Kazarians & Associates, Inc.

Effectiveness of Adopting NFPA 805 in Transition to the Current Fire Protection Program

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Table of Contents

1.0 INTRODUCTION AND SCOPE

The Fire Protection rule, 10 CFR 50.48 (Reference 1), allows the use of risk-informed and performance-based requirements of NFPA-805[1] (Reference 2) to meet the regulations. NFPA-805, in turn, allows the use of Fire Probabilistic Risk Assessment (Fire PRA) to establish the need for additional protection features. Two pilot cases were initiated at Shearon Harris Nuclear Power Plant and Oconee Station to demonstrate the process. Shearon Harris effort is complete and has been approved by the NRC. Oconee submittal is currently being reviewed and is expected to be completed by mid-2011. According to Reference 3, from that time (i.e., Oconee's approval), the industry will have 6 months to complete their NFPA-805 transition related studies. Currently, approximately half of the nuclear power plants have declared their intent to transition to NFPA-805.

NUREG/CR-6850[2] (Reference 4) is the most recent document describing a Fire PRA methodology and provides some of the key data (e.g., ignition frequencies and heat release rates) needed to conduct a Fire PRA. There have been several industry and NRC discussion forums where issues related to the transition process and use of current Fire PRA methods and data have been discussed. Concerns have been raised about the limitations in current state-of-the-art Fire PRA methodology and data that lead the user to inappropriate conclusions. Other issues have also been raised that may also be impeding or discouraging the transition process.

The Advisory Committee of Reactor Safeguards (ACRS) has hired Kazarians & Associates, Inc. to obtain information about the issues related to the NFPA 805 transition. This report summarizes the information obtained from various sources regarding the technical issues and other considerations in transitioning to NFPA 805.

<u>It is important to note that almost all the discussions presented in this report are qualitative. They are based solely on verbal information obtained from interviews and author's interpretation. No attempt was made to gather complete or statistically viable information about a topic.</u>

[1] NFPA 805 is approved by NRC for incorporation by reference in the fire protection regulation (Reference 1) with exceptions which are also listed in Reference 1.

[2] NUREG/CR-6850 is amended via the answers to a set of Frequently Asked Questions (FAQs) and References 5 and 6, which include the issues addressed in some of the FAQs. In this document where NUREG/CR-6850 is mentioned, the ensemble of the original report published in 2005, subsequent completed FAQs and References 5 and 6 is intended.

2.0 INFORMATION GATHERING PROCESS

Information gathering process was limited to phone conversations or face-to-face meetings with members of the following entities:

- Nuclear Regulatory Commission
- Utilities
- Consultants
- Other organizations (e.g., Sandia National Laboratory and NIST)

The following topics were generally discussed (as applicable) with each individual:

- Person's qualifications in terms of responsibilities related to NFPA 805 transition process and Fire PRA, and experience with Fire PRA
- Current status of the Fire PRA or transition process
- The results and conclusions of the Fire PRA in general terms (e.g., the key contributors to risk)
- Difficulties in applying NUREG/CR-6850
- Sources of conservatism in the analysis and their impact on the final results
- Level of effort needed to establish the needed information and complete the Fire PRA
- Effectiveness of peer review process
- Any other issues affecting the transition process

In the next section the various topics that were deemed to be of some significance in influencing the transition process are discussed.

3.0 TOPICS INFLUENCING TRANSITION

3.1 Core Damage Frequency

Core Damage Frequency (CDF) of Fire PRAs ranged from mid-10^{-5} to low 10^{-4} per reactor year. Some of the plants estimated the CDF assuming that the planned modifications are in place and operational. The CDF for these plants were less than 10^{-4} per reactor year. Plant modifications included the following:

- Cable rerouting
- Cable raceway wrapping
- Incipient smoke detectors inside electrical cabinets

- Additional seal injection source for Reactor coolant pump (RCP)
- Oil drip pans under pumps
- Operational and administrative procedures

The number of fire scenarios quantified to estimate the CDF is on the order of one thousand. In most cases, a few major contributors provide the majority of the CDF and the balance of the CDF comes from a very large number of scenarios with small CDFs.

