Limitations Imposed on Fire PRA Methods as the Result of Incomplete and Uncertain Fire Event Data

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Abstract: Fire probabilistic risk assessment (PRA) methods utilize data and insights gained from actual fire events in a variety of ways. For example, fire occurrence frequencies, manual fire fighting effectiveness and timing, and the distribution of fire events by fire source and plant location are all based directly on the historical experience base. Other factors are either derived indirectly or supported qualitatively based on insights from the event data. These factors include the general nature and intensity of plant fires, insights into operator performance, and insights into fire growth and damage behaviors. This paper will discuss the potential methodology improvements that could be realized if more complete fire event reporting information were available. Areas that could benefit from more complete event reporting that will be discussed in the paper include fire event frequency analysis, analysis of fire detection and suppression system performance including incipient detection systems, analysis of manual fire fighting performance, treatment of fire growth from incipient stages to fully-involved fires, operator response to fire events, the impact of smoke on plant operations and equipment, and the impact of fire-induced cable failures on plant electrical circuits.

Keywords: Fire, PRA, event data, event analysis.

1. INTRODUCTION

Data and insights gained from actual fire events have been used in fire probabilistic risk assessment (FPRA) since the earliest applications of these methods. Event data were also a key element of pre-PRA methods such as non-quantitative fire hazards assessment (FHA). For FPRA applications, the most common examples of event data usage are in the estimation of fire occurrence frequencies, manual fire fighting effectiveness and timing, and the distribution of fire events by fire source and plant location. Other factors derived indirectly or supported qualitatively based on insights gleaned form the event data include the general nature and intensity of plant fires, operator performance, and fire growth and damage behaviors.

Currently, the Electric Power Research Institute (EPRI) fire event database (FEDB) [1] is the most commonly applied source of event data for U.S. nuclear power plant (NPP) applications. This database was used in support of the current consensus FPRA method [2] and earlier methods such as *FIVE* [3] and the *EPRI FPRA Implementation Guide* [4]. Limitations to the source data mean that various database fields cannot be completed for most of the known fire events. For key events, the database authors have attempted to fill in missing information through direct interaction with the reporting entity (e.g., the NPP at which a fire occurred) and by incorporating supplemental event information including NRC public records as available.

Ultimately, the reporting of most fire events is voluntary for the U.S. commercial nuclear power industry. Reporting is only required by the industry regulatory authorities, the U.S. Nuclear Regulatory Commission (NRC), when an event meets specific criteria as defined by each NPP's Emergency Alert Levels (EAL). The NRC provides guidance for licensees to assist in defining the

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EAL [5]. Once defined, a fire that satisfies the NPP's EAL is reported via the Event Notification (EN) and/or Licensee Event Report (LER) processes. In general terms, these processes capture the more significant fire events and, in particular, any fire events that actually did cause damage to plant safety systems. These processes will not, however, capture the majority of fire events that are of potential interest to FPRA. The insurance industry also has reporting requirements, but those are generally tied to factors of interest to the insurer (e.g., loss value, claim status) and not risk analysis. The main collection point for voluntary event reporting for over two decades is a database maintained by Nuclear Energy Insurance Limited (NEIL). The NEIL database has served as the primary basis for the last three updates to the EPRI FEDB.

Several factors contribute to the known gaps and shortcomings in the fire event data. One factor is that, because reporting is voluntary, not all plants participate in the NEIL reporting system. A second factor is that while the NEIL reporting system includes a "nuclear supplement" reporting form specifically designed to gather information of interest to FPRA, that form is rarely completed. A third factor is that even when a fire event is reported, the completion of the various data fields is inconsistent and often incomplete.

The lack of more complete and consistent fire event data placed limitations on the extent to which the consensus FPRA method [2] could refine the recommended analysis approaches. That is, lacking any basis for more refined treatments, FPRA methods continue to rely on approaches that are less sophisticated and potentially more conservative than is generally thought desirable. Various aspects of the PRA method could benefit greatly from better fire event reporting. This paper will discuss the potential methodology improvements that could be realized if more complete and consistent fire event reporting information was available. The paper will also discuss the corresponding information needs that would support each potential improvement.

