine surveillance, an operator observed a fire in fire detection instrumentation panel 1FP3. Power to the panel was de-energized, and a number of fire detectors were rendered inoperable. Areas affected included the switchgear rooms, battery room, diesel generator area, and diesel fuel storage area. The fire was extinguished and fire watch patrols were immediately established for the areas involved. The fire resulted from the failure of the panel alarm buzzer relay.

Table C-2 (continued)
Fire events database incidents with incipient fire detection applicability

Incident Number	Date	Location	Cause Fire	Detection Means	Ignition Component	Ignition Combustible	Description
Electric Cabinets (continued)							
369	3/12/1983	Control Room	Component Failure, Electrical Failure	Control room Personnel	Relay		Smoke was coming from the control room. Unit 1 received a 1/2 scram as a result of the relay burning and failing in the tripped condition (failed safe). The low reactor water level RPS relays in the 'B' trip system were operable. The cause was found to be component failure. Control room personnel extinguished the burning relay.
484	8/14/1985		Electrical Failure		Off-Gas Panel		Rain water leaked into panel causing a short and fire.
642	11/4/1987	Switchgear Room	Electrical Failure (Breaker Failure)	Fire Watch	Breaker	Insulation on Wire	Fire watch was on routine patrol when an unusual odor was noticed. Control room was notified immediately. Due to their rapid response, major equipment damage to the electrical bus was prevented.

Table C-2 (continued)
Fire events database incidents with incipient fire detection applicability

Incident Number	Date	Location	Cause Fire	Detection Means	Ignition Component	Ignition Combustible	Description
Electric Cabinets (continued)							
660	12/30/1987		Electrical Failure		Transformer		A transformer short burned the control transformer in MCC 27-1. Fire was self extinguishing. A motor Control Center indicating light socket shorted causing an overload on the control transformer resulting in a fire. The fire destroyed the contents of the entire motor control center bay. This resulted in the loss of remote manual control and remote position indication of a standby coolant supply valve. The system remained operable based on the ability to manipulate the valve locally. The fire was detected and reported to the control room due to smoke buildup in the turbine building.
669	2/1/1988	Cable Spreading Room (Auxiliary Building	Component Failure	Control Room Observation	Control Panel (Alarm Card)	Plastic	Series of erratic alarm annunciations were received in the Unit 2 Control Room with the plant operating at 100% power. There was electrical fire in control panel in Cable Spreading Room. The cabinet Halon System had initiated but did not completely extinguish the fire. Carbon Dioxide extinguishers were used to extinguish the remaining fire. The area wide total flooding halon system did not discharge. Detectors did not alarm.

Table C-2 (continued)
Fire events database incidents with incipient fire detection applicability

Incident Number	Date	Location	Cause Fire	Detection Means	Ignition Component	Ignition Combustible	Description
Electric Cabinets (continued)							
670	2/1/1988	Cable Spreading Room	Component Failure	Control Room Observation	Card (Audio Driver)		Fire located in annunciator panels 2K01 and 2K02. The cabinet halon system had initiated, but when the cabinet doors were opened flames were observed on several circuit boards. CO2 was used to extinguish the remaining fire. The fire was centered in a compartment housing five audio driver cards.
891	3/15/1982	Auxiliary Electrical Room	Electrical Failure	Plant Personnel	Relay (DC)	None	Continued operation of a relay rated for use at 120 VDC in a 130 VDC circuit over a period of 5 years resulted in degradation of the relay coil. The relay overheated and "burned-up". The relay failure rendered three reactor trips modes (1 loop loss of flow, 2 loop loss of flow, and RCP bus undervoltage) inoperable from Train A. this incident resulted in a loss of safety system redundancy. LER ABSTRACT: during monthly reactor protection logic testing (PT-5A), reactor trip relay RT-3XA burned up and failed in a nonconservative mode. This rendered three reactor trips (1 loop loss of flow, 2 loop loss of flow and rcp bus undervoltage) inoperable from train a of the reactor protection system, leading to a degraded mode per tech spec table 3.1-1. The rest of Train A and all of redundant Train B reactor protection trips were operable.

