Draft Report for Information

NRC Fire Risk Research Plan: Fiscal Years 2001-2002

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Acronyms

ACRS	Advisory Committee on Reactor Safeguards (NRC)
ADAMS	Agencywide Documents Access and Management System
ANS	American Nuclear Society
ATHEANA	A Technique for Human Event Analysis
BFRL	Building and Fire Research Laboratory (of NIST)
CDF	Core Damage Frequency
CFAST	Consolidated Model of Fire Growth and Smoke Transport
CFD	Computational Fluid Dynamics
CFR	Code of Federal Regulations
COOPRA	International Cooperative PRA Research Program
CSNI	Committee on the Safety of Nuclear Installations
EPRI	Electric Power Research Institute
FDS	Fire Dynamics Simulator
FIVE	Fire-Induced Vulnerability Evaluation
FPTAP	Fire Protection Task Action Plan
FRA	Fire Risk Assessment
FY	Fiscal Year
GDP	Gaseous Diffusion Plant
HRA	Human Reliability Analysis
IAEA	International Atomic Energy Agency
I&C	Instrumentation and Control
IEEE	Institute of Electrical and Electronics Engineers
INEEL	Idaho National Engineering and Environmental Laboratory
IPEEE	Individual Plant Examination of External Events
MOU	Memorandum of Understanding
NASA	National Aeronautics and Space Administration
NEI	Nuclear Energy Institute
NEIL	Nuclear Electric Insurance Limited
NFPA	National Fire Protection Association
NIST	U.S. National Institute of Standards and Technology
NMSS	Office of Nuclear Material Safety and Safeguards (NRC)
NPP	Nuclear Power Plant
NRC	U.S. Nuclear Regulatory Commission
NRR	Office of Nuclear Reactor Regulation (NRC)
OECD	Organization for Economic and Cooperation and Development
OSHA	Occupational Safety and Health Administration
PRA	Probabilistic Risk Assessment
PSA	Probabilistic Safety Assessment
R&D	Research and Development
RAI	Request for Additional Information
RES	Office of Nuclear Regulatory Research (NRC)
RG	Regulatory Guide
RIRIP	Risk-Informed Regulation Implementation Plan
SDP	Significance Determination Process
SFPE	Society of Fire Protection Engineers
SNL	Sandia National Laboratories
TBD	To Be Determined
UMD	University of Maryland

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Executive Summary

The results of numerous fire risk assessment (FRA) studies and the experience gained from actual fire events show that, depending on the design and operational characteristics of an particular nuclear power plant (NPP), a fire can be a significant or even dominant contributor to plant risk. To support its initiatives to increase the use of risk information in regulatory decision making, the U.S. Nuclear Regulatory Commission (NRC) therefore needs to ensure that this risk contribution is well characterized and understood. In particular, a number of ongoing NRC fire protection-related activities, including the development of a risk-informed, performance-based alternative to the current fire protection regulations in 10 CFR Part 50; support of the revised reactor oversight program; and identification of fire protection vulnerabilities requires FRAs of sufficient quality and accuracy to allow the confident use of their results and insights in the regulatory decision making process.

When used in a risk-informed decision making framework, FRA provides a systematic, integrated method for evaluating the importance of fire protection issues. However, the current FRA state-of-the-art is not as mature as that for assessing the risk contributions of many other important accident initiators in NPPs. To address the need for improved FRA, the Office of Nuclear Regulatory Research (RES) initiated a fire risk research program in FY 1998. The initial plan for this research program was issued in June 1999.

Since the issuance of the plan, NRC has identified a number of areas (including the reactor oversight program) requiring additional fire research (including FRA research) support, the nuclear industry has indicated a number of regulatory applications where increased use of FRA (and associated staff review) is expected, and the Advisory Committee on Reactor Safeguards (ACRS) expressed concern with the breadth and depth of the planned research activities (in terms of their ability to support the NRC's move towards risk-informed regulation). In order to address these needs, provide follow-up to the results of the FRA research to date, and provide details for activities anticipated (but not planned) in the initial plan, the NRC has updated the initial fire risk research plan. The updated plan includes a number of tasks whose results will not only be useful towards the development of improved FRA approaches, they will also support the NRC staff in its prioritization and resolution of current and potential fire protection regulatory issues.

This report documents the updated fire risk research program plan. It contains: an overall description of the research program (including the program objectives and vision, background issues, related regulatory activities, and related NRC and non-NRC research activities); the program's specific technical objectives; the overall technical approach and tasks; project management information; and a discussion of the plan for effectively communicating the program results. Table E1 lists the tasks included in the research program and Table E2 lists a number of key milestones. The report shows that the research program supports the NRC's Risk-Informed Regulation Implementation Plan (RIRIP), primarily by providing improved methods, tools, and data for calculating fire risk in support of risk-informed regulatory decision making. The research program also supports the RIRIP through the support of fire-protection related activities (e.g., the development of alternative fire protection standards for NPPs).

Table E1 - Fire Risk Research Program Technical Tasks, FY 2001-2002

Task	Title
1	Fire risk assessment methods, tools, and data development
2	Fire risk requantification study
3	Fire model benchmarking and validation
4	Fire risk assessment guidance development
5	Fire protection rulemaking support
6	Fire protection for nuclear power plants
7	Fire protection for gaseous diffusion plants
8	Fire significance determination process support
9	Fire risk assessment tools for precursor analysis

Table E2 - Fire Risk Research Program Key Milestones, FY 2001-2002

Milestone	Date
Database: Characteristics of components and fires	April 2001
Draft project plan: Performance of fire risk requantification study	May 2001
Report: Evaluation of fire models for use in regulatory activities	July 2001
Workshop: Fire risk assessment methods, tools, and data	August 2001
Report: Frequencies of challenging fires	September 2001
Report: Results of first international benchmarking exercise	October 2001
Report: Review of fire SDP and recommendations	October 2001
Report: Evaluation of existing fire detection models	March 2002
Report: Gaseous diffusion plant sprinkler system reliability study	September 2002
Report: Demonstration precursor analyses and guidance	September 2002

1. Introduction

This report documents the fire risk research program plan for Fiscal Years (FY) 2001-2002 currently being executed by the U.S. Nuclear Regulatory Commission (NRC) Office of Nuclear Regulatory Research (RES). The report describes the program objectives, the tasks being taken to accomplish these objectives, the intended uses of the program outputs, and the relationship between the research program and other related NRC programs. The report provides an update of the initial program plan [1,2], which was developed using the results of previous NRC-sponsored fire research activities (summarized in SECY-98-230 [3]). As discussed in Section 1.2.4, the update responds to the changing needs of ongoing fire protection regulatory activities, to the lessons learned from research performed to date, and to key comments received on the initial program plan.

Section 1 provides an overview of the current fire risk research program and of the program plan. The details of the program plan are provided in the remainder of the report.

1.1 Program Purpose and Objectives

The overall purpose of the fire risk research program is to support the NRC's Risk-Informed Regulation Implementation Plan (RIRIP) [4], which has been developed to implement the NRC's strategic plan, especially with respect to a number of the performance goals in the Nuclear Reactor Safety and Nuclear Materials Safety strategic arenas [5]. In particular, the program will develop fire risk assessment (FRA) methods, tools, data, results, and insights needed by the agency to perform risk-informed decision making.

The general objectives of the program are as follows.

- Improve qualitative and quantitative understanding of the risk contribution due to fires in operating nuclear power plants (NPPs) and other facilities regulated by the NRC.

- Support ongoing or anticipated fire protection activities in the NRC program offices,[1] including the development of risk-informed, performance-based approaches to fire protection for operating NPPs.

- Evaluate current fire risk assessment (FRA) methods and tools and develop improved tools (as needed to support the preceding objectives).

The specific technical objectives for FY 2001-2002 are listed in Section 2 of this report. Anticipated longer term activities (post-FY 2002) are discussed in Section 5. The RIRIP implementation activities supported by the program are listed in Appendix A.

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[1] The Office of Nuclear Reactor Regulation (NRR) and the Office of Nuclear Material Safety and Safeguards (NMSS).

1.2 Background

1.2.1 Risk Significance of NPP Fires and FRA

Depending on the design and operational characteristics of a particular NPP, fire can be a significant or even dominant contributor to the overall risk for that plant. A significant number of FRA studies have resulted in estimates of mean fire-induced core damage frequencies (CDF) of 10^{-4}/yr or greater, predicted contributions to total CDF (i.e., CDF from all contributors) of 20% or greater, or both [6,7]. Furthermore, a number of fire events, including the fires at Browns Ferry (U.S., 1975), Armenia (Armenia, 1982), and Narora (India, 1993), have been serious core damage precursor events [8].

Not all large NPP fires are significant from a public safety point of view, nor are all safety significant fires large. Differences in such details as the routing of key electrical cables, the separation and orientation of important cable trays and conduits, the fire protection scheme used for a particular compartment, and the procedures employed by plant operators in response to a fire can dramatically alter the risk significance of real and hypothesized fires. FRA is a quantitative tool for addressing these details and showing how they relate to risk.

The risk from fires at other nuclear facilities regulated by the NRC (e.g., gaseous diffusion plants) has been less well studied. However, the fire hazards involved and recent event experience (e.g., Portsmouth, U.S., 1998) indicate that FRA can be a useful tool for these facilities as well.

1.2.2 Related Risk-Informed Regulatory Initiatives

As stated in the NRC's policy statement on the use of Probabilistic Risk Assessment (PRA) [9], the NRC intends to increase the use of PRA technology in "all regulatory matters to the extent supported by the state-of-the-art in PRA methods and data." Recent general activities include efforts to make Part 50 of the Code of Federal Regulations (CFR) more risk-informed [10],[2] the revision of the reactor oversight process to incorporate risk information [11], and the development of a general framework for supporting licensee requests for changes to a plant's licensing basis, described in Regulatory Guide (RG) 1.174 [12].

In the area of U.S. operating NPP fire protection, the NRC is in the process of developing a risk-informed, performance-based alternative to the current fire protection regulations in 10 CFR 50.48 and Appendix R to Part 50 [13]. In support of this process, an industry consensus risk-informed, performance-based standard (NFPA 805) has been developed under the auspices of the National Fire Protection Association (NFPA) [14]. Among other things, the standard prescribes how risk information is to be used in determining the necessary features of a fire protection program for an operating NPP. The prescribed process is intended to be consistent with RG

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[2]As stated in Ref. 4, "A risk-informed approach to regulatory decision making represents a philosophy whereby risk insights are considered together with other factors to establish requirements that better focus licensee and regulatory attention on design and operational issues commensurate with their importance to public health and safety."