3.2 Significant Risk Contributors

As noted in the previous section, typically a handful of scenarios provide the majority of the CDF. These scenarios typically involve electrical cabinets, Main Control Room and places with high concentration of cables. All other significant contributors vary significantly among the plants. The following notes summarize some of the key points regarding significant risk contributors:

- Electrical cabinets and cables of the opposite train nearby are often found to be dominant contributors. Fire propagation and detection and suppression analysis is done to estimate the frequency of fire damage to the opposite train. The heat release rate (HRR) of the electrical cabinets is an important parameter in such computations. Several comments were made that the suggested HRR values in NUREG/CR-6850 are too conservative and do not reflect the reality. However, in the opinion of those with fire experimentation experience, given the proper conditions the reported peak HRRs are possible. This is consistent with the assignment in NUREG/CR-6850 of 75 and 98 percentiles to the peak HRRs which put the bulk of the distribution below the observed lower values.
- The Main Control Room is one of the main risk contributors. In this case, several licensees have assigned 1.0 to the conditional probability of core damage. This is certainly a conservative practice because all plants are equipped with an alternate shutdown capability. It has to be noted that the possibility of spurious actuation of components complicates control room fire scenarios that affect the effectiveness of the alternate shutdown capability.
- Places with high concentration of cables are often found to be important risk contributors.
- At some of the plants, a large number of contributors collectively provide an important part of the CDF. In these cases, since the CDF is distributed among a large number of contributors, any additional analysis to reduce the conservatism in the total CDF was found to require significant resources.
- In PWRs, generally reactor coolant pump seal failure is an important part of dominant risk scenarios. The time to seal damage is often matched against the time that fire brigade takes to bring the fire under control. Therefore, the uncertainties in seal failure probability as a function of time have a significant impact on the Fire PRA results.

3.3 Fire Ignition Frequency

Fire ignition frequencies are provided in NUREG/CR-6850 for plant equipment type (e.g., *Batteries* and *Pumps*) and transient fire events (e.g., *Transient Fires Caused by Welding and Cutting*) by plant location (e.g., Reactor Building and Turbine Building). The frequencies apply to the entire set of equipment type in one reactor unit. Therefore, the analyst is required to prorate the frequencies to estimate the ignition frequencies by ignition source. The following comments were made about ignition frequencies:

- The prorating process yields inconsistent results among the plants. Plants with large number of components within one equipment type would receive smaller frequency per ignition source compared to a plant with small number of components.
- Stand-by equipment (e.g., stand-by pumps) is assigned the same frequency as normally operating equipment. In one case, a stand-by item was found to be important risk contributor.
- Power level has no impact on the frequency. A small pump with small quantity of oil, operating at close to ambient temperature receives the same frequency as a large pump with large quantity of oil and high normal operating temperature.

These issues introduce uncertainty in the application of ignition frequencies that are not explicitly modeled. Depending on the conditions of the plant or equipment item they can either lead to conservative or optimistic results. Except for one isolated case of a stand-by pump which was found to be risk significant, none of the interviewees provided example cases where the above listed shortcomings of the ignition frequency model led to unreasonable conclusions.

3.4 Transient Fire Frequency

Transient fire frequency of a specific room or area within a plant is estimated by prorating the overall frequency based on a ranking scheme influenced by the level of maintenance work, occupancy and storage of combustible materials (transient type) in the room. NUREG/CR-6850 recommends 1, 3, 10 and 50 for these influencing factors. Licensees have found the range inadequate to represent the differences among rooms. For example, there could be an area within a plant where no maintenance activities take place during power operation and it is rarely entered by personnel and never used for storage. Cable shafts and underground cable galleries are examples of such locations. The difference in transient fire frequency between such rooms and one with high level of maintenance, occupancy and storage is no more than a factor of 50. In fact, for a large number of rooms, the difference would be a factor of 10. This difference was deemed too small given the strict administrative controls imposed on such places. There were consultants who elected to use influencing factors other than those provided in NUREG/CR-6850 that provided a much wider span.