Table C-2 (continued)
Fire events database incidents with incipient fire detection applicability

Incident Number	Date	Location	Cause Fire	Detection Means	Ignition Component	Ignition Combustible	Description
Electrical Cabinets (continued)							
891 (continued)	3/15/1982						The relay (Westinghouse BFD 22S) burned up due to overheating. Investigation revealed the relay coil with the same manufacturer's catalog number had a rating of 120v dc versus a 125/130v dc rating of originally installed relays, and thus determined reportable per 10CFR21. All affected relays were replaced with 125/130v dc relays.
935	8/2/1985		Electrical Failure	Control Room Observation, Smoke Detector	Capacitor	Oil	A failing capacitor in a RCIC static inverter caused loss of power in a 125 VDC power feed initiating a trouble alarm in the CR. This was followed shortly by actuation of a smoke alarm indicating in the CR. An operator investigated and found smoke coming from the static inverter. Loss of the inverter caused RCIC to be inoperable and failure of a reactor level indicator which was powered from the inverter. No open flaming was reported.

Table C-2 (continued)
Fire events database incidents with incipient fire detection applicability

Incident Number	Date	Location	Cause Fire	Detection Means	Ignition Component	Ignition Combustible	Description
Electrical Cabinets (continued)							
1030	5/24/1995	Turbine Bldg	Electrical Malfunction/ Failure	Plant Personnel		Relay Coil	ABSTRACT: On May 24, 1995, at 12:49 p.m. Calvert Cliffs Unit 2 was manually tripped from 100 percent power due to the loss of five out of six circulating water pumps (CWP) that resulted from a ground fault inside a non-safety-related motor control center (MCC). The root causes of this event were: (1) plant equipment improperly restored to service; and (2) the assessment of the potential risk to plant personnel and equipment safety was less than adequate. This event did not result in any significant nuclear or personnel safety consequences. Corrective Actions include repair and restoration of the affected MCC, inspection of similar MCCs, strengthened expectations and work practices to increase personnel safety, reduce equipment hazards, and trip potentials.

Table C-2 (continued)
Fire events database incidents with incipient fire detection applicability

Incident Number	Date	Location	Cause Fire	Detection Means	Ignition Component	Ignition Combustible	Description
Electrical Cabinets (continued)							
1039	5/7/2000		Electrical Failure		G-12 Breaker		LER: 338-00-004 From part of the DESCRIPTION OF THE EVENT section: At 0800 hours, Fire contingency action procedure FCA-0, Fire Protections-Operations Response was entered for a fire at the G-12 breaker. The fire brigade scene leader (a licensed operator) responded to the fire at the G-12 breaker. At 0805 hours, the fire was reported out (self extinguished). At 819, the fire at the G-12 breaker re-flashed and the fire brigade was dispatched. At 827 the fire was reported out (self extinguish); however there was still smoke in the area. The fire brigade stayed in the area to monitor for potential re-flashes of the fire.
1053	8/19/1989	Turbine building	E	Plant personnel	Electrical panel	Wire insulation	Shift foreman discovered smoking panel and requested that power be removed. Fire was extinguished with 1 CO2 extinguisher.
1213	2/9/1995	Turbine building	E	Plant personnel	MCC breaker	Transformer	Short in light bulb. No fire equipment used. Equipment was deenergized.

Table C-2 (continued)
Fire events database incidents with incipient fire detection applicability

Incident Number	Date	Location	Cause Fire	Detection Means	Ignition Component	Ignition Combustible	Description
Electrical Cabinets (continued)							
1335	3/3/1992	Switchgear Room	Electrical Failure		Circuit Board		Security was dispatched to area to investigate alarms received on security inverter IKSI. Ernest Bryson of security found smoke in area and some smoke coming out of inverter and notified control room. Power was removed from inverter. Transformers in bottom of KSI appear to have overheated.
2175	6/10/1995	Turbine Building	Electrical Malfunction/ Failure	Detection System Alarm	Switchgear	Electrical Wiring	An operator notices smoke in the TGB switchgear. 29 minutes after operator notices smoke, a fire is reported above the A2 switchgear. The fire brigade attempted to extinguish the fire using Halon, CO2, and dry chemical extinguishers.43 minutes after the initial attempt to extinguish the fire with fire extinguishers, the offsite Fire Department applies water to the insulation above the A2 bus. The degree of damage to the breaker and surrounding equipment indicates that the fault energy of the breaker was extremely high. Due to the extent of the damage during this failure, evidence normally utilized to evaluate the conditions of the circuit breaker was not available. The arc chutes were destroyed, the contact structures were damaged extensively, and the breaker frame and cubicle were also damaged. The main bus and bus compartment experienced severe arcing damage. The center phase (A phase) of the breaker sustained the worst