1.174. The standard also includes a non-mandatory appendix which describes the attributes of an acceptable FRA. Given the present maturity of the FRA state-of-the-art (see Section 1.2.3), this NFPA 805 appendix is written at a fairly high level, i.e., few details on specifically acceptable methods or models are presented. It is expected that later versions of the NFPA 805 standard will incorporate more details as the FRA state-of-the-art is improved.

Regarding fire protection efforts related to the revised NRC reactor oversight process, the NRC has developed a fire protection inspection program that explicitly uses risk information and PRA in identifying areas for inspection [15], and a fire protection inspection finding significance determination process (SDP) [16]. Risk-based performance indicators for fire issues [17] and a process for assessing the fire risk significance of inspection findings not associated with fire protection are being developed.

Other ongoing and potential near-term NRC applications of fire risk methods, results, and insights include: a) the identification of plant-specific vulnerabilities through the Individual Plant Examinations of External Events (IPEEE) program [18], b) the review of proposed industry methods to identify cables that need to be protected against the effects of fire [19], c) the review of analyses supporting proposed changes to specific parts of a plant's fire protection program using RG 1.174, and d) the assessment of the significance of core damage precursor events involving fires [20].

Looking past the NRC's immediate programs and needs, the general drive to increase the use of PRA technology in all regulatory activities (including licensing, inspection, and rulemaking) is expected to lead to an increased need for the ability to routinely estimate the risks associated with fires. The anticipated applications include but are not limited to fire protection concerns, since: a) many decisions will require a consideration of total plant risk (see RG 1.174 [12]) and fires can be important contributors to this total risk; and b) non-fire protection decision alternatives can impact a plant's fire risk.

1.2.3 FRA State-of-the-Art

Over the years, FRA has proven to be a useful tool for NPP designers, operators, and regulators. For example, FRA studies have been performed to support evaluations of the effectiveness of proposed design changes (e.g., see the Zion and Indian Point PRAs [21,22]), and to search for fire-related vulnerabilities and related plant improvements [6,18]. Ref. 23 explores other potential areas and applications where FRA tools may provide useful information.

It can be seen that, when used in a risk-informed decision making framework, FRA is useful in that it provides a systematic, integrated method for evaluating the importance of fire protection issues. However, as pointed out by the ACRS) [24] as well as others, the current FRA state-of-the-art is not as mature as that for assessing the risk contributions of many other important accident initiators. For example, reviews of some IPEEEs have identified situations where variations in FRA analytical assumptions can lead to orders of magnitude variations in estimates of fire-induced CDF, leading to qualitatively different risk insights. Concerns with gaps in current abilities to perform realistic FRAs have also been raised internationally [25].

Ref. 7 identifies specific topic areas where improvements in FRA methods, tools, and data will improve the ability of FRA to support decision making. These areas cover the three elements of fire protection defense-in-depth (fire prevention, fire detection and suppression, and fire mitigation).[3] They address such technical issues as the likelihood of severe fires, uncertainties and limitations in current fire models, configuration- and condition-sensitive fire protection system reliability, the mode-specific fragility of cables, and the response of plant operators to a specific fire. Ref. 7 also identifies topic areas where the fire risk implications of specific issues (e.g., lessons learned from major NPP fire events) need to be better clarified, and areas where programmatic improvements (e.g., regarding international cooperation) are needed. The list of topic areas, and the key subtopics under each topic area, is provided in Appendix B of this report.

1.2.4 Research Program Development and Status

To address the need for improved FRA, RES initiated a fire risk research program in FY 1998. Two key documents supporting the program development are Refs. 7 and 3. As discussed above, Ref. 7 identifies potential research topic areas, shown in Appendix B. These topic areas were identified using both a systematic review of the technical elements of FRA and a consideration of FRA issues raised in other references. Ref. 3 (SECY-98-230) summarizes the results of past NRC fire research efforts, with a focus on the fire risk implications of the results of these efforts.

Using the work underlying Refs. 7 and 3, a research program plan was developed [1]. As described in Ref. 1, the topic areas listed in Appendix B were prioritized in a process that involved input from cognizant fire protection and risk assessment staff in NRR, NMSS, and RES. Fifteen tasks were defined and assigned to a contractors from Sandia National Laboratories (SNL), the University of Maryland (UMD), and a number of engineering consulting firms, as well as RES staff (see Table 1). Presentations were made in meetings with the ACRS, industry, and fire safety researchers to discuss the overall purpose, scope, technical objectives, and schedule of the program. Work on the majority of the fifteen tasks is ongoing; the status of each task is shown in Table 1.

Since the initiation of the fire risk research program, a number of events with programmatic implications have occurred.

- A plan for developing a risk-informed, performance-based fire protection rule has been developed [13]. This plan states that the results of the fire risk research program will be used to support the development of NFPA 805 and the implementing guidance for NFPA 805.

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[3] In a typical FRA, the CDF contribution due to a given fire scenario (where a fire scenario is defined by the location and burning characteristics of the initiating fire) can be decomposed into three components: the frequency of the fire scenario, the conditional probability of fire-induced damage to critical equipment given the fire, and the conditional probability of core damage given the specified equipment damage. Detailed descriptions of the general FRA methodology are provided in a number of references (e.g., [26-30]).

! An initial version of the fire SDP has been developed and applied [16]. NRR has requested that RES support the refinement and improvement of this initial version through FY 2001 [31].

! The Nuclear Energy Institute (NEI) is developing an approach to use FRA methods and data in the identification of cables that need to be protected against the effects of fires [19]. The development process, which is being influenced by available results and insights of the fire risk research program (e.g., see [32]), is expected to be completed in March 2001.

Table 1. Fire Risk Research Program Technical Tasks Identified in Initial Program Plan

Task	Title	Lead	Status[1]
1	Tools for circuit failure mode and likelihood analysis	SNL	C
2	Tools for fire detection and suppression analysis	SNL	I
3	IEEE-383 qualified[4] cable fire frequency analysis: feasibility study	SNL	I
4	Fire modeling toolbox: input data and assessment	SNL	I
5	Experience from major fires	SNL	C[2]
6	Industrial fire experience	SNL	I
7	Frequency and characteristics of switchgear and transformer fires	SNL	I
8	Fire barrier reliability model development and application	SNL	I
9	Integrated model and parameter uncertainty	UMD	C
10	Frequency of challenging fires	[3]	C/I[3]
11	Fire model limitations and application guidance	NRC	I
12	Risk significance of turbine building fires	NRC	I
13	Penetration seals	NRC	I
14	Risk significance of multiple unit interactions	NRC	I
15	Use of advanced fire models in fire risk assessment	NRC	I

Notes:
1) C = complete; I = in progress. Details on task status are provided in Section 3.
2) Technical work is complete; final report is under preparation.
3) Phase 1 of the task is complete; it involved independent efforts by Buttonwood Consulting, Inc.; Information Systems Laboratories, Inc.; and WS Atkins, Ltd. Phase 2 of the task is in progress; Buttonwood Consulting, Inc. has the task lead.
4) The term "rated" was used in Ref. 1.

- The ACRS reviewed the fire risk research program in 1999 and found that the program lacked a "well-developed plan to show that these [fire protection] research activities will, in fact, yield the kinds of tools that the agency will need in its move toward risk-informed regulation" [33]. More recently, the ACRS expressed concerns with the breadth and depth of the ongoing research activities, and recommended that the NRC staff "develop and carry out a defensible strategy for the improvement of its capabilities to perform fire risk assessment" [34].

- Research results have been obtained from a number of the tasks listed in Table 1 (see Section 1.3 below). Some of these results indicate areas where additional work is needed to achieve the program objectives. (See Section 3.)

- A number of cooperative activities with industry and international organizations have been established (see Section 1.4).

The implied requirements from the events listed above, together with the need to plan for anticipated research activities identified in Ref. 1 (especially the fire risk requantification effort discussed in Section 6 of that report), indicate that the fire risk research program plan presented in Ref. 1 needs to be revised. This report documents the plan revision.

1.3 Program Outputs and Regulatory Uses

In addition to the previously mentioned planning documents [1,2,3,7], key outputs of the fire risk research program and their uses include the following:

- A research report summarizing the results of Task 1 in Table 1, "Tools for Circuit Failure Mode and Likelihood Analysis" [32]. The report evaluates currently available data for fire-induced cable failures; indicates that, for many situations relevant to operating plants, the conditional likelihood of fire-induced short circuits (given fire-induced cable damage) appears to be relatively high; proposes a method for estimating this likelihood for a broader set of situations; and proposes an improved method for treating fire-induced circuit failures in FRAs. The report results have been used to support the evaluation of inspection findings, the development of NFPA 805, and NRC reviews of proposed industry approaches (including the use of FRA tools and the results of new experiments) for addressing fire-induced circuit failures.

- A draft research report summarizing the results of Task 5 in Table 1, "Experience from Major Fires" [7]. The report reviews, from an FRA methods standpoint, a number of notable U.S. and international NPP fires. The report identifies a number of observed phenomena (e.g., the occurrence of multiple fires) which are not treated in current FRAs. A number of these findings are addressed in the revised fire risk research program. The report is being prepared for publication as a NUREG/CR report.

- A database containing data from a series of NRC-sponsored full scale enclosure fire tests designed to support the validation of compartment fire models [35]. The database, which has been widely distributed, was used to support an evaluation of an Electric Power Research Institute (EPRI)-recommended fire modeling approach (regarding the use of heat

loss factors, as described in Ref. 29) used in a number of IPEEEs, to generate associated Requests for Additional Information (RAIs), and to support discussions with EPRI concerning revised guidance in this area. It will support ongoing international efforts to benchmark a number of fire models (see Section 1.4 below).

! A formal approach for treating model and parameter uncertainties in a consistent framework and a demonstration of that approach to a number of fire modeling issues [36]. The results of this work will be applied in upcoming work (especially the fire risk requantification effort discussed in Section 3.3 below); they are aimed at addressing the ACRS' concerns with the quantification of uncertainties in FRA [34].