A memorandum of understanding (MOU) exists between the NRC Office of Nuclear Regulatory Research (RES) and EPRI that allows for collaboration between these agencies on research topics of current interest. An effort is currently underway as a part of the MOU to improve the scope and quality of the available fire event data. One goal of this effort is to address many of the topics that will be discussed, although some elements will still remain beyond the scope of the planned short-term data improvements. The summary section provides further discussion on this subject.

2. FIRE IGNITION FREQUENCY

One of the earliest and most direct applications of fire event data is in the calculation of fire ignition frequencies. While methods have been refined considerably, the basic reliance on event data continues and will likely continue for the foreseeable future. This section will discuss four topics related to data quality and the calculation of fire ignition frequencies; namely, assessing the risk-relevance of specific fire events, assigning each fire event to a specific fire ignition source group (or bin) and/or location, incomplete participation by plants in the reporting process, and identifying frequency trends over time.

2.1 Assessing the Risk-Relevance of Reported Fire Events

In the consensus FPRA methodology [2], considerable effort went into defining which fire events are actually relevant to the ignition frequency calculations. That is, there are certain types of events that are reported as fires that are not really relevant to the FPRA. This can include, for example, fires that occur in portions of the licensee controlled area that are not risk-relevant (e.g., office building and warehouse fires) or that occur during plant construction. This can also include "fires" that had no potential to generate the sort of fire scenarios that are postulated in a FPRA. Examples here might include smoldering cigarette butts found outside the door to a plant building or a "smoked component" which might simply be a failed or overheating component with no actual burning. The ability to sort the risk-relevant fires from those that are not risk-relevant is especially dependant on the completeness of the event reports.

The risk-relevance classification scheme applied in the consensus methodology identified each fire event as “non-challenging,” “potentially challenging,” or “unknown.” These definitions translate, roughly, to “not risk-relevant,” “risk-relevant,” and “risk-relevance undetermined” respectively. As of 2005 when the consensus method was published, the FEDB contained roughly 1400 fire events. Of these, roughly 42% were classified as potentially challenging and 34% were classified as non-challenging. The remaining 24% were classified as unknown.

The events classified as “unknown” typically provided exceedingly terse event descriptions and mostly blank database fields. Often, a single sentence was provided stating that, on a certain date a fire occurred, perhaps with a plant location specified and possibly with a statement that the fire was “quickly suppressed.” Nominally one might presume that if the event had been of significance, more information would have been provided. However, no basis for this presumption has yet been established and FPRA needs to look at event relevance in a rather specialized way. Even a statement that a fire was quickly suppressed is not enough to conclude that an event is not risk-relevant because the FPRA may consider similar fires under alternate circumstances where prompt suppression might not occur. In the development of FPRA scenarios, a range of alternative circumstances are considered for fires that are similar in nature to those reported in the event database but that may occur at a different plant or plant location where different fire protection systems and features, configurations of nearby flammable materials, and proximity to FPRA targets might be observed. Overall, a lack of information is not sufficient to dismiss an event as not risk-relevant.

For the consensus method, “unknown” events were treated statistically in the fire frequency analysis by counting them as a half-event each. This is equivalent to assuming that if complete information were available, half of the unknown events would have been called potentially challenging and the other half would have been called non-challenging. Given this approach, the unknown events represent roughly 22% of the total event count used in the frequency calculation $[(1/2*24)/(42+(1/2*24)) \approx 0.22]$, although that fraction may be higher or lower for any individual grouping of ignition source as used in the fire frequency analysis[2].

A definitive resolution of the unknown events would have two effects on fire frequency estimates. First, it would likely have a modest impact on the final fire frequency point estimate values (either up or down) depending on the ratio of potentially challenging to non-challenging determinations. Second, it would substantially reduce the uncertainty associated with this key input parameter.

The principal strategy for reducing the number of unknown events for the events already identified in the FEDB would be to seek out additional information. This is a viable option for key ignition sources where the unknown events are of particular importance (e.g., an ignition source group where the majority of the events contributing to the total event count are “unknowns”). However, this sort of information gathering is a time-intensive activity with sharply decreasing likelihood of success for older events given that both corporate and individual memories are lost over time. Overall, it is not practical to attempt to fill in the missing information for the 300-plus fire events in the current FEDB that were identified as unknowns.