Table C-2 (continued)
Fire events database incidents with incipient fire detection applicability

Incident Number	Date	Location	Cause Fire	Detection Means	Ignition Component	Ignition Combustible	Description
Electrical Cabinets (continued)							
2175 (continued)	6/10/1995						damage. The right phase (B phase, looking at the front of the breaker) arcing contact was hardly damaged, the middle phase arcing contact was totally destroyed, and the left one (C phase) was partially destroyed. The main contacts on all the phases were destroyed. The fire caused major damage to the #1 & #2 cubicles and destroyed approximately 10 feet of the feeder cables. Cubicle #1 contained the 4160 volt feeder from the Unit Auxiliary Transformer (UAT) and Cubicle #2 contained the Potential Transformer and associated relays and components. There was general smoke and slight heat damage to the exterior of the remaining cubicles in the A2 bus. In addition, there was external heat damage to the jackets of four (4) of the fifteen (15) feeder cables from the Start Up Transformer (SUT) to the A2 bus. There were also burn marks on the conduit of the cables, which supply 6.9 KV to RCP 1A and 2A motors. Although the heat release rate was undoubtedly large (estimated to be much larger than in most switchgear fires), severe damage was limited to two cubicles on the A2 bus and the cables in the UAT A to A2 bus duct. Minor damage occurred to the SUT A to A2 bus duct and adjacent A2 and A1 switchgear cubicles. The B train of offsite power (SUT B to B2

Table C-2 (continued)
Fire events database incidents with incipient fire detection applicability

Incident Number	Date	Location	Cause Fire	Detection Means	Ignition Component	Ignition Combustible	Description
Electrical Cabinets (continued)							
2175 (continued)	6/10/1995						and its bus duct tie to B3) was not affected. The two trains of offsite power are well separated; the bus ducts are physically separated by about 20 feet and a concrete block radiant shield separates the switchgear cubicles themselves.
2227	3/2/1997	Turbine Building	Other (Loose lead on motor starter contact)	Other (Compressor trip / smelled smoke)	Electrical Cabinet	Electrical Wiring	Insul. burned off 1 lead to motor starter contactor & fuse blocks above severely melted. Term. screws loose on starter input terminals. Thermography checks would have identified. Extinguished when de-energized.
2236	10/22/1997	Auxiliary Building	Electrical Malfunction/ Failure	Control Room Indication (other than alarms)	Other (Static Inverter)	Other (Small transformer inside inverter)	
2276	7/6/1995	Auxiliary Building	Electrical Malfunction/ Failure	Maintenance / Operations Personnel	Electrical Cabinet	Electrical Wiring	Breaker failed to open causing too much current to the trip coil. 5 fire brigade members responded to this event. Fire was reported at 0845 and extinguished at 0855. 1 CO2 fire extinguisher was used.
2281	5/14/1998	Auxiliary Building	Electrical Malfunction/ Failure	Fire Watch (continuous)	Electrical Cabinet	Electrical Wiring	Approximately 1440 on 5/14/98 a fire occurred in relay 63X-4 in the unit 1 local waste control panel, 19.5 RAB. At 1454 the fire brigade leader deenergized the panel and the fire was declared out. At 1501 the fire team was secured.

