October 2, 1998 SECY-98-230

FOR: The Commissioners

FROM: L. Joseph Callan /s/
Executive Director for Operations

SUBJECT: INSIGHTS FROM NRC RESEARCH ON FIRE PROTECTION AND RELATED ISSUES

PURPOSE:

To update earlier material summarizing the U.S. Nuclear Regulatory Commission's (NRC's) research plans and results concerning the assessment and assurance of commercial nuclear power plant safety with respect to accidental fires. This update responds to Item 5 of the Staff Requirements Memorandum for SECY-98-058, in which the Commission directed the staff to "Summarize NRC's fire protection-related research activities conducted to date and seek Commission approval before initiating further research."

SUMMARY:

This paper indicates that, although past research has provided useful support to past and ongoing regulatory activities, additional work is still needed to address gaps in current capabilities to perform realistic fire risk assessment (FRA) and thereby support an expanded use of risk-informed, performance-based methods for fire protection. Toward this end, the Office of Nuclear Regulatory Research (RES) has an ongoing project for improving FRA. This project, which started in fiscal year (FY) 1998, is included in the Probabilistic Risk Assessment (PRA) Implementation Plan. Consistent with this plan, this work has been approved by the Commission through the planning and budget process for FYs 1998, 1999, and 2000. The staff currently has no plans to perform further fire protection-related research activities. If the need for such activities arises, the staff will seek Commission approval before initiating the research.

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BACKGROUND:

On March 26, 1998, the staff submitted SECY-98-058, which proposed that the staff defer the fire protection rulemaking and instead work with the National Fire Protection Association (NFPA) and the industry to develop a performance-based, risk informed consensus standard for fire protection at nuclear power plants. In the SRM dated June 30, 1998, the Commission approved the staff's proposal. The research completed to date and the current ongoing research related to FRA are being used by the staff to support the development of the NFPA standard.

Depending on the design and operational characteristics of a given nuclear power plant, fire can be a significant or even dominant contributor to the overall risk for that plant. "Near misses" of core damage caused by fire have occurred in the U.S. and abroad (e.g., Browns Ferry, 1975; Vandellos, 1989; Narora, 1993). A number of early FRAs and more recent Individual Plant Examinations of External Events (IPEEEs) have resulted in estimates of mean fire-induced core damage frequencies (CDFs) of $10^{-4}$/yr or greater, predicted contributions to total CDF of greater than 20 percent, or both. To support regulatory activities assuring nuclear power plant fire safety and to enable the assessment of the level of safety achieved, NRC has conducted a number of fire protection-related research activities over the years.

The largest effort, the Fire Protection Research Program (FPRP), was started in fiscal year (FY) 1975. The initial objective was to confirm the effectiveness of fire protection measures and the operability of safety-related equipment during a fire. The research areas addressed were identified by a review of current design standards and guidelines, as well as by the Browns Ferry fire investigation. As described in NUREG-0298 and NUREG-0581, the program's primary elements addressed cable tray separation,[1] fire shields (including tray covers and fire barriers), fire-retardant coatings, material aging, standard fire tests, equipment fragility, fire detection system performance, and the effectiveness of fire extinguishing agents. Most of the work was performed at Sandia National Laboratories (SNL) with some assistance from Brookhaven National Laboratory (BNL).

In parallel with the FPRP, NRC sponsored efforts to develop a FRA methodology. Work at the University of California at Los Angeles resulted in a methodology and associated tools (including the fire modeling computer code COMPBRN) that were used in the utility-sponsored Zion (1981) and Indian Point (1982) PRAs. The same basic methodology still forms the basis of the approaches taken by current FRAs.