The more viable approach is to focus on improving future fire event reporting where the need could be readily met given more complete and consistent reporting of fire events. If we can improve the quality and completeness of event reporting in the future and once the new data has reached a level of statistical significance we would be less reliant on, and could likely abandon, the less complete older data. This particular improvement to the fire event data is actually quite straightforward. All that is really needed here is a more conscious effort on the part of the reporting party to provide more complete reports on each fire incident and to make that information available for compilation into the FPRA fire event database. Even a more complete narrative description of the event being reported

[2] For example, the consensus methodology defines 37 ignition source groups or “fire frequency bins” – see Reference 2, Table 6-1.

would largely resolve this particular need provided the narrative included items such as the nature of the ignition source, the means and timing of detection and suppression, the extent of any fire spread or damage if any, and the impact of the fire on plant operations. For example, even given the existing FEDB, a definitive classification of the fire events was always possible provided the report included a reasonable paragraph describing the fire event even if the data fields themselves were largely blank.

Current efforts to update and improve the FEDB are specifically targeting this area. These efforts are discussed in the Summary section below.

2.2. Grouping the Fire Events by Source and Location

The FPRA approach defines and analyzes fire scenarios that might occur at key locations in the plant. Each fire scenario is accompanied by a fire ignition frequency and the accuracy of the scenario-level fire frequency is a key driver to the overall accuracy of the FPRA. One of the challenges in the analysis of the event data is to parse the fire events into groups of similar fire ignition sources which were called "fire frequency bins" in the consensus methodology [2]. Ignition source groupings are generally defined either based on the object which initiated the fire or based on the fire location. Parsing by location is generally reserved for key plant locations such as the main control room (MCR). Most fires are parsed based on the initiating object.

Ideally, it would be desirable to define many highly specific ignition source groups. This would allow for a far more case-specific characterization of fire frequency. Unfortunately, our ability to parse the fire events is limited by the availability of information on the nature of the initiating object.

To illustrate, consider that fires in electrical cabinets are one of the most common fire risk scenarios analyzed in a FPRA. Historically, electrical fires are the single most common class of fires for the nuclear power industry, and electrical cabinets are one of the most numerous and widely distributed fire ignition sources in a typical plant. Hence, electrical cabinets tend to play a significant role in the overall FPRA.

The generic designator "electrical cabinet" encompasses everything from low-voltage instrument racks to medium-voltage power distribution and switching cabinets. It seems reasonable to assume that fire frequency for an individual electrical cabinet would depend on the cabinet characteristics. Key factors impacting fire frequency would likely include cabinet function (e.g., instrument signal conditioning versus power switching), the density of components inside the cabinet, the maximum voltage level contained within a cabinet, and the current or power level passing through a cabinet. In the current FEDB a typical report may cite that a fire occurred in an electrical cabinet but it is unlikely that the cabinet characteristics will be provided in substantive detail. The most common information provided is to identify the involved cabinet in relatively broad function terms (e.g., control cabinet, switchgear cabinet, motor control center, etc). This type of functional identification appears to be provided in particular when that information is germane to some other aspect of the event. For example, a cabinet might be identified as an "electrical distribution panel" if the fire resulted in loss of a power bus. Rarely a specific description is provided (e.g., 480VAC motor control center).

Overall the majority of cabinet fire events provide little information upon which to bin the cabinets by type. While a subset of the events can be parsed along functional lines, the majority of the events cannot. As a result, most of the electrical cabinet fires were grouped into a single fire ignition source bin (with the exception of high energy arc fault events and those events occurring in the main control board). The ignition source counting and fire event partitioning approach assumes that electrical cabinet fire events will be distributed evenly among all electrical cabinets. The source counting is based on the number of "distinct vertical sections" with no distinctions made for cabinet type, function, or any other characteristic.

This is, again, a relatively straight-forward data completeness issue that could be readily resolved by more complete event reporting. In the specific case of electrical cabinet fires, reporting of the ignition source characteristics including the cabinet type, cabinet function, and internal voltage would allow for a far more refined parsing of that event set. The information would be needed for a sufficient fraction of the total event set so as to provide confidence that those events where cabinet type is not known do not dominate the total data set. Again, because tracking down supplemental information on older events is generally not practical, this aspect of the fire frequency analysis will likely not improve until several years' worth of complete event data has been gathered.