As ongoing and future tasks are completed, the program is expected to produce new FRA-relevant knowledge (e.g., analyses of experimental results), recommendations (e.g., areas where improved analytical tools are needed to support regulatory decision making), methods (e.g., for quantifying the likelihood of fire-induced circuit failures), data (e.g., for cable damage temperatures), and guidance (e.g., appropriate methods for applying the research results). To support the regulatory applications discussed in Section 1.2.2, these results will be disseminated through a variety of means, including research reports and papers, a public workshop, and presentations to the NRC Fire Research Coordinating Committee (see Section 1.4.1 below). Additional details on the communication of the research results are provided in Section 5 of this report.

1.4 Relationship with Other Ongoing Research Programs and Activities

1.4.1 NRC Programs and Activities

RES has five ongoing programs and projects with activities directly relevant to FRA: the IPEEE program, the human reliability analysis (HRA) methods development program, a program investigating the effects of smoke and soot on digital instrumentation and control (I&C) systems, a project developing an updated fire events database, and a project to identify potential risk-based performance indicators.

As stated in Refs. 17 and 37, the primary goal of the IPEEE program is for the licensees to identify plant-specific vulnerabilities to severe accidents due to "external events" (including internal fires) that could be fixed with low-cost improvements. RES is responsible for the review of the licensee submittals; the final draft report on the insights gained from the IPEEE process is scheduled for completion in 2001. This report will: a) describe the overall IPEEE process, findings, and conclusions regarding the dominant risk contributors for the major areas of evaluation (including internal fires); b) summarize the plant improvements made by licensees resulting from their IPEEE analyses; c) describe the overall technical strengths and weaknesses of the IPEEE submittals; and d) assess the effectiveness of the IPEEE program in meeting its stated objectives. Plant-specific insights developed during the review process are documented in publically available Technical Evaluation Reports.

The RES IPEEE program has provided input to the identification and prioritization of potential research topics relevant to the present fire risk research program. Specific topics identified during the IPEEE submittal reviews and included in the fire risk research program

include the study of IEEE-383 qualified cables (Task 3 in Table 1) and the investigation of turbine building fires (Task 12 in Table 1). For its part, the fire risk research program has provided information supporting the resolution of RAIs, as discussed in Section 1.3 above. A number of research program task results (e.g., regarding the likelihood of fire-induced circuit failures), are also expected to support the development of the IPEEE insights report.

In the area of HRA, work has been initiated to:

- Characterize current FRA treatments of plant operator performance given complex fire response procedures.

- Develop insights regarding the risk associated with the impact of fires and fire-induced failures on operator situation assessment, decision making, and associated actions.

- Develop insights regarding the application of an improved HRA method, ATHEANA (A Technique for Human Event Analysis) [38], to fire scenarios.

- Develop recommendations for FRA improvements and areas for further investigation.

The results of this work will be used to support the fire risk requantification effort discussed in Section 3.

Regarding the work on digital I&C, RES has sponsored a number of experiments investigating the vulnerability of electronic components to the effects of smoke and soot [39,40]. This work has identified an important failure mode (circuit bridging) and its potential functional effects. A follow-on NUREG/CR report addressing the impact of smoke on digital I&C and electronic components is expected to be released shortly.

Regarding the database project, RES staff are currently working on an update of an earlier analysis of fire events at U.S. operating NPPs [41]. This update includes additional data from more recent events (up through 1999) obtained from NRC and industry sources.

Regarding the performance indicator work, RES is investigating the feasibility of various risk-based performance indicators to potentially enhance the reactor oversight process [17]. These indicators are intended to: a) assess the potential risk impact of degraded equipment performance, b) be based on performance data for risk-significant equipment, c) detect changes in performance in a timely manner, and d) support the use of performance thresholds in a manner consistent with the graded approach described in SECY-99-007 [42]. The possibility of indicators for fire protection is being investigated as part of this work. A draft report has been recently released for public comment [43], and public meetings to discuss these comments are scheduled for early 2001.

Finally, it should be noted that the NRC has established a Fire Research Coordinating Committee with members drawn from NRR, NMSS, and RES. The purpose of the committee is to provide management oversight and review of all NRC fire research activities.

1.4.2 Other Programs and Activities

The NRC has a number of activities with industry and international organizations aimed at enhancing the exchange of fire-risk related information and thereby improving the efficiency of the research programs of all participants.

Regarding its interactions with the nuclear industry, the NRC and EPRI have a Memorandum of Understanding (MOU) addressing, among a number of topics, cooperative fire risk research and development (R&D) [44]. The objectives of the fire risk portion of the MOU are: to ensure the timely exchange of information (e.g., objectives, milestones) on planned and ongoing activities; to ensure the sharing of data needed by the NRC and EPRI R&D programs; and to ensure the timely sharing of R&D results and tools. To date, this MOU has enabled the exchange of exchange of a number of research reports and the joint discussion of each organization's fire risk research plans.

Outside of the nuclear arena, the NRC staff is also involved with activities involving the NFPA (e.g., by participating on the technical committee developing NFPA 805 and by participating on a technical committee for fire risk assessment methods) and the Society for Fire Protection Engineers (SFPE) (e.g., by participating in meetings and contributing to the SFPE Handbook).

The NRC has also established an MOU with the National Institute of Standards and Technology (NIST) Building and Fire Protection Laboratory (BFRL), U.S. Department of Commerce (see Section 3.4). The NRC and the NIST BFRL have recognized that ties between the two organizations are mutually beneficial and can lead directly to increased effectiveness in accomplishing their respective missions. In recognition of mutual interests in fire computer codes, an agreement has been entered into under which NIST will provide support to the NRC staff in the development of skills and expertise in the use of NIST fire computer codes. The main objective of the NRC is to develop in-house staff expertise in the use of the NIST fire computer codes to analyze NPP fire issues, and support NRC's emerging risk-informed, performance-based regulatory framework for fire protection.

Internationally, RES is participating in a number of cooperative activities relevant to NPP fire safety. Formal interactions include RES' participation on the Organization for Economic and Cooperation and Development (OECD)/Committee on the Safety of Nuclear Installations (CSNI), which has developed an FRA state-of-the-art report [25] and RES' participation in the International Cooperative PRA Research Program (COOPRA). A third activity is the recently initiated International Collaborative Project to Evaluate Fire Models for Nuclear Power Plant Applications [45]. Through these activities, the fire risk research program has collected and is continuing to collect information on a number of subjects (e.g., the objectives, characteristics, and results of recent fire tests performed in France; fire event data from Canada) relevant to the program's objectives and activities.

1.5 How To Use This Report

The remainder of this report covers the fire risk research program's specific technical objectives (Section 2); project leadership, schedule, and milestone information (also Section 2); the overall technical approach and tasks (Section 3); a discussion of the plan for effectively

communicating the program results (Section 4); and a discussion of potential activities following FY 2002. The list of references is provided following Section 5. Appendix A identifies the NRC's RIRIP implementation activities addressed by the research program; Appendix B lists the FRA research areas identified in the state-of-the-art review performed at the beginning of the research program [7].

Readers interested in a project overview should consult Section 2, Section 3.1 (which includes a list of the current and completed tasks), Section 4, and Section 5. Readers interested in the details of a specific task should consult Section 3; this section provides the technical objectives and approach for each task, as well as limited background notes concerning the motivation for the task.

2. **Technical Objectives and Project Management, FY 2001-2002**

2.1 Technical Objectives

The technical objectives of the fire risk research program over FY 1998-2000 are documented in Ref. 1. These objectives are, for the most part, aimed at improving the FRA state-of-the-art to a level which is, loosely speaking, comparable in quality to that for current PRA for other internal events.

In FY 2001-2002, the fire risk research program will complete these FRA improvement activities. In addition, the program includes a task involving the application of the resulting FRA methods, tools, and data. The purpose of this fire risk requantification study is to develop insights regarding both fire risk and FRA. Other tasks support the fire protection rulemaking and oversight processes, nuclear materials safety activities, and the dissemination of FRA research lessons learned to the NRC staff, industry, and the public.

The specific objectives for FY 2001-2002, organized by the overall program objectives stated in Section 1.1, are as follows.

I. Improve qualitative and quantitative understanding of the risk contribution due to fires in operating NPPs.
   - A. Develop fire risk results and insights (e.g., regarding key risk contributors) from the application of improved FRA methods, tools, and data to operating plants.
   - B. Develop insights regarding the FRA topics identified in Ref. 7.

II. Support ongoing or anticipated fire protection activities in the NRC program offices, including the development of risk-informed, performance-based approaches to fire protection.
   - A. Support the development of a risk-informed, performance-based fire protection rule.
   - B. Support the improvement of the fire SDP.
   - C. Develop methods, tools, and data for analyzing the risk significance of fire-related operational experience.
   - D. Develop methods, tools, and insights for nuclear materials applications.

III. Evaluate current FRA methods and tools and develop improved tools (as needed to support the preceding objectives).
   - A. Complete the FRA methods and tool development activities started in FY 1998 (see Table 1).
   - B. Develop insights regarding the application of these methods in practical studies.
   - C. Develop guidance concerning the practical application of these methods in plant-specific studies.
   - D. Support international activities involving the benchmarking of existing computer fire models, and the development of improved computer fire models for use in nuclear safety applications.

2.2 Project Management

2.2.1 Key Personnel

Technical Oversight:	N. Siu (NRC/RES)
Project Management:	H. Woods (NRC/RES)
Principal Investigator, Tasks 1[4] and 3:	M. Dey (NRC/RES)
Principal Investigator, Tasks 1-2, 5-6[5], 8	S. Nowlen (SNL)

2.2.2 Tasks and Milestones

The tasks to be performed during FY 2001-2002 are listed in Table 2. (Details on the tasks are provided in Section 3.) Table 2 also identifies those tasks either formally requested through a user need letter, or identified in formal correspondence as being required to resolve an existing fire protection issue.

Figure 1 provides a summary schedule for the tasks listed in Table 2 and Table 3 lists the associated milestones. Post-FY 2002 anticipated activities are not addressed in these tables, but are discussed in Section 5.

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[4]Lead for fire detection modeling portion of Task 1.

[5]Lead for the cable testing portion of Task 6.

