The U.S. Nuclear Regulatory Commission's Fire Risk Research Program: Status and Results

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Abstract

The U.S. Nuclear Regulatory Commission (NRC) fire risk research program has several tasks aimed at improving the nuclear power plant fire risk assessment (FRA) state of the art. Current results to date include an evaluation of available test data relevant to the estimation of fire-induced spurious actuation probabilities, FRA methodology issues raised by a review of past fire events, and a framework for using test data in the quantification of fire model uncertainties.

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1. Introduction

Since its development in the late 1970's and early 1980's, nuclear power plant fire risk assessment (FRA) has proven to be a useful tool for plant designers, operators, and regulators (e.g., see [1]). However, situations can arise for which there currently is no "right" or "best" modeling approach and where variations in modeling assumptions can lead to orders of magnitude variations in estimates of fire-induced core damage frequency (CDF) and qualitatively different risk insights. These state of the art limitations place some restrictions on the extent to which FRA results and insights can be used to support decision making.

To improve the FRA state of the art, the U.S. Nuclear Regulatory Commission (NRC) initiated a fire risk research program in 1998 [2]. The program is designed to provide improvements in the FRA treatment of each of the three classical elements of fire protection defense in depth (fire prevention, fire detection and suppression, fire mitigation). The fifteen tasks currently being performed are listed in Table 1.

This paper briefly describes key results for three recently completed tasks: Task 1 (Tools for Circuit Failure Mode and Likelihood Analysis), Task 5 (Experience from Major Fires), and Task 9 (Integrated Model and Parameter Uncertainty). It concludes with a discussion of upcoming research program activities.

Table 1 – Fire Risk Research Program Tasks

Task	Title
1	Tools for Circuit Failure Mode and Likelihood Analysis
2	Tools for Fire Detection and Suppression Analysis
3	IEEE-383 Rated Cable Fire Frequency Analysis
4	Fire Modeling Toolbox: Input Data and Assessment
5	Experience from Major Fires
6	Industrial Fire Experience
7	Frequency and Characteristics of Switchgear and Transformer Fires
8	Fire Barrier Reliability Model Development and Application
9	Integrated Model and Parameter Uncertainty
10	Frequency of Challenging Fires
11	Fire Model Limitations and Application Guidance
12	Risk Significance of Turbine Building Fires
13	Penetration Seals
14	Multiple Unit Interactions
15	Use of Advanced Fire Models in Fire Risk Assessment

2. Tools for Circuit Failure Mode and Likelihood Analysis (Task 1)

Task 1 dealt with the conditional probability of different fire-induced circuit failure modes (including spurious actuations), given (assuming) fire-induced cable damage. This is an important issue for FRA, not only because fire-induced spurious actuations have been shown to be risk significant in some FRAs, but also because the likelihood of such failures can significantly affect the resources needed to construct a plant-specific FRA model. In particular, if fire-induced spurious actuations are low likelihood events, routing information for a large number of cables may not be needed.

The task objectives were to: develop an improved understanding of the mechanisms linking fire-induced cable damage to potentially risk significant failure modes of power, control, and instrumentation circuits; develop improved methods and data for estimating the conditional probabilities of key circuit faults, given damage to one or more cables; and identify areas where additional work needs to be done to improve understanding of the risk associated with fire-induced circuit failures. The work performed to address these objectives included a review of publicly available papers and reports documenting cable fire tests, and analyses of cables and control circuits commonly used in nuclear power plant safety applications. Results were obtained regarding: a) the

likelihood of various cable failure modes (open circuits, shorts to ground, hot shorts), and b) the performance of circuit failure analysis in FRA [3]. Some key results are as follows.

Regarding the likelihood of cable failure modes, it was found that, for certain situations, substantial experimental data are available for estimating the likelihood of different initial cable failure modes. (The data are, in fact, sufficient to indicate clear distinctions in the relative likelihood of the failure modes depending on cable type; this argues against the current FRA practice of using of a single hot short probability for all cable types.) For multi-conductor instrumentation and control (I&C) cables without armor, shields, or drain wires, the conditional likelihood that the initial fault is a conductor-to-conductor hot short, given that the cable is damaged, is quite high. (The available data indicate it is on the order of 0.7.) For I&C cables with shield and drain arrangements, the hot short probability is substantially lower. (For a two-conductor cable with a shield and drain, the available data indicate that the hot short probability is on the order of 0.05.) The data also indicate that, following the initial conductor-to-conductor short, any number of conductors may become involved. Thus, an analysis may need to consider short circuits involving more than pairs of conductors within a cable. Finally, the data show that post-test examinations of cables are not a reliable means for determining whether or not a cable has failed during the fire test, since some insulation healing can occur after the cable cools down.

The review also shows that experimental data are sparse or entirely lacking in a number of important areas. These areas include cable-to-cable short circuits, the duration of fire-induced short circuits, and the effects of various potentially important scenario-specific factors (e.g., wire gage, cable tray type, routing in conduits, raceway loading and orientation, cable bundling, and fire exposure).