2.3 Incomplete Participation by Plants in Voluntary Reporting Processes

It is often observed in the analysis of the fire event data that the vast majority of events in the FEDB have been reported by a minority of the U.S. NPPs. Given the general age of the U.S. nuclear plant fleet, it is unlikely that any plant in the country has never experienced a fire. While it is possible that one or more members of the U.S. NPP fleet has never experienced a reportable fire based on NRC reporting requirements, it is likely that essentially every plant has experienced one or more minor fires over the course of their operating lifetime that would be of interest to FPRA.

The fact that roughly half of the U.S. fleet is not represented at all in the current FEDB would tend to indicate some degree of under-reporting in a strictly statistical (not regulatory) sense. As noted above, even a minor fire event can be relevant to FPRA ignition frequency because FPRA specifically postulates fires similar to those included in the FEDB that might occur under circumstances where a minor fire might grow into a more significant fire. Hence, the apparent statistical under-reporting of fires could mean that fire frequencies are also being under-estimated to some degree. This effect could be partially or fully offset by other refinements (e.g., by the resolution of unknown events as discussed in Section 2.1 above) so the net effect of more complete participation in the voluntary reporting system cannot be predicted with confidence.

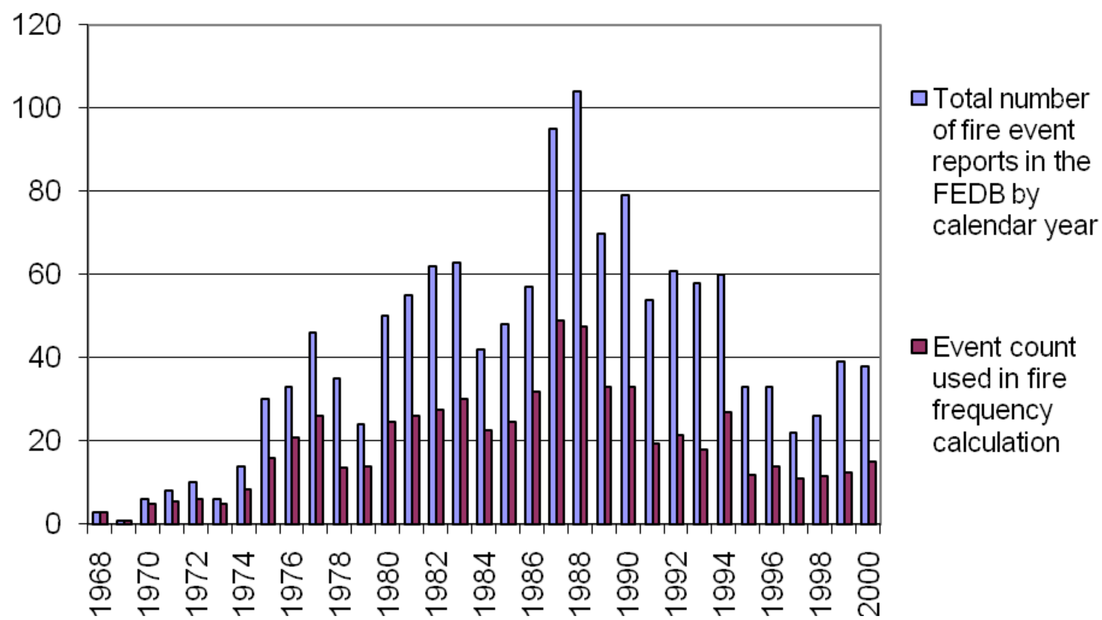
Fire event reporting requirements are unlikely to change in the near future. Hence, fire reporting for most events will likely remain voluntary. It will take a concerted effort by those industry analysts who are interested in improving FPRA methods to encourage their colleagues to contribute to the FEDB. With more complete participation in event reporting we can likely gain more robust statistics and qualitative insights supporting a wide range of FPRA needs.