Table 2. Fire Risk Research Program Technical Tasks, FY 2001-2002

Task	Title	User Need Statement
1	Fire risk assessment methods, tools, and data development	SECY-98-247[a,b]
2	Fire risk requantification study	
3	Fire model benchmarking and validation	
4	Fire risk assessment guidance development	
5	Fire protection rulemaking support	
6	Fire protection for nuclear power plants	
7	Fire protection for gaseous diffusion plants	
8	Fire significance determination process support	User Need Letter[c]
9	Fire risk assessment tools for precursor analysis	

[a]The issue of explosive electrical faults, dispositioned to the fire risk research program in SECY-98-247 [55], is addressed under Task 1. (See the summary discussion on switchgear and transformer fires in Section 3.2.2 of this report and the more extended discussion in Section 3.7 of the FY 1998-2000 fire risk research program plan [1].)

[b]The issue of fire detection methods, dispositioned to the fire risk research program in SECY-98-247 [55], is addressed under Task 1. (See Section 3.2 of this report.)

[c]Task 8 (see Section 3.9) responds to a user need letter requesting support of the reactor oversight process [31].

Table 3. Fire Risk Research Program Milestones, FY 2001-2002 (Page 1 of 2)

Task	Milestone	Date	Objectives Supported[1]	Other Tasks Supported[2]
1	Report: Significance of smoke effects	October 2000	IB, IIIA	2, 8, 9
1	Database: Characteristics of components and fires	April 2001	IB, IIIA	2, 8, 9
1	Report: Fire protection system reliability	April 2001	IB, IIIA	2, 7-9
1	Report: Circuit analysis and fire-induced spurious actuations	May 2001	IB, IIIA	2, 6-9
1	Workshop: Fire risk assessment methods, tools, and data	August 2001	IB, IIIA	2, 6-9
1	Report: Frequencies of challenging fires	September 2001	IB, IIIA	2, 8, 9
1	Report: Reliability of fire barriers	December 2001	IB, IIIA	2, 9
1	Report: Self-ignited cable fires	December 2001	IB, IIIA	2, 9
1	Report: NPP switchgear and transformer fires	December 2001	IB, IIIA	2, 9
1	Report: Evaluation of existing fire detection models	March 2002	IB	2
1	Report: Lessons learned from industrial fires	September 2002	IB, IIIA	
1	Report: Improved fire detection models	September 2002	IB	2
2	Draft Project Plan: Performance of requantification study	May 2001	IA, IB, IIIB	4
2	Final Project Plan: Performance of requantification study	June 2001	IA, IB, IIIB	4
2	Complete technical preparation	December 2001	IA, IB, IIIB	4
2	Initiate requantification analyses	TBD[3]	IA, IB, IIIB	4
2	Report: Requantification study	TBD[3]	IA, IB, IIIB	4

[1] Identifies directly supported objectives (see Section 2.1). A number of milestones also provide indirect support to additional objectives.
[2] Task descriptions are provided in Section 3.
[3] TBD = To be determined. (See Section 3.3.4.)

Table 3. Fire Risk Research Program Milestones, FY 2001-2002 (Page 2 of 2)

Task	Milestone	Date	Objectives Supported	Other Tasks Supported
2	Workshop: Requantification study results and insights	TBD[3]	IA, IB, IIIB	4
2	Report: Ability of FRA to support risk-informed regulation	TBD[3]	IA, IB, IIIB	4
3	Report: Evaluation of fire models for use in regulatory activities	July 2001	IIIA, IIID	1,2
3	Proposal: First full-scale test for fire model validation	August 2001	IIIA, IIID	1,2
3	Report: Results of first international benchmarking exercise	October 2001	IIIA, IIID	1,2
3	Test: First full-scale test for fire model validation	June 2002	IIIA, IIID	1,2
3	Report: Results of first international standard problem exercise	September 2002	IIIA, IIID	1,2
4	Report: NRC FRA guidance needs	July 2002	IIIC	
4	Report: Draft FRA guidance	TBD[4]	IIIC	
6	Report: Results of full-scale fire tests for circuit failures	April 2001	IB, IIA, IIIA	1
7	Report: Sprinkler system reliability study	September 2002	IID	
7	Report: Combustible liquids properties study	September 2002	IID	
8	Report: Review of fire SDP and recommendations	October 2001	IIB	
9	Report: Evaluation of existing precursor analysis methods	April 2002	IIC	
9	Report: Proposed precursor analysis method	June 2002	IIC	
9	Report: Demonstration precursor analyses and guidance	September 2002	IIC	

[3] TBD = To be determined. (See Section 3.3.4.)
[4]See Section 3.5.4.

Task	Description	Start	End	FY 2001/1	FY 2001/2	FY 2001/3	FY 2001/4	FY 2002/1	FY 2002/2	FY 2002/3	FY 2002/4
1	**Fire risk assessment tool development***	10/01/2000	09/30/2002								
2	**Fire risk requantification study****	10/01/2000	09/30/2002								
3	**Fire model benchmarking and validation**	10/01/2000	09/30/2002								
4	**Fire risk assessment guidance development*****										
5	**Fire protection rulemaking support******										
6	**Fire protection for nuclear power plants**	10/01/2000	09/30/2002								
7	**Fire protection for gaseous diffusion plants**	10/01/2001	09/30/2002								
8	**Fire significance determination process support**	10/01/2000	10/31/2001								
9	**Fire risk assessment tools for precursor analysis**	12/01/2001	06/30/2002								

Notes:

*Most subtasks completed in FY 2001; FY 2002 activity involves fire detection modeling and review of industrial fire experience.
**Study planning and preparation activities through December 2001.
***Survey of FRA guidance needs.
****Schedule and milestones are dependent on rulemaking schedule under review.

Figure 1. Fire Risk Research Program Summary Schedule

3. Technical Approach

3.1 Summary of Approach

The fire risk research program technical tasks for FY 2001-2002 are listed in Table 2. These tasks represent: tasks identified in the initial program plan [1]; necessary follow-on efforts identified as a result of research efforts; or tasks associated with specific NRR and NMSS needs. Note that the task numbering is different from that provided in Ref. 1; tasks indicated as being "in progress" in Table 1 have been subsumed into the tasks listed in Table 2 (see the mapping in Table 4).

Section 3.2 provides, for each task, the task objectives, a brief description of the technical approach, the task lead, and key milestones.

3.2 Task 1 - Fire risk assessment methods, tools, and data development

The purpose of this task is to develop improved FRA methods, tools, and data. This generally involves the completion of a number of the FRA development tasks initiated in FY 1998-2000 (see Table 4) and the treatment of issues identified as a result of the FY 1998-2000 work.

Note that the FY 1998-2000 tasks were developed based upon a systematic review of the current FRA state-of-the-art, as discussed in Ref. 7. The process used to prioritize the issues identified in this review is summarized in Appendix B of this report. Ref. 1 provides a more detailed technical discussion regarding the motivation and approach for each of the FY 1998-2000 tasks.

3.2.1 Task 1 - Objectives

The objectives of this task are to:

- develop the technical basis for estimates of the conditional likelihood of fire-induced spurious component actuations (given fire-induced cable damage) that account for key scenario-specific factors;
- develop configuration- and condition-sensitive fire protection system reliability and effectiveness estimates, including guidance for application;
- determine the feasibility of estimating the frequency of self-ignited fires involving flame-spread resistant cables;
- develop a database for important fire-related component characteristics (including mode-specific thermal fragilities for cables and characteristic heat release rates);
- develop guidance for identifying scenarios for which smoke effects may be risk significant;
- develop insights from non-nuclear industrial fires relevant to current FRA practices;

- characterize the likelihood and consequences of NPP switchgear and indoor transformer explosive faults and subsequent fires;

- develop estimates of the reliability and effectiveness of fire barriers based upon currently available nuclear and relevant non-nuclear experience;

- develop estimates of the frequencies of challenging fires that account for key scenario-specific factors;

- assess the adequacy of current methods for analyzing fire scenarios in turbine buildings; and

- evaluate existing analytical tools to model and predict fire detection and develop (as needed) improved tools.

Table 4. Mapping Between FY 1998-2000 Tasks [1] and FY 2001-2002 Tasks

	Task ID	
Title	1998-2000	2001-2002
Tools for circuit failure mode and likelihood analysis	1	Completed
Tools for fire detection and suppression analysis	2	1
IEEE-383 rated cable fire frequency analysis: feasibility study	3	1
Fire modeling toolbox: input data and assessment	4	1
Experience from major fires	5	Completed
Industrial fire experience	6	1
Frequency and characteristics of switchgear and transformer fires	7	1
Fire barrier reliability model development and application	8	1
Integrated model and parameter uncertainty	9	Completed
Frequency of challenging fires	10	1
Fire model limitations and application guidance	11	3
Risk significance of turbine building fires	12	1
Penetration seals	13	[a]
Risk significance of multiple unit interactions	14	2
Use of advanced fire models in fire risk assessment	15	3

[a]Task terminated due to resource constraints and low user-office priority [57].

3.2.2 Task 1 - Description of approach

Given the varied nature of the technical objectives for this task, a number of approaches will be used to achieve these objectives. Additional details and discussion can be found in Refs. 1 and 7.

Regarding the conditional likelihood of fire-induced component actuations (given fire-induced cable damage), data identified during the FY 1998-2000 work documented in Ref. 32, and data from ongoing EPRI/NEI cable tests (being performed in connection with the development of a risk-informed approach to circuit analysis [56]) will be analyzed to support an EPRI-sponsored expert elicitation activity. Under the MOU with EPRI (see Section 1.4.2) and Task 6 below (see Section 3.7), RES is cooperating in both the cable tests (through a review of the test plan and the provision of an insulation resistance testing apparatus) and the expert elicitation (through the support of an expert participant. RES will review the EPRI and NRC data resulting from the cable tests and will document its conclusions in a NUREG/CR report (that also contains the material published in Ref. 32).

Regarding the analysis of fire detection and suppression reliability and effectiveness, an existing network model [46, 47] will be updated using recently available fire event data. (A review of the model and recommended modifications is presented in Ref. 48.) Available information on fire protection system reliability relevant to treating system- and configuration-sensitive effects (e.g., the effect of maintenance unavailability, the effect of fire protection code non-compliances) will be reviewed and incorporated into the model, as appropriate. Information on suppression system effectiveness, misdirected manual suppression efforts, and the effectiveness of compensatory measures (with respect to fire suppression) will be collected and evaluated.

Regarding the likelihood of self-ignited cable fires involving flame-spread resistant cables (e.g., IEEE-383 qualified cables), currently available data relevant to NPP cable fires will be reviewed to determine if there is an adequate basis for developing fire frequency estimates. If such data are not available, this activity will investigate the feasibility of developing a practical approach for estimating the frequency of such fires based upon the phenomenology of such fires.