3.5 Human Error Analysis

Human actions are an important part of the internal events PRA. The same human actions are also addressed in the Fire PRA. Additional human action cases are typically identified in a Fire PRA that address: (1) accident sequences not fully modeled in the internal events plant response models, (2) recovery of equipment that have failed due to circuit failure and (3) operator actions after Main Control Room abandonment. Operator actions are generally found to be an important part of fire risk.

To establish the human error probabilities (HEP), recent Fire PRAs have had the benefit of recently published joint EPRI and NRC report on human reliability analysis under fire conditions (Reference 7). Screening values are generally used for HEPs. This is especially the case for the HEP for achieving safe shutdown from the alternate shutdown panels after Main Control Room abandonment. It should be noted that in majority of Fire PRAs, the Main Control Room is found to be one of the important risk contributors.

In general, human error probabilities were not mentioned as a source of conservatism in the Fire PRA. However, a few comments were made that Reference 7 has overly conservative suggestions. For example, it is recommended to use 1.0 for HEP for those situations where the operators must wear a breathing apparatus. This effectively disallows operator action credit for plant areas where personal protective gear should be used according to the procedures or conditions of the event.

3.6 Multiple Spurious Operations

All licensees are required to conduct a Multiple Spurious Operations (MSO) analysis to identify combinations of spurious operations that could potentially be risk significant. A generic set of MSO cases (see Appendix G of Reference 9) is typically used to identify the potential scenarios. The results are then incorporated into the plant response model.

When asked about the impact of the MSOs, typically it was noted that the impact on the level of effort was relatively small. Typically only a handful of additional cables had to be analyzed for their routing information. Regarding the contribution of the MSOs to overall fire risk, the response was mixed. It ranged from minimal impact on risk to an important contributor. In one case, according to preliminary results, the MSOs are a part of 10% of the CDF. In other cases, MSOs were one of the elements of risk dominant scenarios. MSOs have led to conditions that require additional operator actions and accident scenarios that were not previously considered for the fire scenario. Also, MSOs may lead to scenarios where the effectiveness of the alternate shutdown system is affected. In a few cases it was mentioned that the impact of the MSOs was difficult to incorporate. One example was noted that the MSO scenario not only caused failures but also initiated a safety injection signal that would help the conditions.

3.7 Pump Oil Fire

The same frequency and heat release rate is provided in NUREG/CR-6850 for pumps regardless of size. For small pumps, this is deemed to be conservative because they contain small quantity of oil. This point was raised by several analysts, but there are no actual example cases where a small pump was found to be a dominant contributor due to proximity to cables or other equipment items.

3.8 Incipient Fire Detection

Incipient fire detection systems were considered in a few cases as a planned modification. The Fire PRA was based on the assumption that these systems will be installed as planned. In those cases, the total CDF was found to be affected considerably. In all cases, the detection system was considered for electrical cabinets. These were cabinets that had cables or electrical cabinets of opposite train present within the same room. The peak HRR distribution provided in NUREG/CR-6850 for those electrical cabinets led to risk results that were not considered as acceptable by the licensee.

3.9 Adherence to NUREG/CR-6850

Every licensee that was contacted has used NUREG/CR-6850 (Reference 4) for its Fire PRA. As noted earlier, several parts of Reference 4 has been modified since its publication through the FAQ[3] process which are partly included in References 5 and 6. The level of adherence to NUREG/CR-6850 varies among the licensees. At least one licensee elected to limit its analysis to the guidance and data provided in NUREG/CR-6850 as published in 2005, disregarding the FAQs and other modifications. Most licensees have used NUREG/CR-6850 as modified by References 5 and 6 and the FAQs and there are cases that elected to deviate from those sources.