In FY 1983, to support NRC's changing regulatory needs (note that Appendix R to 10 CFR Part 50 had been adopted in 1981), the FPRP objectives were modified. As stated in NUREG-1148, the new objectives were to develop test data and analytical capabilities to support evaluations of: plant fire risk; fire effects on control room equipment and operations; and the effect of suppression system actuations on safety equipment. The main program elements involved: the characterization of fire sources in nuclear power plants; the determination of the environment induced by a fire; the determination of failure thresholds for safety equipment; and the

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[1]This element actually built on ongoing NRC-funded work to evaluate the adequacy of then-current cable tray separation criteria. The project was conceived in July 1974 (i.e., some 8 months before Browns Ferry).

assessment of control room habitability during a fire. Most of the work was performed at SNL; BNL provided support for some tasks. The FPRP was terminated before completion of some of its tasks in FY 1987.

Since then, a number of studies have been conducted by RES, the Office of Nuclear Reactor Regulation (NRR), and the Office for Analysis and Evaluation of Operational Data (AEOD). Studies performed over the period 1987-1993 have been performed to assess: (a) the importance of a set of topic areas not included in the scope of current FRAs; (b) the effect of aging on cables, fire barriers, and other components; (c) the technical basis for resolving Generic Issue 57 ("Effects of Fire Protection System Actuation on Safety-Related Equipment"); (d) the performance of a Thermo-Lag barrier system; and (e) the fire risk for a number of plants. The latter studies were performed as part of larger risk assessments [e.g., the NUREG-1150 and LaSalle Risk Methods Integration and Evaluation Program (RMIEP) studies]. Work performed since 1993 includes studies of: (a) the effect of smoke on digital components; (b) improved methods for qualifying fire barriers; (c) the risk implications of imperfect fire mitigation features (e.g., barriers); (d) penetration seals; (e) turbine building fire hazards; (f) the risk implications of safe shutdown methods (in the event of a serious fire) that cause station blackout; (g) current operational experience with respect to fires; and (h) current FRA needs.

At present, as one of the items identified under element 2.4 ("Methods Development and Demonstration") of the PRA Implementation Plan, RES is developing improved FRA methods and tools. RES also has the lead in reviewing the IPEEEs and is interacting with industry groups (including the Electric Power Research Institute -- EPRI) and international researchers through a variety of forums (e.g., direct discussions, conferences, standards committees). These activities, through their development of analysis tools, databases, and insights, support RES' mission to provide technical bases for cost-effective, risk-informed regulatory decision making.

DISCUSSION:

Fire Protection-Related Research Results

There have been numerous research activities supporting the evolution of the NRC's fire protection regulations and associated programs (ranging from Regulatory Guide 1.75, through Appendix R, to the increased use of risk-informed, performance-based methods).[2] This section organizes the findings of these activities into four areas: (a) fire prevention; (b) fire detection and suppression; (c) fire mitigation; and (d) fire safety evaluation. The first three areas are the elements of defense-in-depth required of U.S. plant fire protection programs. The fourth area also might be considered as a fourth element of defense-in-depth; it provides a feedback tool to assist program optimization and learning.

It should be noted that a number of research results (e.g., regarding cable tray separation) have directly supported the development and evaluation of NRC's fire protection requirements and guidelines. In addition, many of the results, although not directly incorporated into NRC's requirements and guidelines, have provided the staff with information supporting various

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[2]A useful summary of the work performed over the period 1975-1987 is provided in NUREG/CR-5384. The findings of that report are included in this paper.

regulatory activities (e.g., reviews of proposed exemptions to Appendix R).

Research Relevant to Fire Prevention

Because of their common cause failure potential, fires involving electrical cables (as sources, targets, or both) can be highly risk significant. NRC has performed research to better understand the ignitability and flammability of cable insulation. Research has also been performed to characterize the fires to which key components (including cables) might be exposed, and to determine the likelihood of fires. Some of the key findings are as follows.

- As expected, cables that pass the flammability test portion of the Institute of Electrical and Electronic Engineers 383 standard (i.e., "qualified cables") are significantly more difficult to ignite than unqualified cables. However, qualified cables can be ignited under exposure fire conditions. Furthermore, once ignited, they can lead to more challenging fires than unqualified cables.

- The flammability of cable insulation appears to decrease with thermal aging.