Regarding the component characteristic database, open literature reports have been reviewed for relevant information on the thermal properties of cables (including ignitability, effects of radiation feedback and oxygen depletion, damageability), the damageability of other components, and heat release rates associated with typical NPP fire sources. A Microsoft Access® database containing either the actual data, or references to appropriate reports, will be created. The database will also include an evaluation of key factors (e.g., potential biases) affecting the use of the data in FRA.

Regarding the guidance for identifying potentially important scenarios involving smoke generation and propagation, experiments investigating the vulnerability of electronic components [39,40] and high voltage equipment have been performed. The FRA implications of the experimental results will be developed based upon an evaluation of the data.

Regarding switchgear and indoor transformer fires, methods and data to estimate the frequency and magnitude of low- to medium-voltage switchgear (480V to 6900V) and indoor transformers feeding these switchgear will be investigated. This activity will consider both thermal and mechanical (e.g., blast) effects.

Regarding the reliability of fire barriers, currently available information on fire barrier performance and reliability (including information obtained from a review of industrial fires at non-nuclear facilities), as well as information on current methods for predicting barrier performance and reliability, will be reviewed. Best analysis practices will be identified and recommendations regarding potential improvements will be developed.

Regarding the frequency of challenging fires, a model will be developed to handle the early stages of the fire development. This model will be supported by qualitative and quantitative information from actual industrial fire events (including events at non-nuclear facilities) and fire tests. It will also be supported by evaluations of the likelihood of self-ignited electrical cable fires and of the characteristics of switchgear and transformer fires. The model will provide a framework for an expert elicitation process, which will address the likelihood and the physical characteristics of fires at operating NPPs.

Regarding the non-nuclear industrial fires, data and event narratives from industrial fires involving equipment and occupancies similar to those found in nuclear power plants will be reviewed. This review may provide useful qualitative information (e.g., how well do operators perform in degraded environments) as well as indications of the relative likelihood of different scenarios (e.g., low intensity vs. severe switchgear fires). The results of this review will be used to supplement the results of the activities discussed above.

Regarding current FRA treatments of turbine building fires, this task will review available literature for information concerning the frequency-magnitude relationship for turbine building fires and to determine the adequacy of current FRA tools for predicting the environment induced by a severe turbine building fire.

Regarding the development of tools for modeling fire detection, a number of simple tools are available for use in simple building environments. The applicability of these tools to NPP-specific conditions (including obstructions, ventilation, and source fire concerns) will be evaluated. Using the results of Task 3 (see Section 3.4), practical methods for using field models (CFD) either directly or indirectly (e.g., through the modification of existing simple models) will then be developed, if needed. A number of applications will be performed to demonstrate these methods. Finally, inspection guidance will be developed based on the results of these applications.

Available results from the above FRA methods and data development activities will be discussed in a public workshop to be held late in FY 2001. It is expected that the workshop will be coordinated with an international seminar on fire protection in NPPs, tentatively scheduled for August 2001.

3.2.3 Task 1 - Lead organization

The majority of the Task 1 work will be performed by SNL. The framework for dealing with challenging fires and the expert elicitation process will be performed by Buttonwood Consulting, Inc. NRC/RES staff will have the lead responsibility for developing improved fire detection models.

3.2.4 Task 1 - Milestones

Most of the following milestones represent the completion of FY 1998-2000 activities aimed at improving specific portions of FRA. Many of these activities are relatively independent; the one exception is the activity developing lessons from industrial fires. Depending upon the availability of data for such fires, the results of this activity may be useful for the fire barrier reliability, self-ignited cable fire, switchgear/transformer, and challenging fire activities.

Note that the changes in the schedule (as compared with the schedule provided in Ref. 1) are due to both re-prioritizations of efforts to accommodate other high-priority RES activities and project scope changes (e.g., requirements for more in-depth analysis of specific topics).

!	Report: Significance of smoke effects	October 2000
!	Database: Characteristics of components and fires	April 2001
!	Report: Fire protection system reliability	April 2001
!	Report: Circuit analysis and fire-induced spurious actuations	May 2001
!	Workshop: FRA methods, tools, and data	August 2001
!	Report: Frequencies of challenging fires	September 2001
!	Report: Reliability of fire barriers	December 2001
!	Report: Self-ignited cable fires	December 2001
!	Report: NPP switchgear and transformer fires	December 2001
!	Report: Evaluation of existing fire detection models	March 2002
!	Report: Lessons learned from industrial fires	September 2002
!	Report: Improved fire detection models	September 2002

The results of this task, combined with the results of work completed in FY 1998-2000, will provide much of the information needed to perform the fire risk requantification study (see Task 2 below). In addition, some of these results will support the review of the fire SDP (see Task 8, Section 3.9) and the development of fire-initiated precursor analyses (see Task 9, Section 3.10). The fire suppression modeling and the fire characteristics database activities will also support the work supporting gaseous diffusion plant applications (see Task 7, Section 3.8). Finally, the early results of the detection modeling activity are likely to qualitatively support the fire risk requantification study (see Task 2, Section 3.3). However, the complexity of the detection analysis issue (due to concerns with the applicability of available modeling tools and data) is likely to prevent its completion in time to provide quantitative support to the fire risk requantification study.

3.3 Task 2 - Fire risk requantification study

This task is intended to update the current state of knowledge regarding fire risk by updating a number of existing FRAs using the improved FRA methods, tools, and data developed under Task 1, the results of the HRA/FRA work performed under the ATHEANA program, and the fire modeling research conducted under Task 3. The study will also provide insights concerning the applicability of results generated using earlier FRA methods, recommendations as to how the improved methods should be used in practical applications, and areas where further work is needed to better understand the risk contribution due to fires at operating NPPs.

3.3.1 Task 2 - Objectives

The objectives of this task are to:

- develop, for a limited number of plants, state-of-the-art FRA estimates (including uncertainty) of the fire-induced CDF that reflect the use of the improved FRA methods, tools, and data developed under Tasks 1 and 3, and under related RES programs (including the HRA program);

- determine the qualitative and quantitative impact on predicted fire CDF associated with the use of these improved FRA methods, tools, and data;

- develop insights regarding the applicability of results generated using earlier FRA methods, tools, and data (including those used in the IPEEE fire analyses);

- develop insights regarding the FRA topics identified in Ref. 7;

- develop examples for the practical use of the Task 1, Task 3, and other RES program results and recommendations in plant-specific studies; and

- identify remaining areas where further improvements in FRA methods, tools, and data are needed to significantly improve the current understanding of fire risk at operating NPPs.

3.3.2 Task 2 - Description of approach

To accomplish the above objectives, a limited number of existing FRAs will be updated to include the improved FRA and HRA methods, tools, and data developed under the fire risk research and the ATHEANA programs. The updating will address all aspects of FRA; i.e., it will not be limited to FRA topics for which improved methods have been developed under either Task 1and Task 3 of this program or the ATHEANA program. One example of such a topic is the treatment of fire-induced main control room abandonment. In general, it is anticipated that this task will involve limited methods development activities to: a) address specific topic areas, and b) employ the Task 1 and Task 3 results in the context of a practical study. Note that the task on multiple unit interactions discussed in the original fire risk research program plan (see Task 14 of Ref. 1) is now included as part of this task.

To ensure realistic results, this task will require close cooperation between the NRC and industry. It is currently expected that the task will be performed as a cooperative research activity with EPRI under a modified version of the existing MOU (see Section 1.4.2). It is hoped that the FRAs to be updated will represent a range of plant types (e.g., boiling water reactors vs. pressurized water reactors), plant ages, and FRA types (e.g., vulnerability analyses performed using the Fire-Induced Vulnerability Evaluation [49] - FIVE - method vs. detailed FRAs). The potential for applying the updated FRAs to evaluate specific issues at a plant will also be a consideration in the selection of plants to be analyzed. The precise plants to be analyzed, the specific analysis objectives, the project milestones, and the roles and responsibilities of the participating organizations will be developed through discussions with EPRI in FY 2001. The results of these discussions will also determine the amount of RES resources needed to perform each study. This, in turn, will affect the number of plants that can be analyzed.

It is currently expected that the results of the requantification study will be discussed at a public workshop. The study and the subsequent workshop discussions will be considered by the NRC staff in an evaluation of the ability of state-of-the-art FRAs (as represented by the updated FRAs) to support a wide variety of risk-informed regulatory applications.

3.3.3 Task 2 - Lead organization

SNL is expected to be the lead organization for NRC's contribution to Task 2 (including the HRA). Note that the HRA will be performed under the RES HRA program, since the requantification effort will support the development of ATHEANA. It is also expected that NRC staff will perform technical analyses (e.g., fire modeling) in support of this task. Depending on the results of discussions with EPRI, industry staff and contractors may perform a significant portion of the technical analyses as well.

The NRC staff will take the lead in evaluating the results of the requantification study (from the perspective of determining the ability of state-of-the-art FRAs to support risk-informed regulatory applications).

3.3.4 Task 2 - Milestones

!	Draft Project Plan: Performance of requantification study	May 2001
!	Final Project Plan: Performance of requantification study	June 2001
!	Complete technical preparation	October 2001
!	Initiate requantification analyses	TBD
!	Report: Requantification study results and insights	TBD
!	Workshop: Requantification study results and insights	TBD
!	Report: Ability of FRA to support risk-informed regulation	TBD

As indicated in the previous section, this task requires close cooperation with industry. A definite schedule for the technical analyses will be established following discussions with EPRI and participating utilities.

The results of this task will support the development of FRA guidance, as discussed under Task 4 below.

3.4 Task 3 - Fire model benchmarking and validation

Fire modeling, the prediction of the dynamic physical environment induced by a fire, plays an important role in FRA. Fire models are currently used in FRAs to predict which plant components (including cables) might be affected during the course of a postulated fire scenario, and to estimate when damage will occur. (Some of the available fire models can also be used to characterize smoke generation and transport, although these capabilities have not, to the staff's knowledge, been exercised in U.S. NPP FRAs.) The analysis generally involves the estimation of the time-dependent temperature and heat fluxes potentially affecting target components. It requires the treatment of a variety of phenomena as the fire grows in size and severity, including the spread of fire over the initiating component (or fuel bed), the characteristics of the fire plume and ceiling jet, the ignition of additional combustibles, the development of a hot gas layer, and the propagation of the hot gas layer or fire to adjacent compartments. It also requires an appropriate treatment of uncertainties in the structure and parameters of the models used to perform the analysis.