Regarding the performance of circuit failure analysis for FRA, it should be recognized that the occurrence of a hot short does not necessarily imply the occurrence of a spurious actuation. The work performed has identified a number of important circuit features that need to be addressed to determine the effect of the hot short (or any other cable failure mode, for that matter). These include the grounding of the circuit (if any), the existence of latching relays or similar logic that locks in a command signal, and the existence of "double breaks" in circuits (open contacts at both ends of a circuit leg). Failure Modes and Effects Criticality Analysis appears to be a useful method for addressing these issues in an FRA.

3. Experience from Major Fires (Task 5)

Task 5 was aimed at determining if current FRAs address the lessons conveyed by nuclear power plant actual fire experience. The task objectives were to: identify key fire risk and FRA insights from serious U.S. and international nuclear power plant fires; and develop recommendations for FRA improvements and areas for further investigation.

To achieve these objectives, information on 25 fire incidents (13 involving U.S. plants) was reviewed. These incidents included "challenging" (from a nuclear safety perspective), "severe" (from a traditional fire protection perspective) and "interesting" (from an FRA methods perspective) fires. The incident reviews were conducted from two angles. First, looking at the chronological chain of events during each fire, the question was asked as to how the key events would be treated by current FRAs. Second, looking at the analysis elements of FRA (e.g., fire initiation, fire propagation, fire detection and suppression, equipment damage, impact on plant safety functions, recovery and operator actions), the question was asked as to whether current treatments of these elements are consistent with

the lessons learned from each incident. As a result of these reviews, a number of important FRA insights were obtained [4]. These include the following.

- A number of fires have involved such challenges as extended station blackouts, loss of core cooling functions, and adverse impacts (due to heat and smoke) on operators. This confirms that fire can be an important contributor to nuclear power plant risk and supports the need for a careful FRA.

- The overall FRA framework, which addresses the basic elements of fire protection defense in depth (fire prevention, rapid detection and suppression, mitigation), can accommodate all of the key issues identified by the review.

- Current FRAs would typically not credit some of the operator recovery actions observed (e.g., non-proceduralized actions, actions performed in smoky and flooded areas).

- Current FRAs do not address observed complications in some incidents, including multiple fires (either caused by a single initial fault or caused by fire-induced damage or demands) and multiple initiators (e.g., fire and flooding, fire and turbine missiles).

4. Integrated Model and Parameter Uncertainty (Task 9)

The objective of Task 9 was to address the quantification of "model uncertainty," i.e., the uncertainty in model output due to modeling approximations. It also addressed the impact of uncertainties in model parameters, because these are often difficult to distinguish from the model uncertainties. The specific objectives of the task were to (1) develop a conceptual, unified, framework and methodology for treating model and parameter uncertainties, (2) provide guidelines for practical applications, and (3) apply to representative cases from fire risk models. The results of this effort are discussed by Droguett [5]. These results include formulation of a Bayesian framework for an integrated assessment of model and parameter uncertainties, and a demonstration of its relation to less general and in some cases ad hoc model uncertainty analysis techniques suggested in the past. The approach treats models as sources of evidence concerning the unknown of interest (e.g., the temperature at a given point in a fire plume). It allows for the use of various types of information ***from*** models (e.g., comparisons of measurements with model predictions) as well as subjective evidence ***about*** the models themselves (e.g., expert assessments of model quality and applicability). Many variations of the basic framework have been formulated to accommodate specific forms of qualitative and quantitative information from and about models.

Reference 5 also presents two example applications of the framework to fire modeling. In the first example, performance data from the use of the COMPBRN IIIe fire model is used to develop the uncertainty distribution for code results. In the second example, a point source fire model is used to predict the plume temperature of a line fire source. This example illustrates the ability of the framework to use qualitative information concerning the degree of validity of a model developed for one situation when applied to a different situation. It is expected that the methodological results will be useful for risk assessment applications where physical model predictions are used as an integral part of the analysis.

5. Future Activities

It is anticipated that, by the end of 2000, completion of the fire risk research program tasks listed in Table 1 and a number of follow-on activities needed to address issues identified above will yield a set of methods and tools that will be useful for performing improved FRA. However, the results of these tasks will not provide a summary statement of the overall qualitative and quantitative impact of the FRA improvements, nor will it provide a summary set of guidance for performing improved FRA.

One mechanism for addressing these issues is the application of the research program results to the requantification of fire risk for one or more plants. This activity should satisfy a number of objectives. In addition to providing improved CDF estimates for the plants involved and implicit guidance for performing FRA, it should help identify those areas where the FRA improvements will most affect the fire risk results, provide experience concerning the practical implementation of these improvements, and provide insights concerning the reliability of previous FRA methods and tools. The NRC is in the process of updating the fire risk research program; it is expected that a task addressing requantification will be included in the updated plan.

6. References

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