The following notes summarize what was learned about the deviations from NUREG/CR-6850:

- For one plant, the contractor conducting the Fire PRA elected to deviate from NUREG/CR-6850 in modeling the human reliability, fire in ventilated electrical cabinets, fire affecting sensitive electronics and transient combustible fires. The frequencies of transient fires were revised by reviewing the raw data and re-assigning the events.
- In another case, the contractor used Fire Dynamics Simulator (FDS) to model fire growth within an electrical cabinet.
- On several occasions it was noted that dominant risk scenarios included transient fire events in plant areas that are administratively prohibited to conduct maintenance and store any combustibles or flammables, and are seldom visited. Given these restrictions,

[3] Frequently Asked Questions (FAQs) that were put forward by various sources were addressed by a combined industry and NRC team. The completed FAQs can be downloaded from the NRC website.

the transient frequencies were deemed to be conservative. To reduce the level of conservatism, the analysts elected to use different values for the influencing factors[4] than the values recommended in NUREG/CR-6850.

It must be noted that the peer reviewers of these cases reviewed the modified parameters carefully and challenged them accordingly. Also, the NEI guidance on peer review process (Reference 9) has identified a Fact & Observation (F&O) category as "Unreviewed Analysis Method" for those cases that the peer review team may feel an industry level review is needed. This vehicle is being used to verify the adequacy of some of the deviations noted in the Fire PRAs.

In one case, the analyst chose to use FDS model to analyze fires within an electrical cabinet. This raises an important point about the analysts' understanding of NUREG/CR-6850 methodology. There is an inter-relationship among the various models in NUREG/CR-6850 that must be taken into account when adjusting one part of the model. For example, the ignition frequencies were based on "challenging" fires (see Appendix C of NUREG/CR-6850 for its definition) which in effect incorporates a level severity in the initial fire which is not explicitly defined. Fire propagation, detection and suppression models presented in NUREG/CR-6850 were intended to take into account this initial severity. Therefore, modeling the initial phases of a fire event to establish the time to fully grown fire inside a cabinet may render inapplicable other elements of NUREG/CR-6850 model (e.g., detection and suppression time).

In another case, as noted above, a consultant elected to go back to the raw data and reproduce some of the frequencies and probabilities of NUREG/CR-6850 based on the consultant's interpretation of the events. This has serious implications that deserve attention. The raw fire event data used in developing the various frequencies and probabilities that are presented in NUREG/CR-6850 had undergone careful review by several people from the NRC and EPRI sides. There is no doubt that the process was imperfect as each data element was imperfect and subject to a range of interpretations. Therefore, re-interpreting the raw data at this stage by one entity cannot be defended as unbiased. Probability values obtained from such re-interpretations should not be considered as valid.

The interviews also revealed a notion among some members of the industry that NUREG/CR-6850 methodology and data should be followed closely. For example, NUREG/CR-6850 does not specify the decay phase of a fire. This group concluded that NUREG/CR-6850 requires the assumption that fires continue to burn indefinitely at peak HRR. Certainly this does not coincide with the physics and chemistry of a fire event. There is always a limited amount of combustibles available for each fire event and fires would eventually burn out. Depending on the amount of available fuel, it is quite likely for decay to occur before target damage. Such strict interpretation of NUREG/CR-6850 is not recommended anywhere in that document or any other sources.

[4] See Section 3.4 for a discussion on treatment of transient fire frequencies. The influencing factors are qualitatively assigned rankings that are used to pro-rate the transient frequencies of the reactor unit down to each room or plant area. See Section 6.5.7.2 of NUREG/CR-6850.

3.10 Peer Review Process

The peer review process is an integral part of the use of Fire PRA in NFPA 805 transition process. It is a requirement by ASME/ANS Standard on PRA (Reference 10).