Current U.S. NPP FRAs use quite simple zone model-based tools, e.g., the correlations provided as part of the FIVE method [49] and the COMPBRN IIIe computer code [50], to predict the thermal environment due to a variety of fire sources, including cable tray, electrical cabinet, and oil pool fires. However, it is not always recognized in FRAs that these tools have been developed to address specific classes of fire problems and are not applicable to all situations. For example, the inherent modeling assumptions in both FIVE and COMPBRN do not address many practical complexities (e.g., obstructions in the fire plume, complex compartment geometry, complexities in forced ventilation flow, physical movement of fuel, room flashover) which can be important in some analyses. Further, the correlations employed implicitly or explicitly by these models are not appropriate for all situations. Some scenarios of potential concern include very small fires (e.g., single wire electrical insulation fires), very large fires (e.g., very large oil spill fires), or elevated fires. To date, the limitations of these simple models have not been succinctly characterized to inform FRA analysts, many of whom may not have strong background in fire dynamics, when they should be cautious in the application of the model predictions. Improved guidance is needed to assist users in making appropriate use of these models and in interpreting their results.

Over the last few years, improvements made to state-of-the-art "field models," i.e., models which explicitly address the computational fluid dynamics (CFD) aspects of fire (e.g., the NIST Fire Dynamics Simulator - FDS - [51,52]), have increased the potential attractiveness of these models for FRA applications. These models directly address some of the technical weaknesses associated with zone models (e.g., obstructions in the fire plume, complex compartment geometry, complexities in forced ventilation flow). Although these models are currently too resource intensive (including analyst time as well as computation time) for routine use in FRAs, it appears that they should be useful tools for evaluating, and even modifying, the simpler FRA models.

One of the purposes of this task is to define the limitations and uncertainties in current and advanced fire models with respect to FRA applications. It is expected that the results of this work will lead to an identification of areas for future modeling improvements.

This task includes an interagency agreement between the NRC and NIST BFRL for the NRC to develop the capability to use the CFAST [53] and FDS [52] fire computer codes to provide regulatory research support in analyzing complex NPP fire issues, and developing risk-informed, performance-based methods for fire protection. The codes are currently being exercised to simulate the thermal and smoke environment from cable tray fires of redundant safety trains, and major oil fires in a turbine building.

In order to achieve its goals in this topic area, the NRC has co-organized an International Collaborative Project to Evaluate Fire Models for Nuclear Power Plant Applications [45]. The objective of this collaborative effort is to share the knowledge and resources of various organizations to evaluate and improve the state-of-the-fire modeling methods and tools for use in NPP fire safety evaluation.

The collaborative project is divided into two phases. The objective of the first phase is to evaluate the capability and limitations of current state-of-the-art fire models for fire safety analyses in NPPs. A second phase of the project will be initiated, once the limitations of the current state-of-the-art are defined, to improve fire modeling methods and tools in order to support their extended use for fire safety analyses. The current project plan [45] includes tasks to conduct international benchmark and standard problem exercises with fire computer codes. Plans are being developed to conduct full-scale fire experiments to validate fire models for NPP applications.

3.4.1 Task 3 - Objectives

The objectives of this task are to:

- identify the areas of uncertainty and limitations associated with fire models which are either currently used in FRAs or might be used in future FRAs;
- develop improved guidance for using these fire models in FRAs; and
- benchmark and validate fire models.

3.4.2 Task 3 - Description of approach

In order to accomplish the task objectives, an analytical framework defining the different classes of fire scenarios that are addressed in FRAs will be developed. The framework will reflect key scenario-dependent phenomena that need to be addressed by fire models. This framework will provide a systematic means for identifying fire scenarios to be treated in benchmarking and validation exercises (see following discussion); it will also provide a tool for abstracting the results of these exercises. Following the development of the framework, a number of currently available fire models (both zone and CFD) will be compared against each other (in benchmarking exercises) and against experimental results (in validation exercises) for a specified set of scenarios. At the present, it is expected that the evaluation will include the CFAST, FDS, COMPBRN-IIIe, and FIVE computer fire models. This work will be performed by the NRC staff with the support of NIST BFRL. It will be supplemented by results from the International Collaborative Project to Evaluate Fire Models for Nuclear Power Plant Applications (see Section 1.4.1). This latter activity will take advantage of relevant research activities being performed by other organizations within the U.S.

and abroad, and will provide results for other computer models (e.g., MAGIC, FLAMME-S, CFX, COCOSYS, HADCRT, and JASMINE) not evaluated by NRC.

A plan for defining and conducting full-scale experiments for validating fire models on a cooperative basis with the other participants in the collaborative project, is being developed.

Note that, as shown in Table 3, the original fire risk research program tasks on fire model limitations and advanced fire models (see Tasks 11 and 15 of Ref. 1), are now included as part of this task.

3.4.3 Task 3 - Lead organization

NRC/RES has the lead responsibility for this task. This responsibility involves both the performance of technical analyses and coordination of international collaborative efforts. NIST BFRL will provide technical support to the NRC in the use of NIST fire computer codes in the benchmark and standard problem exercises. NIST will also provide technical support to the NRC staff in the design of experiments for validating fire models, and may conduct the full-scale fire tests at its fire test facilities.

3.4.4 Task 3 - Milestones

!	Report: Evaluation of fire models for use in NRC regulatory activities[6]	July 2001
!	Proposal: First full-scale test for fire model validation	August 2001
!	Report: Results of first international benchmarking exercise	October 2001
!	Test: First full-scale test for fire model validation	June 2002
!	Report: Results of first international standard problem exercise	September 2002

It is expected that the early results of this task will directly support the fire risk requantification study (Task 2 above). In addition, depending on the starting date for the actual requantification effort (which depends upon the results of discussion with industry), and depending on the pace of this task (which depends upon the contributions of multiple international partners), some of the code validation results may also be available.

The early results of this task will also support the Task 1 activity (see Section 3.2) on fire detection modeling.

3.5 Task 4 - Fire risk assessment guidance development

As discussed in Section 3.3 above, the fire risk requantification study (Task 2) will provide an example concerning the performance of a state-of-the-art FRA and associated recommendations. The purpose of this task is to develop explicit FRA guidance (including the

[6]This report will characterize NPP fire scenarios for fire modeling, identify limitations and uncertainties in a number of current fire models, identify potential uses of CFD fire models in FRA, and evaluate the capability of current fire models to analyze smoke effects.

treatment of uncertainties) intended for use in a variety of regulatory applications (including review as well as analysis).

3.5.1 Task 4 - Objective

The objective of this task is to develop FRA analysis and review guidance intended for use in needed regulatory applications.

3.5.2 Task 4 - Approach

A list of NRC FRA needs will be developed and prioritized through interactions with the NRC Fire Research Coordinating Committee and other user organizations. It is anticipated that these needs will include concerns involving technical reviews of FRAs, as well as those involving the performance of FRAs.

For each of the highest priority needs, FRA guidance will be developed based on the results and insights of Task 2, other fire risk research program tasks, and other relevant NRC programs (e.g., the IPEEE program).

Note that EPRI is currently planning on developing an updated Fire PRA Implementation Guide following the completion of the requantification study. Task 4 will be coordinated with EPRI to avoid unnecessary duplication of effort.

3.5.3 Task 4 - Lead organization

The lead for this task will be determined at a later time.

3.5.4 Task 4 - Milestones

The schedule for this task depends in part upon the schedule for Task 2. However, the identification of FRA guidance needs will be performed in FY-2002.

!	Report: NRC FRA guidance needs	July 2002
!	Report: Draft FRA guidance	TBD

It is expected that the final report on FRA guidance will be published in FY 2003. The milestones for this task will be further developed when the requantification study (Task 2) draws to a close.

3.6 Task 5 - Fire protection rulemaking support

As discussed in Section 1.2.2, the NRC is in the process of developing a risk-informed, performance-based alternative to the current fire protection regulations in 10 CFR 50.48 [13]. This task provides FRA support to the rulemaking process.

3.6.1 Task 5 - Objective

The objective of this task is to provide FRA support to the fire protection rulemaking process.

3.6.2 Task 5 - Approach

The particular form of the support needed will be identified by NRR and discussed with the Fire Research Coordinating Committee. It is currently anticipated that the support activities will consist largely of technical reviews of the proposed rule and associated regulatory guidance documents.

3.6.3 Task 5 - Lead organization

SNL is expected to be the lead organization for this task.

3.6.4 Task 5 - Milestones

The schedule for this activity will be developed to support the rulemaking schedule (which is currently under review).

3.7 Task 6 - Fire protection for nuclear power plants

In the past several months, a number of potential NPP fire protection issues have been identified in discussions with NRR staff. These potential issues cover a broad range of topic areas, including the effectiveness of Halon replacements on fires in NPPs; the reliability, availability, and effectiveness of fire protections systems; smoke propagation through penetration seals; the effect of smoke on operators; and the damageability of fire resistant cables.

This task provides input to the resolution of selected NPP fire protection issues. For example, it provides input to the fire-induced circuit failures issue resolution process. (This issue is referred to in SECY-97-127 [54] and SECY-98-247 [55] using the term “hot shorts;” NEI’s risk-informed approach for resolving this issue is briefly discussed in Sections 1.2 and 1.3 of this report.)

Note that Attachment 2 to SECY-97-127 lists and defines 12 potential fire protection issues raised in NRC’s Fire Protection Task Action Plan (FPTAP); Attachment 2 to SECY-98-247 indicates how these potential issues will be resolved. In particular, two of these potential issues, i.e., “fire detection methods” and “analysis of explosive electrical faults,” will be addressed by the fire risk research program. Both of these issues are being addressed under Task 1 (see Section 3.2).

3.7.1 Task 6 - Objective

The objectives of this task are to:

- develop technical information supporting the resolution of the fire-induced circuit failures issue; and

- develop fire protection and risk information needed to support the resolution of other designated NPP fire protection issues.