2.4. Frequency Trends

Another aspect of the fire frequency estimates is the analysis of industry trends. It would be desirable to reflect industry trends in the calculation of fire frequencies, but this is actually a relatively challenging task. Figure 1 provides a simplistic representation of the fire event data as analyzed in the consensus FPRA methodology. This chart plots the total number of fire event reports contained in the FEDB and the total event count that was ultimately used in the fire frequency calculation. To put these plots in some perspective, the total event count includes all fire event reports including those ultimately deemed to be non-challenging or not risk-relevant. The fire frequency count reflects the results of the event screening process as described in Section 2.1 above (total number of potentially challenging events plus ½ the total number of unknown events). Both plots are for the "all fires" category (i.e., the events have not been parsed based on either fire source type or location). Also note that these counting values have not been adjusted to reflect operating experience (i.e., they are a raw count of events per calendar year for the U.S. industry as a whole, not events per reactor year as typically used in FPRA). Unfortunately, a simplistic look at the fire data does not tell the entire story relative to fire trends. A number of factors need to be considered when validating an apparent trend in fire frequency.

One factor to consider is that fire frequency trends should have some explanation. That is, changes in the rate of fire events should generally result from actual changes taking place in industry that would act to either increase or decrease the frequency of fires. For example, one factor that would be expected to reduce the rate of fires is a general decrease in the rate of 'infant-mortality' type equipment failures and fires as the U.S. NPP fleet matures and such failures 'wash out' of the experience base. Other factors such as a heightened awareness of the importance of fire safety throughout industry, improvements in plant maintenance and housekeeping, and general improvements in fire protection systems and features might all lead to a general reduction in the rate of NPP fire events. However, each of these factors would be expected to have a gradual effect on fire frequencies and would not generally explain the abrupt change in the rate of fire events that appears to occur between 1994 and 1995 based on Figure 1. All of these factors are likely in play, but alone cannot explain the apparent abrupt change in the annual number of reported fire events.

Figure 1: Illustration of the fire event reports contained in the FEDB by calendar year.



Likely there are other factors in play that are also might impact the rate of certain types of fires while not impacting other types of fires. One factor that cannot be ignored is the potential impact of reporting guidelines on the rate of fire event reporting. That is, changes to reporting guidelines could impact the rate of fire event reporting while not impacting the actual rate of fire events. The insurance industry (e.g., NEIL) has its own reporting criteria and the authors are not conversant in the evolution of those criteria over the past 3-4 decades. In the case of the NRC, reporting guidelines have changed a number of times over the past three decades [5]. An NRC staff analysis [5] concluded that "Although the criteria for reporting fires has (sic) changed, licensees are not required to adopt the new criteria, nor are they, or were they ever, required to inform the NRC that they had not adopted the new criteria. … After reviewing the documents and the criteria outlined in each, it was concluded that none of the reporting thresholds were significantly different enough to have an impact on this report or skew the data in a measurable way." This staff analysis has examined EN and LER reports from 1999-2008 and concluded that there was no statistically significant trend evident in the rate of such reports over that time period. The staff has not yet analyzed older event reporting data so it is not clear whether or not the sharp change noted in the EPRI FEDB is also reflected in the number of EN and LER reports over the same time period. Regardless, the event reporting practice should be dealt with as a potential factor in any trend analysis.

The point to be made here is that any fire frequency trend analysis will be complicated by the need to consider a range of factors, each of which could lead to real changes in the rate of fire event occurrence or to apparent changes in the rate of fire events that are actually changes in the rate of event reporting not the rate of actual fires. Any given factor might influence fires of a particular type, or might have a more general impact on fire frequencies by impacting a broader range of potential fires. Regardless, a fire frequency trend analysis should be able to explain the observed trends. The question of fire frequency trends could be pursued with greater confidence if we had greater confidence in the FEDB itself. That is, if the database were more complete, and if more plants participated in voluntary reporting of even minor fire events, it would be possible to track fire frequency trends not only for industry as a whole, but for various specific fire ignition source types where an upward or downward trend might be anticipated based on changes observed or implemented by industry and its suppliers.

3. FIRE DETECTION AND SUPPRESSION

3.1 Incipient Fire Detection Systems

One developing area of technology is very early warning, or incipient, fire detection systems. These systems provide a means to detect the early signs of material or equipment degradation well before an actual fire occurs. For example, a failing electrical component will often experience an initial period of overheating followed some minutes, or even hours, later by actual failure and ignition of a fire. A properly designed and installed incipient detection system could detect up early indications of such behavior providing an alert well in advance of an actual fire.