Table C-2 (continued)
Fire events database incidents with incipient fire detection applicability

Incident Number	Date	Location	Cause Fire	Detection Means	Ignition Component	Ignition Combustible	Description
Electrical Cabinets (continued)							
2313	8/16/1999	Turbine Building	Electrical Malfunction/ Failure	Security Personnel	Electrical Cabinet	Other (Circuit board and power supply)	At 14:43 on August 16 1999 a security guard noticed smoke coming from the unit 3 condensate demineralizer control panel 2253-11. Thick grey smoke required the use of breathing apparatus. A power supply in the panel was unplugged to extinguish the fire.
2314	8/24/1999	Intake Structure	Natural Condition	Maintenance / Operations Personnel	Electrical Cabinet	Electrical Wiring	A lightning strike on site caused a fire in a power control center and wooden broom handles stored in the area. The bus supplying power to the control center was de-energized, extinguishing the fire in the control center. The broom handles were extinguished by the fire brigade. The fire was discovered by plant operations personnel while investigating the cause of loss of indication of the 1B screen wash pump.

Table C-2 (continued)
Fire events database incidents with incipient fire detection applicability

Incident Number	Date	Location	Cause Fire	Detection Means	Ignition Component	Ignition Combustible	Description
Electrical Cabinets (continued)							
2336	8/22/1990	Control Room/ Building	Electrical Malfunction/ Failure, possible foreign material	Maintenance / Operations Personnel	MCC	Electrical Wiring	Incident Report Number 1-90-52. While removing Clearance 594741 on HS-P-1B places MCC pan back on bus, closed cubicle door and turned linestarter on. At the local pump controller the operator noted the green 'off' light flickering. When the control switch was placed to the "on" position a loud explosion was heard. Smoke and Flames were seen at MCC 1-12 cubicle B (located in normal switchgear room in the control building). Cubicle door had blown open, MCC had tripped and Control Room noted loss of "F" 480 volt substation. A CO2 fire extinguisher was used by the operator to extinguish the fire. MCC inspection revealed what appears to have been shorted bus-bars. Motor was cool to the touch. Both MCC supply breaker and substation feeder breaker tripped on overcurrent. It is suspected that a piece of foreign material (possibly broken stab spring) was jarred loose when contactor on MCC pan was pulled in resulting in a phase-to-phase short.
2367	12/13/1983	Turbine Building	Electrical Malfunction/ Failure	Not Available	Electrical Cabinet	Electrical Wiring	DRE83-478

Table C-2 (continued)
Fire events database incidents with incipient fire detection applicability

Incident Number	Date	Location	Cause Fire	Detection Means	Ignition Component	Ignition Combustible	Description
Junction Box							
665	1/19/1988	Switchgear Room	Electrical Malfunction/ Failure	Maintenance / Operations Personnel	Electrical Cable/ Wiring	Electrical Wiring	A bad splice in junction box 529 caused an electric fire. A CO 2 extinguisher was discharge and the power was removed from the cabling in the junction box. Cable splice (480 volt) failed in junction box. Electric arc burned hole in cover. De-energized electrical equipment.
745	8/17/1988	Auxiliary System	Electrical Failure (Dissimilar metals)	Smoke Detectors (Ionization)	Cable	Insulation,	Early warning detection alarmed in the control room in the auxiliary building, 752 level. This detection is below the fire area containing the fire source: Smoke travelled down a 4 inch conduit into the control room to set off the detector. Fire discovered inside junction box to fan motor. Aluminum cable connected to copper with single lug. Fan de-energized at breaker.
1369	7/27/1997	Auxiliary Building	Electrical failure	Fire watch	Motor, junction box	insulation	Crimp in insulation on power cables at lug connection. Power cables/insulation burned. Confined to junction box on motor.

Table C-2 (continued)
Fire events database incidents with incipient fire detection applicability

Incident Number	Date	Location	Cause Fire	Detection Means	Ignition Component	Ignition Combustible	Description
Electrical Panels (Main Control Board)							
163	7/12/1979	Control Room	Electrical Failure	Plant Personnel	Resistor		A small fire occurred in the radiation monitoring readout panel for the auxiliary building waste gas system monitor. The readout panel was located on the back panel in the control room. The fire was extinguished immediately by control room personnel using a CO2 fire extinguisher. The readout panel's circuit boards sustained substantial damage and the entire readout panel was to be replaced. The cause was suspected to be an overheated resistor. The radiation monitor was still in service and could be read locally.
480	7/14/1985	Control Room	Electrical Failure, Overheated Material		Resistor		At 0750 hours on July 14, 1985 Waterford 3 Steam Electric Station was at 100 percent reactor power when a reactor trip occurred as result of an electrical fault in the digital electro-hydraulic control panel. The fault was due to an overheated resistor on a solid-state circuit board. The overheating initiated a fire in the control panel which was quickly extinguished by the Halon fire extinguishers. Plant conditions were subsequently stabilized in mode 3.