3.7.2 Task 6 - Approach

Regarding the fire-induced circuit failures issue, EPRI is in the process of performing a number of full-scale fire tests and analyzing the test results, and NEI is planning to submit a risk-informed method for identifying cables requiring fire protection in August 2001. (This method will be documented in an update to the draft NEI 00-01 [56].) NRR has the lead in providing feedback to NEI on its testing plans and risk-informed approach. Under Task 6, RES will provide comments to NRR in both areas. In addition, RES will perform a number of tests aimed at addressing potentially significant data gaps identified in Ref. 32 but not covered in the EPRI test plans. These additional testing activities will involve the use of an insulation resistance testing apparatus to be incorporated in the EPRI tests (cooperation with EPRI is addressed under the MOU discussed in Section 1.4.2). The possibility of further confirmatory testing activities (beyond those performed in conjunction with the EPRI tests) will be considered following evaluation of the EPRI and NRC test restuls.

In addition to the cable tests, EPRI is currently planning to conduct an expert elicitation regarding the likelihood of fire-induced circuit failures. RES will support the participation of a fire expert in this activity.

Regarding RES support of the resolution of other NPP fire protection issues, potential issues will be identified by NRR and discussed with the Fire Research Coordinating Committee. Formal requests for RES support (which may require the performance of fire experiments and tests) will be made through the user need letter mechanism.

3.7.3 Task 6 - Lead organization

SNL will have the lead responsibility for developing and performing the cable failure tests described above. The lead responsibility for the other fire protection issues will be determined based upon the specifics of the issues.

3.7.4 Task 6 - Milestones

- Report: Results of full-scale fire tests for circuit failures April 2001

The full-scale fire test results will not only support ongoing NRR activities, they will also be used in the development of improved FRA methods, tools, and data associated with the prediction of fire-induced circuit faults (see Task 1, Section 3.2).

3.8 Task 7 - Fire protection for gaseous diffusion plants

As discussed in Section 1 of this report, the fire risk research program is focused on addressing fire protection issues associated with operating NPPs. However, the methods, tools, and data developed for such applications have some applicability to other industrial facilities of interest to NRC.

The gaseous diffusion plants (GDPs) regulated by the NRC have significant fire hazards (e.g., large tanks of lubrication oil). In order to conduct a risk-informed evaluation of regulatory options for fire protection at these facilities, NMSS needs a number of analytical tools. The purpose of this task is to develop these tools.

3.8.1 Task 7 - Objectives

The objectives of this task are to:

- develop analytical tools to support the determination of appropriate intervals for laboratory testing of in-service sprinklers;
- assess the fire properties of combustible liquids used in nuclear fuel cycle processes under actual process conditions; and
- develop fire protection and risk information needed to support the resolution of other designated GDP fire protection issues.

3.8.2 Task 7 - Approach

Regarding the sprinkler system analysis tool development, the work will involve: (1) a review of investigations of past sprinkler failure events at GDPs and the characterization of root causes/failure scenarios that appear to be attributable to aging or prolonged service in an adverse environment; (2) a survey of other installations of interest to NRC/NMSS and an analysis to determine if the above-mentioned root causes and failure scenarios are generically applicable; (3) the identification of data and research needs for developing predictive models for time-dependent sprinkler system component reliability; (4) the development of predictive models for time-dependent component reliability; (5) the assessment of the time-dependent reliability of representative sprinkler systems (including testing, maintenance, and human-related unavailabilities; and (6) the development of guidance concerning the use of the time-dependent reliability results in the evaluation of testing intervals. The work will take advantage of the suppression system reliability work currently being performed under Task 1 (see Section 3.2).

Regarding the combustible liquids fire properties assessment, the work will: (1) identify mechanisms underlying changes in key fire properties (e.g., flash point, fire point, ignition temperature, heat of combustion, rate of burning) as combustible liquids of interest are used in GDPs; (2) assess the magnitude of these changes; and (3) propose alternative methods (e.g., chemical tests as opposed to tests for fire properties) to predict these changes.

Regarding RES support of the resolution of other non-NPP fire protection issues, potential issues will be identified by NMSS and discussed with the Fire Research Coordinating Committee.

Formal requests for RES support (which may require the performance of fire experiments and tests) will be made through the user need letter mechanism.

3.8.3 Task 7 - Lead organization

The lead for this task will be awarded to a contractor to be determined at a later time.

3.8.4 Task 7 - Milestones

!	Report: Sprinkler system reliability study	September 2002
!	Report: Combustible liquids properties study	September 2002

3.9 <u>Task 8 - Fire significance determination process support</u>

As discussed in Section 1.2.2, the NRC has developed a fire protection inspection finding SDP [16]. As the fire SDP is currently executed, Phase 2 of the process uses a highly simplified FRA model to develop a scoping estimate of the risk significance of a given finding related to fire protection concerns. (Phase 1 involves a qualitative analysis.) For findings that are determined to be potentially significant, more detailed FRA analyses (typically based on the plant's IPEEE fire analysis) are performed in Phase 3 of the SDP to develop an improved estimate of risk significance.

In March 2000, NRR requested that RES review and provide technical feedback on the fire SDP through a user need letter [31]. The current requirements of NRR have been refined through feedback from cognizant NRR staff on this research plan. This task provides the requested support.

3.9.1 Task 8 - Objective

The objective of this task is to review and provide technical feedback on the current fire SDP.

3.9.2 Task 8 - Approach

While the review will address the entire SDP, the focus will be on the Phase 2 model. Areas for refinement will be identified and potential refinements, based on the results of the fire risk research program, will be recommended. Note: it is expected that guidance for reviewing Phase 3 analyses will be developed as part of Task 4 (see Section 3.5 above).

RES will provide periodic briefings to cognizant NRR staff to reflect RES insights developed as the work progresses, and from the results of relevant work performed under Task 1 (see Section 3.2).

3.9.3 Task 8 - Lead organization

SNL is expected to be the lead organization for this task.

3.9.4 Task 8 - Milestones

!	Report: Review of fire SDP and recommendations	October 2001

3.10 Task 9 - Fire risk assessment tools for precursor analysis

In its reviews of the ongoing fire risk research program, the ACRS has pointed out that FRA tools for assessing the risk significance of fire-related accident precursors (including fire-protection relevant conditions, as well as actual fire events) are needed [33, 34]. The purpose of this task is to develop tools suitable for routine application by the NRC staff.

3.10.1 Task 9 - Objective

The objectives of this task are to:

- develop FRA tools for evaluating the significance of fire-related accident precursors;
- demonstrate the application of these tools; and
- develop guidance to support the routine application of these tools.

3.10.2 Task 9 - Approach

Two proposed approaches for evaluating fire-related operational experience have been previously investigated by RES. The first approach, which relies on the use of an existing FRA, is documented in Ref. 20. The second approach, which employed a highly simplified fire event tree, was explored by the Idaho National Engineering and Environmental Laboratory (INEEL) under JCN W6355. This latter approach provided a framework that has been modified and refined for use in Phase 2 of the current fire SDP (see Section 3.9 above).

This task will evaluate the approach proposed in Ref. 20 and that used in the fire SDP from the standpoint of the needs of precursor analysis. Based upon this evaluation, and upon consideration of the results of Task 1 (see Section 3.2 above), an appropriate approach (perhaps a hybrid of the two) will be developed. This approach will be demonstrated through applications to a selected set of representative events and conditions. Based upon the lessons learned through these demonstrations, practical guidance for routine application will be developed.

3.10.3 Task 9 - Lead organization

The lead organization for this task will be determined at a later date.

3.10.4 Task 9 - Milestones

! Report: Evaluation of existing precursor analysis methods	April 2002
! Report: Proposed precursor analysis method	June 2002
! Report: Demonstration precursor analyses and guidance	September 2002

4. **Communication Plan**

In order to achieve the overall program objectives listed in Section 1, the fire risk research program includes a number of activities supplementing the technical tasks identified in Section 3. These additional activities, described in this section, will ensure that the research results are readily available to the NRC staff and industry for effective use in regulatory activities.[7] Furthermore, they will ensure that interested members of the general public can stay abreast of the research program and access results as desired.

4.1 Communication of Research Planning

The following activities have been or will be performed to inform stakeholders regarding the fire risk research plan objectives, activities, and schedule, and to gain feedback from these stakeholders.

- SECY-98-230 [3] was written to summarize the lessons learned from earlier NRC fire protection-related research, and to discuss the need for the fire risk research program.

- A report containing the plan for the FY 1998-2000 research activities was written and disseminated [1]. This report is available in the Public Document Room. A summary version of the report [2] is publicly available through the NRC Agency-wide Documents Access and Management System (ADAMS).

- Numerous presentations describing potential FRA research topics and summarizing the research program have been made or are planned. These include presentations to:

  - NRC management and oversight committees (e.g., the ACRS Subcommittee on Fire Protection, the NRC Fire Research Coordinating Committee);
  - the nuclear power industry (e.g., at NEI-sponsored Fire Protection Information Forums and meetings with EPRI under the MOU for fire risk research);
  - other government agencies (e.g., the National Aeronautics and Space Administration - NASA);
  - international cooperative research organizations (e.g., the International Cooperative PRA Research Program - COOPRA, the OECD/CSNI working group on probabilistic safety assessment); and
  - the general fire safety and probabilistic risk assessment technical communities and interested members of the public (e.g., through presentations at the Water Reactor Safety Information Meeting, the OECD/CSNI Workshop on Fire Risk Assessment, the Probabilistic Safety Assessment and Management conference series, and the NRC's Regulatory Information Conference).

- As part of the research planning process, possible approaches for developing quantitative goals for FRA improvements will be formulated and discussed with the ACRS.

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[7]See Section 1.2.2 and Appendix A for a description of these activities.)

! The research plan for FY 2001-2002 is documented in this report. The report will be published as a NUREG document and will publicly available through the Public Document Room, ADAMS, and various locations on the NRC web site.

4.2 Communication of Research Results

The following activities have been or will be performed to inform stakeholders regarding the results of the fire risk research program.

! Letter reports documenting the results of specific tasks will be widely distributed using standard channels (e.g., mailing lists, responses to requests, placement in the Public Document Room, posting on the NRC web site, posting in ADAMS).

! Summary papers of key results will be submitted to archival journals, and summary presentations will be made at a variety of meetings, including:

  S meetings of the ACRS Subcommittee on Fire Protection;
  S scientific conferences and workshops;
  S meetings of international cooperative working groups;
  S meetings with EPRI under the MOU for fire risk research;
  S the NEI-sponsored Fire Protection Information Forums.

! A periodically updated list of currently available products from the fire risk research program will be placed on the NRC web site.

! The Fire Research Coordinating Committee will be kept abreast of the research program's status and the availability of results. (One of the Committee's responsibilities is to support the application of research results in rulemaking, licensing, and inspection activities.)