Peer review process has gone through a learning phase. Overall, it is the opinion of many that it has matured and it serves its intended purpose. The following comments were noted:

- The type, number and quality of comments received have varied among the teams. This can be attributed to the learning phase of the peer review process. Peer reviews done in the beginning suffered from poorly qualified reviewers. This lesson has led to constraints that have manifested as difficulties in scheduling qualified reviewers.
- In at least one case, systemic errors were noted in a contractor's deviation from NUREG/CR-6850 which was challenged by the peer review team. This in fact proves the merits of peer review process.
- Peer reviews have been done for incomplete Fire PRAs. In those cases, the main reason noted was difficulty rescheduling the peer review because of constraints in the availability of qualified reviewers. Conducting peer review of incomplete Fire PRA certainly affects the efficiency of the review process requiring an additional review when the study is complete. Also, it points to the limitations that industry faces in terms of availability of qualified persons.

3.11 Level of Effort

The level of effort to conduct a Fire PRA was found to be significant. Over 15,000 person hours were often needed. In a few cases, the licensee had to stop the analysis because of budget limitations and accept the results as they were (i.e., no further analysis was conducted to reduce the level of conservatism in the analysis). In those cases, hardware modifications were considered to reduce the risk.

Quality of cable (circuit) location information has often been a major factor in the level of effort. The quality is dependent on past efforts in complying with Appendix R and in the method used to catalog the cables. In most cases, the existing cable location information was found to be adequate. The level of effort for locating additional circuits (e.g., MSO and instrumentation related circuits) were found to be a small part of the overall effort. However, there are cases where the original cable location data had to be redone completely leading to a major addition to the level of effort.

3.12 Other Observations

The following are a collection of observations that were deemed partly relevant to the objectives of this study:

- The Conditional Core Damage Probability (CCDP) by room ranges widely. It is common to find a handful of rooms within a plant with CCDP greater than 0.1. These rooms are generally found to be dominant risk contributors.
- In circuit failure analysis, it is assumed that shorts in DC circuits do not clear by themselves[5] and require an operator action to reset the affected equipment. It is believed that this assumption leads to conservative results.
- The timing of shorts in electrical cables and cabinets affecting control circuits is also an important factor. It assumed that short occurs as soon as fire is initiated. The plant response sequences and especially operator actions and HEPs may be very different if this assumption is relaxed.

4.0 THE CASE OF MONTICELLO

Monticello Nuclear Generating Plant is a 618MWe Boiling Water Reactor (BWR) that started operation in 1971. Plant management initially decided to adopt NFPA 805 to address the open items in compliance with the fire protection regulations. The open items included compliance with MSO requirements and three Appendix R (Reference 11) exemptions. It should be added that plant management considered their compliance level with Appendix R requirements very robust. After a review of the nature of the open items, their options for addressing MSO cases and level of compliance with Appendix R, management decided against NFPA 805 transition. The three exemptions involved conditions that could be shown as low risk to plant safety. MSO issues could be addressed using a method not involving NFPA 805. Therefore, management decided to reallocate the budget for NFPA 805 transition to hardware modifications that would in the long run bring tangible return on the investment than a set of analyses.

[5] Currently tests are underway that may shed some light on this topic.

5.0 CONCLUDING REMARKS

The purpose of this study was to explore the limitations in the use of current Fire PRA methods and data in NFPA 805 transition process. Several members of the industry, consulting companies and NRC who are involved with Fire PRA were approached for a verbal discussion of their opinions and experiences regarding use of Fire PRA.

Fire PRA is a complex process where the internal events model is modified to include electrical cables (i.e., power, control and instrumentation circuits) along with location of these cables. Additionally, for each location a range of possible fire scenarios are postulated. Fire ignition, growth, detection and suppression is modeled for each scenario along with the possibility of damage to the equipment and cables in the area.