- Reportable fires are neither extremely common nor extremely rare occurrences at U.S. nuclear power plants. (The average frequency of reported fires is around 0.3/plant-yr.) Fires leading to significant safety impacts are much less frequent.[3]

Although the available fire data are sufficient to draw some useful conclusions regarding the likelihood of reported fires on a plant-wide or even fire area basis, they are too sparse to support high-confidence estimates of parameters needed in FRAs (e.g., the frequency of large, transient-fueled fires in a particular portion of a room). Furthermore, because many fire events (e.g., the small worker-initiated fires prior to the large cable fire at Browns Ferry) are not included in current databases, current FRAs are incomplete. To reduce these uncertainties and limitations, improved data and methods for estimating the likelihood of key fire scenarios are needed.

Research Relevant to Fire Detection and Suppression

The performance objectives (e.g., rapid detection and suppression before damage of safety-related equipment) and service conditions for automatic detection and suppression systems in nuclear power plants can vary from those in many other commercial installations. Research has been performed to assess the adequacy of general industry practices in detection and suppression for nuclear power plant applications. Research has also been performed to determine the effectiveness of various suppression agents and to assess the effect of aging on fire detection and suppression system reliabilities. Some of the key findings are as follows.

- Industry standards for automatic detection and suppression are largely effective for

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[3]Out of the 341 U.S. at-power nuclear power plant fire events during 1965-1994 covered by a recent NRC study (AEOD/S97-03), only the Browns Ferry fire involved the loss of multiple safety-related systems. Eleven fires caused a reactor scram and loss of a single safety-related train, and one fire caused a reactor scram and loss of offsite power. All the other fires had a significantly lesser impact on nuclear safety.

nuclear power plant applications. The only exception noted was that nuclear power plant rooms often have obstructions to smoke and gas movement (e.g., cable tray stacks) that can reduce the effectiveness of detection systems.

- In-cabinet smoke detectors (which are not required by industry standards) are highly effective in detecting incipient fires in electrical cabinets. The results of a number of IPEEEs show that the use of in-cabinet detectors can significantly reduce the risk associated with main control room fires.

- Plant aging appears to have little effect on the performance of active fire protection systems with one exception: there have been significant effects of corrosion on the performance of water-based suppression systems.

The results of NRC's research in this area provide confidence that properly installed and maintained fire protection systems will detect and extinguish challenging fires. They are not, however, in a form to support the assessment of a key FRA parameter: the probability that a given fire will be detected and suppressed by a specified time. Although NRC has supported the development of a methodology for performing this assessment, the methodology is relatively insensitive to a number of scenario-specific issues (e.g., the relative locations of fire source, target, and suppressant discharge). Improvements in the methodology are needed to address these issues and others (e.g., the design and maintenance of the fire protection system) that can be important in risk-informed, performance-based fire protection applications.

<u>Research Relevant to Fire Mitigation</u>

Current fire protection regulations and design practices provide several means to reduce the damage potential of a fire even if it is not rapidly suppressed. NRC has supported research on the effectiveness of a number of these, including spatial separation, cable coatings, and fire barriers. A related research topic also covered by NRC's programs is component fragility. Some of the key findings are as follows.

- Under exposure fire conditions, fires can propagate readily between cable trays separated according to the criteria provided by Regulatory Guide 1.75 (which was current at the time of the Browns Ferry fire). This result supported the development of the Appendix R separation requirements.

- Credible source fires can damage target cables separated from the source fire by a large (6.1 m, i.e., 20 ft) gap without intervening combustibles. However, active suppression systems, if installed and available, are likely to suppress the fire before cable damage occurs.

- Commercial cable fire retardant coatings can delay cable damage and ignition for some period of time (on the order of a few minutes), depending on the characteristics of the exposing fire, but the effectiveness varies strongly from coating to coating. Coatings do not provide the same degree of protection as rated fire barriers.