The consensus FPRA method provides no treatment for incipient detection systems due to, essentially, a total lack of experience-based data. Incipient detection systems remain somewhat rare in the U.S. nuclear power industry, but their popularity is increasing and new systems are currently being installed by at least two utilities. These systems have been used more widely in other industries with apparent success (e.g., aerospace applications). It is likely that more and more such systems will be installed in commercial NPPs as time goes by. The primary applications appear to be in those plant locations that the FPRA indicate are dominant contributors to fire risk.

As an interim measure, the NRC has accepted an analysis approach that adjusts the fire frequency downward for those types of fires for which an incipient detection system is expected to provide early warning [6]. The interim approach is considered acceptable for now because the current fire frequency statistics reflect plant experience in the absence of such systems. However, moving forward in time, as more incipient detection systems are installed then their impact should be reflected as a general decrease in the occurrence rate of certain types of fires; namely, those fire types that are amenable to early detection.

The challenge moving forward will be to apportion the credit for incipient detection systems to those locations that actually have such systems installed rather than over the entire population of, for example, electrical cabinets. If FPRA continues to rely on the interim solution then, in effect, the fire event statistics for plants lacking incipient detection systems would be artificially reduced by the prevention of fires at plants that have the systems installed. The continued application of the interim solution will be effectively double counting the beneficial effects of the incipient detection systems and would therefore become less acceptable over time.

A long term approach to the treatment of incipient detection systems in FPRA will hinge on the gathering of critical performance data for these systems. The challenge will be to, in some manner, record and track those "fires that never happened" because an incipient detection system alerted plant operators to a potential fire and action was taken to resolve the situation before a fire broke out. The current FEDB is a poor choice for this aspect of data gathering because that database is designed to record actual fire events, not "non-fires." An alternate approach to performance data gathering is clearly needed.

In this case it is likely that those utilities that are installing these systems will need to develop their own performance tracking data, perhaps in concert with system vendors, for use in future FPRA updates. In particular, it would be prudent for a utility that wants to take full credit for their systems to track performance in order to establish a longer-term basis for crediting these systems in their FPRA. Performance indicators that would be helpful to track would include overall system reliability indicators (e.g., system down time, equipment failures, repair times, etc.), system actuation experience (regardless of cause), personnel response to system actuations, findings relative to actuation investigations, clear documentation of cases thought to have involved a prevented fire, and the local incidence of fires in both protected and unprotected plant locations (as a basis for comparison). These factors would provide a basis for a longer term solution to the incipient detection credit.

3.2 Manual Fire Fighting

Another key element of the FPRA that has long relied on fire statistics is the crediting of manual fire fighting effectiveness and timing. The approach used in the consensus methodology was intended to be an evolutionary step forward as compared to past practice, but in application, has not worked as intended. The consensus methodology's approach was to lump all of the fire suppression time data into fire suppression groupings (or bins) that are similar to the fire frequency groups, but organized at a somewhat less detailed level. Using the fire suppression time data, curves of the probability of non-suppression versus time were developed for each suppression group. These curves are documented in Appendix P of Reference 2. The intent was that the analyst would calculate the time from ignition to detection, the time from detection to fire brigade response, and then would apply the fire suppression curves to define a likelihood distribution for the total fire duration.

Unfortunately the application of this approach has had unintended consequences. In particular, the approach tends to give little or no credit to fire suppression in the first 10-15 minutes of a fire when the fire event data clearly show that many fires are extinguished within minutes of discovery. The flaw in the approach is two-fold. First, the fire suppression time[3] data are incomplete. In the absence of a specified fire suppression time, the total fire duration was used in the data analysis. Second, the approach provides inadequate treatment of early fire suppression by personnel other than the plant fire brigade. An explicit credit is given for a posted fire watch, but many fires are suppressed by general plant personnel who happen upon a fire during its early stages.

An interim approach has been developed that provides a continuous fire suppression credit beginning at the time of detection rather than the time of fire brigade arrival at the fire scene. This analysis uses the fire duration data exclusively. A companion paper (see Hyslop and Nowlen) at this conference discusses this interim solution in some detail, and provides a discussion of potential future developments in manual fire fighting response modeling. The reader is referred to the companion paper for a further discussion of related data issues and needs.

4. FIRE GROWTH AND DAMAGE BEHAVIORS

4.1 General Fire Growth and Damage

Another logical area where FPRA could likely benefit from better event data is in the area of fire growth and damage. In particular, it would seem logical to assume that fire events would at least provide qualitative, if not quantitative, insights into the timing of fire growth and damage to plant equipment. This is, however, an especially challenging area of analysis in part because of the way that FPRA treats the analysis of fire scenarios.