Table C-2 (continued)
Fire events database incidents with incipient fire detection applicability

Incident Number	Date	Location	Cause Fire	Detection Means	Ignition Component	Ignition Combustible	Description
Electrical Panels (Main Control Board) (continued)							
537	9/4/1986	Control Room (Control Building)	Electrical Failure	Control Room Observation, Smoke Detectors (POC)	Card (Electronic Circuit)	Insulation	Electrical fault in a control room cabinet circuit card creates sufficient heat to ignite insulation and card materials. Extinguished by control room shift superior using portable halon extinguisher.
928	3/1/1989	Control Room	Personnel Error	Control Room Observation	Instrumentation		Maintenance was performed on a solenoid operated Auxiliary Feed- water pump trip/throttle valve. The worker performing the maintenance failed to perform all of the required tests, and in fact, the valves overspeed trip mechanism was misaligned and nonfunctional. A control room operator (CRO) initiated actions to test the valve in coordination with a turbine building operator (TBO). Two attempts were made to trip the valve from the CR. After the second attempt, the Control Room supervisor "heard the noise" (a bussing coming from the CR trip switch) and instructed the CRO to remove the access panel for the switch. The switch was found to be on fire, deenergized shortly thereafter due to blowing of the circuit fuse, and the fire was extinguished using a portable Halon extinguisher. At the same time the TBO noticed smoke coming from the valve solenoid (through no open flaming). The

Table C-2 (continued)
Fire events database incidents with incipient fire detection applicability

Incident Number	Date	Location	Cause Fire	Detection Means	Ignition Component	Ignition Combustible	Description
Electrical Panels (Main Control Board) (continued)							
928 (continued)	3/1/1989						TBO obtained a portable fire extinguisher, but the solenoid stopped smoking when the circuit fuse blew so use of the extinguisher was not required. The duration of the CR was estimated at 1-2 minutes. In addition to damage to the switch, lead wires to two AFW inlet pressure indicators located near the switch were found charred and required repair.
980	3/23/1990	Control Room, back of panel	Personnel error	Plant personnel (CRO)	Pump trip feature bypass switch	Electrical wiring	CRO was changing the light bulb in the "auto" side of the dilution pump #2 trip feature switch. When CRO screwed the new bulb in, he saw a flash. Going to the back of 12XR panel he saw flames from 2 wires on the back of the switch at which time he announced to the control room that there was a fire. GOS grabbed Halon extinguisher and CRO went and got a CO2 extinguisher. Hit fire with 1 shot from Halon extinguisher and then used the CO2 extinguisher. GSS took dilution pump #2 feature switch to bypass and de-energized the ckt. Fire was out.
Pumps							
209	5/21/1980	Turbine Building	Component Failure, Electrical Failure		Motor		The motor shorted out, burning the 1AS gland exhauster. Two maintenance persons put fire out.

Table C-2 (continued)
Fire events database incidents with incipient fire detection applicability

Incident Number	Date	Location	Cause Fire	Detection Means	Ignition Component	Ignition Combustible	Description
Pumps (continued)							
224	10/5/1980	Reactor Building (Containment Drywell)	Overheated Material		Pipe (Steam Lines - Oil)	Oil, Insulation, Hydraulic Oil	Small oil fires caused by oil on the hot main steam lines. Hydraulic oil leak Unit 2 drywell by 1D MSIV.
238	1/24/1981	Auxiliary Building (CCW Pump Rm)	Component Failure	Plant Personnel	Motor (CCW)	Insulation	The motor for component cooling water pump P-52C caught on fire. The motor was stopped, the fire extinguished, and a reflash watch posted. The fire was caused by motor bearing failure from apparent loss of lubricating oil. Cause of oil loss could not be determined. Entire motor was replaced to restore pump operability.
388	6/19/1983	Lake Screen House Pump Room	Overheat Material, Component Failure		Engine (Fire Pump)		Fire pump engine overheated and did not trip (fan belt broke).
1269	8/14/1992	Reactor building	E	Plant personnel	Other pump	Motor	Motor overload condition caused fire.
1362	2/3/1998	Fire Pump House	Other (leaking oil and lagging)	Plant personnel	Fire pump X-05	Anti-freeze	Lagging soaked in antifreeze ignited when fire pump started. Burnt insulation.
1363	2/6/1998	Fire Pump House	Unknown	Plant personnel	Fire pump X-05	Lube oil	Lube oil from pump motor.