To date, NRC has conducted little research on post-fire consequences and associated mitigation activities. Two risk-important problem areas that require investigation are the likelihood of fire-induced spurious actuations and the effectiveness of plant operators during fire scenarios. Regarding passive fire mitigation measures, research may also be needed to develop improved, more performance-based methods for qualifying barriers (given the problems with Thermo Lag barriers and the recent identification of potential problems with other fire barriers -- as discussed in NRC Information Notice 97-59). These improved methods, which will ensure that barrier performance is adequate with respect to the relevant fire hazard, may be useful in reducing licensee burden. Research is also needed to reduce current uncertainties in damageability of components (especially cables), and to determine the fragility of sensitive components with respect to smoke effects.

Research Relevant to Fire Safety Evaluation

A number of research activities associated with the evaluation of fire safety have been discussed in the sections on fire prevention, detection and suppression, and mitigation. Two additional important activities are fire modeling and FRA. NRC's fire modeling research efforts have included:

- The development of a simple zone model for use in FRA (COMPBRN).
- Feasibility studies regarding the use of field models (which model dynamic fluid flow and heat transport in three dimensions) in various applications.
- Limited fire model validation studies.
- Performance of experiments to generate data for additional model validation studies.

Weaknesses in the fire models currently used in FRAs have long been recognized as an important source of uncertainty. However, the magnitude of these uncertainties is not well understood. Work is needed to both improve the fire models (including the possible application of field models, such as the Large Eddy Simulation models being developed by the National Institute of Standards and Technology) and to better define the uncertainties in their predictions. Work is also needed to address specific applications problems, e.g., the effect of explosive faults in electrical switchgear.

NRC's past FRA activities have been discussed in the "Background" section of this paper. Not including the results of numerous FRA studies performed for various plants and issues,[4] the key products of these activities include:

- The basic methodology used in most FRAs to date.
- Analysis tools that have been used in a number of FRAs. These include the Sandia Fire Events Database as well as COMPBRN.
- Various assessments of the FRA state-of-the-art. In particular, the “Fire Risk Scoping

[4]The LaSalle RMIEP study, for example, identifies important contributions to fire risk, discusses the effect of the plant’s fire protection features on risk, and identifies opportunities for further reducing risk.

Study" (see NUREG/CR-5088) identified a number of issues not included in the scope of then-current (c. 1989) FRAs. These issues are being addressed in the IPEEE program.

The most recent staff assessment of FRA needs appears in NUREG/CP-0162, where 42 potential FRA problems (including all problems discussed in this section) were identified. These potential problems have been grouped into 17 FRA topic areas. The approach being taken for their disposition is discussed in the following section.

CONCLUSIONS:

Although NRC fire research efforts have yielded both important results and useful tools, a number of important questions regarding the assessment and assurance of nuclear fire safety remain.[5] This paper identifies significant gaps in current capabilities for performing realistic FRAs. These gaps need to be addressed in order to increase confidence in the application of FRA to a broad variety of fire protection issues.

RES staff will therefore continue ongoing efforts to develop improved FRA methods and tools, as indicated under element 2.4 ("Methods Development and Demonstration") of the PRA Implementation Plan. Consistent with this plan, this work has been approved by the Commission through the planning and budget process for FYs 1998 through 2000. The six FRA topic areas currently being addressed are: circuit failure mode and analysis, fire modeling, experience from major fires, impact of fires on operator performance, risk significance of turbine building fires, and FRA applications issues. These areas were selected using prioritization input from RES, NRR, and AEOD staff. They have also been discussed with representatives from EPRI and the Nuclear Energy Institute.

Planning has started for the disposition of the 11 (out of 17) FRA topic areas not currently being addressed and will be completed in early 1999 (calendar year). This planning will involve interactions with the Advisory Committee on Reactor Safeguards and industry. It will address specific areas and modes of interaction with active industry and international efforts. The results of this planning process will be incorporated into the PRA Implementation Plan and thereby coordinated with the planning and approval of other PRA activities.

The staff currently has no plans to perform further fire protection-related research activities beyond those identified in the PRA Implementation Plan. If the need for such activities arises, the staff will seek Commission approval before initiating the research.

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[5]Note that fire science itself is a relatively young field, with some of the pioneering papers written in the early 1960s. It should not be surprising, therefore, that questions remain.

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