FPRAs will generally decouple the fire growth and damage analysis from the fire detection and suppression analysis. The typical approach is to first analyze the fire growth and damage behavior assuming no intervention in the fire by either fixed or manual suppression. The analyst then independently assesses the likelihood that fire suppression measures would succeed within a specific

[3] Suppression time was defined as the time actually spent by fire fighters on the scene suppressing the fire. That is, the time from first response to suppression.

time period; namely, before key FPRA damage targets (typically cables and equipment) are failed by the fire.

In contrast, as a general rule and with a few exceptions, most fires are attacked aggressively by plant personnel upon discovery. As a result, fire events provide few insights into what might have happened had a fire not been attacked aggressively; i.e., insights into the validity of the FPRA fire growth and damage analysis. Any analysis of the fire event data in this context must recognize this key difference.

That said, the current fire event reports provide few insights of value to this aspect of the analysis. Event reports rarely provide details as to the extent of fire growth and damage, especially for those fires that remain relatively small and/or that are suppressed quickly. Generally the event reports provide information at both ends of the growth and damage extremes. That is, many fire reports will state that there was no spread of fire beyond the initiating object and in the case of much rarer large fire, the extent of fire damage is often well characterized. What is lacking is a description of fire growth and damage behavior for the vast majority of relatively minor, quickly suppressed fires where some fire spread or secondary damage may or may not have been observed. If the event reports were more complete in this regard, then it might be possible to begin benchmarking the models that are use to predict fire growth and the extent of fire damage over time.

4.2 The Role of Smoke in Fire Events

The old saying goes that "where there's smoke, there's fire." In the case of the NPP and the types of fuels that are typically present, it is quite accurate to turn this statement around saying "where there's fire, there's smoke." Electrical equipment, cables, oil and transient fuels (e.g., trash fires) are all typically associated with prodigious smoke generation. An often debated but poorly understood question is what impact smoke has on fire response. In general, smoke has three potential impacts of interest.

First, smoke may complicate the response of fire fighters. If fire fighters cannot find the fire, then they cannot effectively fight the fire. This could delay fire fighting response and some FPRA analyses have speculated that fire fighters unable to locate the source of a fire might even spray water on the wrong equipment leading to additional equipment failures.

Second, smoke in sufficient quantities may cause damage to exposed plant equipment. It is well known that smoke left on equipment long-term can be highly corrosive and damaging. However, FPRA is specifically concerned with short-term equipment failure and generally not with long-term failures (long-term failures would be captured in general equipment reliability and failure statistics). Testing of electronic equipment has demonstrated that smoke deposition in sufficient quantities may cause short-term failure [7]. Experience has also shown that smoke can cause circuit bridging and shorting in high voltage equipment [8]. The vulnerability of medium voltage equipment to smoke induced failure is less certain, but some anecdotal evidence is available indicating that this potential does exist.

Third, smoke may complicate operator responses to the fire. In certain fires both in the U.S. and abroad, smoke intrusion into the MCR has complicated or compromised operator habitability and performance [8]. FPRAs typically assume that operators will be unable to enter a fire-impacted fire area to perform any recovery actions until well after a fire has been extinguished.

While fire reports will sometimes note smoke conditions in passing, they rarely focus on smoke as a substantive element of the fire event. This makes it difficult to quantify the impact of smoke in any one of the three impact areas noted immediately above.

4.3 Cable Failure Modes and Effects

One difficult issue for FPRA analyses is the treatment of cable failure modes and effects. In particular, the event data, both in the U.S. and abroad, clearly demonstrates the potential for the spurious actuation of plant equipment and systems as the result of fire-induced cable failures [8]. Testing over the past 10 years has also confirmed this potential [9-11]. One of the early efforts to develop FPRA methods to deal with potential spurious actuations performed an analysis of certain circuits that were damaged during the 1975 Browns Ferry fire and that reportedly experienced spurious actuations [12]. These analyses did confirm that relatively simple conductor-to-conductor short circuits within certain control cables did indeed hold the potential to induce the observed spurious actuations. Kazarians and Nowlen [8] report a handful of additional events where fire-induced spurious actuations are reasonably well documented.