Table C-2 (continued)
Fire events database incidents with incipient fire detection applicability

Incident Number	Date	Location	Cause Fire	Detection Means	Ignition Component	Ignition Combustible	Description
Pumps (continued)							
1506	2/24/1998	Serv Wtr Intake Pmphse	Overheated Material	Plant Personnel	Diesel Fire Pump	Fire Pump Engine Gasket	While performing operability testing on unit 2/3 Diesel Fire Pump (DFP) a fire started between the manifold and the valve covers. The prompt investigation claims that the cause of the fire was residual antifreeze on the engine. The FIN team found that a gasket had been blown out where the turbo attaches to the exhaust manifold. The two year PM performed recently should have identified this problem. Therefore this is a maintenance preventable functional failure.
RPS MG Sets							
217	8/8/1980	Auxiliary Building (Control Building))	Electrical Failure	Plant Personnel	Breaker		Electrician smelled something burning and reported the fire to Control Room. Control Room personnel sounded site fire alarm, passed word over PA-location in CRD Equipment Room. Fire was discovered at rear cabinet #5 from smoke, heat. Transfer switch Rod 5, Group 6 was burning. Back panel was opened and CO2 extinguisher used to put out flames. As CO2 was no longer applied, flames reignited. Reactor was tripped removing source of current and fire was again extinguished.

Table C-2 (continued)
Fire events database incidents with incipient fire detection applicability

Incident Number	Date	Location	Cause Fire	Detection Means	Ignition Component	Ignition Combustible	Description
RPS MG Sets (continued)							
557	1/31/1987	Cable Spreading Room (Auxiliary Building	Electrical Failure	Plant Personnel	Circuit Breaker	Circuit Board	Unit is in cold shutdown with no fuel in the core. An RPS M-G set power supply breaker started smoking while a load transfer test was being conducted. The on-site fire brigade was dispatched to the site. At about 0458 the fire brigade opened the smoking breaker and the smoking stopped.
611	7/2/1987	Auxiliary Building	Component Failure	Control Room Observation	Circuit Breaker (Reactor Trip Brkr)	None	During control rod drop testing, plant personnel observed that the rod control demand counter was not indicating. Upon investigation, smoke was observed in the area of the reactor trip breaker cubicle and the control room was notified. The reactor breakers were tripped from the Control Room. Even though the breaker position indicated OPEN, further investigation of the smoke revealed that reac trip breaker B had not tripped. The breaker was finally opened while manually tensioning the closing spring inside the breaker. The breaker was prevented from opening by mechanical binding (the center line lever was found to have a cracked weld where it joins the pole shaft. The time from detecting smoke to de-energizing the breaker was 12 minutes. No open flaming was reported.
656	12/17/1987	Auxiliary Building	Component Failure	Plant Personnel	Rod Drive MG Set		Failure of dry rod drive MG set caused it to burn. Fire alarm failed.

Table C-2 (continued)
Fire events database incidents with incipient fire detection applicability

Incident Number	Date	Location	Cause Fire	Detection Means	Ignition Component	Ignition Combustible	Description
RPS MG Sets (continued)							
720	5/28/1988	Auxiliary Building (Elevator Penthouse	Component Failure, Overheated Material	Plant Personnel	Motor (Elevator)		At approximately 7:55 a call was make to the Shift Foreman's office to report the existence of smoke on Auxiliary Building. Mike went up to the penthouse to further investigate the problem. When he opened the door to the penthouse, he saw flames and smoke coming out of the M.G. set. He quickly turned the power off, and the fire went out. There was not automatic detection/suppression system available in the fire area.

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