Fire PRA addresses a very complex set of phenomena that involves reactor safety, fire occurrence, growth and propagation, fire detection and suppression, circuit failure, and operator response. Each part has its own modeling methods and data that should be compatible with the models and data of other parts. For example, the ignition frequencies may represent certain initial severity of the fire. Fire propagation analysis for time to damage should take into account this fact. This compatibility issue is noted here because reducing the level of conservatism in one part of the methodology should be done in concert with all other elements.

A wide range of topics were brought forward in the interviews. The following is a summary of key points:

- Fire PRA CDF ranges between mid-10^{-5} and low-10^{-4}. In several cases plant modifications had to be considered for CDF to be below 10^{-4} per reactor year.
- Dominant risk contributors typically include electrical cabinets with cables or cabinets of the opposite train nearby, the Main Control Room and places with high concentration of cables. All other significant contributors vary significantly among the plants.
- In PWRs, reactor coolant pump seal failure is an important part of dominant risk scenarios.
- A large number of fire scenarios (on the order of one thousand) are typically analyzed to arrive at the CDF. Often past the few dominant contributors, a very large number of scenarios with small CDF provide the balance of the total CDF.
- In general, the HEPs were not noted as a source of conservatism in the Fire PRA. However, it should be noted that the HEPs associated with the Main Control Room fire scenarios are mostly estimated using conservative and simplified approaches.
- Multiple Spurious Operations (MSOs) were not found to be a major obstacle nor does it add significantly to the level of effort. Its contribution to the fire risk varies significantly among the plants.
- In a few plants, the incipient fire detection system was found to be important to reducing the CDF of the dominant contributors.

- Level of adherence to the NUREG/CR-6850 methodology and data varies significantly. There are licensees that have elected to adhere to the original values and methods of NUREG/CR-6850 (i.e., FAQs are disregarded). At the other end of the spectrum, there are analysts that have modified the values and methods according to their understanding of the fire events. The latter deserves further discussion as provided below.
- Peer review process has gone through a learning phase. The reviewers have provided valuable contribution to the process. They have challenged cases that were considered as a systemic error. However, it seems that the pool of qualified persons is limited. This puts a constraint on scheduling the reviews and forcing the utilities to conduct the reviews while the Fire PRA is incomplete.

Unrealistic level of conservatism is a common critique of current status of Fire PRA methodology and related data. In this study, an attempt was made through the interview process to identify sources of conservatism. Undoubtedly some level of conservatism is built into the Fire PRA model and data. This is an inherent part of all PRAs because otherwise the methodology and data would be considered as inappropriate. However, none of the various parts of a Fire PRA stood out as a potential candidate for undue level of conservatism. The following are author's opinion, based on the interviews and his personal experience about potential sources of conservatism that skew the results:

- Simple models are used for analyzing the Main Control Room fire scenarios and perhaps more importantly the human error probabilities associated with Main Control Room fire scenarios are estimated conservatively.
- To analyze a fire scenario the analyst has to use models for fire ignition (i.e., occurrence frequency), propagation, damage to a target set, detection, suppression and in some cases circuit failure and its associated probabilities. These models must be compatible to one-another to yield a reasonable result. For example, fire propagation analysis should assume an initial fire severity that ignition frequency has considered. This severity is not explicitly articulated or quantified in the current model. This implies that there is an element of uncertainty in each part of the Fire PRA methodology that is not explicitly articulated in current models. Fire risk analyst has to give careful consideration of the inter-relationships among the various models to minimize the potential for biased results. Therefore, the variations in the analysis assumptions associated with these inter-relationships that are either inherent or introduced by the analyst could potentially be a source of conservatism.

It is important to note two additional concluding remarks:

- The analysts should be restricted from conducting their own interpretation of raw fire event data and re-estimating probabilities and frequencies. Because of insufficient information contained in most event descriptions, experience has shown that a wide range of interpretations is possible. Therefore, one person's or one entity's interpretation can easily be skewed.
- Peer review process has proven to be an important part of verifying the technical accuracy of the Fire PRAs. Schedule related decisions should take into account the limited number of qualified analysts.

6.0 REFERENCES

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