However, as a general rule little attention is paid to the impact that cable failures have on plant systems and performance. In reality, fires that lead to cable damage are relatively rare, most fires being suppressed before they reach such stages. However, in those cases where cables have been damaged it is rare to see any concerted effort made to determine exactly how plant systems responded and then to follow up with failure modes and effect type analyses to determine the cause of the observed behaviors. Even cases where cables were damaged and spurious actuations did not occur are of interest.

Additional attention to events in this regard would likely provide both qualitative and quantitative insights that could be incorporated directly into FPRA. For example, high levels of uncertainty are currently assigned when predicting the conditional probability of spurious actuation given cable failures. If efforts were made to seek specific electrical and physical configuration information for failed cables, and to trace the root cause of observed circuit faults, the actual events could lead to substantive refinements in the current circuit analysis methods.

5. OPERATOR PERFORMANCE

The final area of interest to be discussed in this paper is operator response to fire events. In fire PRA, this aspect is treated via Human Reliability Analysis (HRA) techniques. HRA typically identifies potential Human Failure Events (HFEs) which are built into the plant response models. These HFEs are then quantified based on a Human Error Probability (HEP). HRA is a rather specialized field of study in general, but especially so for fire HRA. HRA in general applications considers factors such as stress levels, training, operating procedures, etc., in assessing HEP values. Fires introduce additional complications whose impacts are poorly understood. These include the potential added stress associated with fires in general, the potential loss or unreliable operation of plant control and instrument systems, uncertainties relative to the plant and fire status at any given time, reliance on plant procedures that may be less familiar to operators, and the potential need to implement operator actions at locations other than the MCR (up to and potentially including abandonment of the MCR).

In general practice, HRA methods can draw insights from other industries and applications. This is more difficult in the case of NPP fires. One key difference between a NPP fire and a typical industrial fire is that in the plant staff is expected to continue safe shutdown operations in a NPP whereas the primary concern in an industrial fire is safe evacuation of personnel. Hence, fire HRA faces a unique challenge when attempting to gain insights from other applications. As a result, fire event reports specific to the nuclear power industry are a potential source of information that would support the development and benchmarking of fire HRA methods. Unfortunately, few fire event reports focus attention on operator performance.

6. SUMMARY

This paper has discussed a number of areas where FPRA methods could benefit from more complete reporting of even minor fire events by the nuclear power industry. This includes providing more complete information for fires that are reported and more complete participation by plants in the voluntary event reporting processes. Improvements in any of the areas cited would help to both refine point estimates of fire risk and to reduce the uncertainty in those risk estimates. Given incomplete information, the current FPRA methods are forced to rely on methods that are less sophisticated than they could be, and that are potentially more conservative than necessary. However, the methods cannot simply be relaxed without a firm basis or important risk scenarios could be missed. The key to the improvements is reasoned and well-based refinement of methods to more closely reflect the reality of plant fires.

Currently, an effort is under way to improve the U.S. NPP fire event database. The effort is being conducted in collaboration between the U.S. NRC/RES and EPRI. The first goal of this effort is to improve the quality of the fire event reporting. The second goal is to increase participation by U.S. utilities in the voluntary reporting process and to collected new and more recent event data. The intent is to develop a more focused and reporting format and fields for FPRA and to simplify the reporting process.

The first intended application of the improved database is the application discussed in Section 2.1 above; namely, identifying those events that are relevant to FPRA and resolving the issue of the “unknown” fire events. The database structure will include both raw reporting fields and derived data fields. Raw reporting fields will be those that are completed by the reporting entity. These fields will include factual elements of the event such as when, where, what burned, suppression methods and timing, detection methods and timing (as available), extent of damage, etc. Derived data fields will be completed by analysts of the event data. These include items such as which fire frequency bin and which suppression bin an event would be assigned, key fire event timeline indexes, etc.

The database is also structured to accept documentation of a fire event as provided by either the reporting entity or by the data analysts. For example, a utility would be encouraged to attach the actual plant event records as a part of the report, and a data analyst may add public records as available from the U.S. NRC (e.g., LERs or even Daily Event Report records).

Once the database has been updated and the events classified for risk relevance, the intent is to then update the fire event frequency estimates including a re-examination of fire frequency trends. Additional applications will follow potentially including many of the items and issues discussed above.

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