! RES staff will work with the NRC staff and contractors responsible for the external events training course to ensure that the research results are incorporated into the training, as appropriate.

! A public workshop will be held in late FY 2001 (see Task 1, Section 3.2). The objectives of the workshop will be to summarize the current results of the research program and to discuss the implications of these results for ongoing activities.

! A public workshop will be held following the completion of the requantification study (see Task 2, Section 3.3). The objective of the workshop will be to communicate the results of the requantification study, including the risk insights gained and the lessons learned regarding practical implementation of the improved FRA methods and tools developed during Task 1.

! Work will be initiated in FY 2002 to identify alternative methods (e.g., an information base with tailored search tools posted on the NRC web site or provided on a CD/ROM) to increase the availability of key research results. If there is sufficient demand, work on one or methods may be initiated in FY 2003.

5. Potential Activities Beyond FY 2002

As stated in Section 1.1, the fire risk research program will develop fire risk assessment methods, tools, data, results, and insights needed by the NRC to perform risk-informed decision making. These products are needed because, as discussed in Section 1.2.2, NRC's general drive to increase the use of PRA technology in all regulatory activities (including licensing, inspection, and rulemaking) is expected to lead to an increased need for the ability to routinely estimate the risks associated with fires. The anticipated applications include but are not limited to fire protection concerns. As pointed out by the ACRS, NRC needs FRA tools to perform these routine applications.

Most of the fire risk research program activities are expected to lead to information that can be used by both NRC Regions and Headquarters staff in routine activities. For example, Task 1 (Fire risk assessment tool development) will provide insights regarding specific methodological issues, Task 2 (Fire risk requantification study) will indicate the risk significance of these issues, and Task 3 (Fire model benchmarking and validation) will indicate the degree of confidence that can be put into FRA results that rely upon specific fire models.

In addition, Task 4 (Fire risk assessment guidance development) and Task 9 (Fire risk assessment tools for precursor analysis), are specifically aimed at developing FRA tools for staff use in routine analyses. The former provides guidance for both the review of FRAs and the performance of FRAs (using the tools and results from the fire risk research program). The latter provides tools for analyzing fire-related accident precursors.

However, it is not expected that successful completion of the FY 2001-2002 activities will provide the final answers to all potentially important questions in FRA. A number of challenging issues will not be completely addressed by FY 2002, and new issues are likely to be identified as risk-informed applications increase. Therefore, it is expected that there will be a continuing need for fire risk assessment research and development.

Potential post-FY 2002 fire risk assessment research activities include the following:

- Data collection and generation. In order to reduce the current uncertainties in FRA model parameter values, continuing efforts to collect operational data (e.g., for fire occurrences, suppression times, fire effects) and generate experimental data (e.g., for equipment fragilities and for model validation) are needed. RES will support a recent OECD/CSNI initiative to develop and maintain a database relevant to the estimation of FRA model parameters and expects to support a recent International Atomic Energy Agency (IAEA) initiative to summarize fire safety lessons learned from operational experience.

- Fire model benchmarking and validation. It is expected that the FY 2001-2002 activities under Task 3 will provide valuable results, but will not cover all potentially risk significant scenarios. It is expected that the benchmarking and validation work under Task 3 is will be expanded past FY 2002 to address a broader range of potentially important scenarios. Note that this activity will address the prediction of smoke generation and transport, as well as that of temperatures and heat fluxes.

- Fire model development and application. Using the results of the fire model benchmarking and validation activity, it is expected that improved fire models (suitable for use in a wide variety of risk-informed and performance-based applications) will be developed and tested. As part of this activity, the uncertainties in the improved fire model predictions will be explicitly addressed.

- Fire suppression effectiveness. The currently planned activities on the analysis of fire detection and suppression are largely focused on the issue of detection and suppression reliability. It is expected that future research efforts will explore improved quantitative treatments of the performance and effectiveness of detection and suppression systems, as well as of plant fire brigades.

- Risk significance of fire effects on digital systems. As plants upgrade their control and protection systems, and as new plant designs with advanced digital systems are developed, the risk impact of fire scenarios involving damage to these systems will likely need to be assessed. To confidently perform such an assessment, research will be needed to assess the local transport of smoke (e.g., including preferential transport to areas of high electrical field density) and the smoke fragility of electronic components, as well as to assess the generation and global transport of smoke within and between compartments. Research may also be needed to assess other non-thermal fragilities (e.g., associated with the effect of humidity) associated with digital systems, and the digital system failure modes associated with non-thermal hazards.

- Aging effects on fire risk. A potential concern with currently operating nuclear power plants is that the likelihood of propagating electrical fires might increase as the plants age [58]. Previous NRC-supported research has shown that aging reduces the flammability of fire retardant cable insulation [59]. Research may be needed to reconcile these perspectives.

- Other FRA improvements. The importance of a number of potentially important issues identified by ongoing research work (e.g., multiple fires, initiators involving multiple hazards including fires - see Ref. 8, operator performance during fire incidents, the effects of smoke on plant safety) will be investigated as part of Task 2 (the fire risk requantification study). The results of the requantification study may show that additional research and development is needed to appropriately address these issues. Similarly, experiences with a number of current FRA and related applications (e.g., the fire SDP, the development of risk-based performance indicators, the treatment of non-core damage related fire-induced radiological releases) may show that additional FRA work in these areas may be needed.

The specific activities to be addressed and their priorities will be discussed at appropriate times with the Fire Research Coordinating Committee and the ACRS Subcommittee on Fire Protection. The plan for post-FY 2002 fire risk research will be developed as part of the process of updating the NRC's RIRIP, and will be documented as an update to this report.

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Appendix A - Risk-Informed Regulation Implementation Plan Activities Addressed by Fire Risk Research Program

The NRC's RIRIP [3] lists the implementation activities which are being performed to implement specific strategies in the NRC's Strategic Plan [4]. Some of these activities address specific fire protection issues; others are related to more general applications of risk-informed decision making which can be affected by fire risk assessment. This appendix lists the fire-relevant RIRIP implementation activities and describes how the fire risk research program supports these implementation activities.

For ease of reference, Table 2 (which lists the research tasks included in this program plan) is reproduced as Table A.1 at the end of this appendix.

Implementation Activity MS 1-6 (UB3-6): *Undertake enhancements to our risk-informed reactor oversight process*. The recently developed SDP for fire protection findings [15] is currently being used. It is expected that field applications will lead to the identification of areas where refinements are needed. Task 8 of the fire risk research program, through an independent review of the SDP and selected applications, provides an additional means for identifying areas for refinement. The results of Task 1 (e.g., regarding suppression analysis) will support the performance of Task 8, by indicating what types of refinements are possible within the current FRA state-of-the-art.

Implementation Activity MS 3-4: *Produce accident sequence precursor analyses*. Task 9 of the fire risk research program will provide the analytical tools needed to address fire-initiated events and plant conditions affecting fire risk.

Implementation Activity MS3-6: *Review IPEEE submittals and issue insights report*. NRC's review of the IPEEE licensee submittals is nearing completion. According to current schedules, a draft IPEEE insights report is to be prepared by April, 2001, and a final insights report will be prepared by October, 2001. Many of the results of Task 1 of the fire risk research program will be available in time to support the writing of the draft insights report. Some of the earlier results from Task 3 may be available in time to support the development of revisions to the final insights report.

Implementation Activity MS5-1 (UB1-3): *Establish guidance for risk-informed licensing basis changes*. Although the current description of this implementation activity does not specifically address guidance for fire risk-related issues, one or more licensee applications to modify their plant fire protection programs under RG 1.174 may be provided to the NRC in Calendar Year 2001. The review of such applications will require insights regarding the strengths and weaknesses of the FRA methods used to support the applications.

The results from most of the Task 1 activities and some of the Task 3 activities are expected to be available in time to support NRC's review of these submittals. Future submittals and reviews will, of course, benefit from the lessons learned from Tasks 2 and the FRA guidance developed under Task 4.

Implementation Activity MS8-4: *Develop alternative fire protection standards for nuclear power plants*. This activity includes both the development of a risk-informed fire protection rule and the resolution of the fire-induced circuit failures issue mentioned in Sections 1.2, 1.3, and 3.7.

Regarding the rulemaking process, Task 5 of the fire risk research program provides direct support to the development of the initial package. The results of Tasks 1 and 3 (which will include critical reviews of existing methods and, in some cases, improved methods for addressing specific issues) are also expected to be useful at this stage. Depending upon the rulemaking schedule (which may need to be revised depending upon discussions concerning NFPA 805), the results of Task 2 (which will provide risk insights resulting from the application of improved FRA methods) may be available in time to support the development of the final rulemaking package. The results of Task 4 may not be available in time to support the current rulemaking process schedule, but should be useful when NFPA 805 (whose use will be addressed by the rulemaking package) is updated.

Regarding the fire-induced circuit failures issue, earlier (pre-FY 2001) results of the fire risk research program (e.g., see Ref. 32) have already been used to address key technical issues associated with this activity (e.g., the likelihood of fire-induced conductor-to-conductor short circuits, key parameters that need to be addressed in related fire tests). The results have been used to frame the ongoing discussion between the NRC and NEI on NEI's proposed risk-informed method for identifying important circuits. They have also been used to support the development of those portions of NFPA 805 dealing with circuit analysis. The results of Task 1, including the follow-on work investigating spurious actuations (see Section 3.2), and the test results developed under Task 6 (see Section 3.7) will be used to support NRC's review of the NEI method.

Implementation Activity EE1-2: *Develop standards for the application of risk-informed, performance-based regulation in conjunction with national standards committees*. See the preceding discussion on Implementation Activity MS8-4.

Implementation Activity EE1-3: *Develop improved methods for calculating risk in support of risk-informed regulatory decision making*. All of the fire risk research work performed (including the work during FY 1998-2000) directly supports this activity.

Nuclear Materials Safety Implementation Activity 2: *Continue to develop improved risk assessment methods and data for calculating risk in support of risk-informed regulatory decision making*. Although not specifically identified in the RIRIP, the work performed under Task 7 is aimed at developing improved data supporting assessments of risk at gaseous diffusion plants (GDPs). The need for this work has been identified through interactions with NMSS representatives on the Fire Research Coordinating Committee.

Table A.1 - Fire Risk Research Program Technical Tasks, FY 2001-2002

Task	Title
1	Fire risk assessment tool development
2	Fire risk requantification study
3	Fire model benchmarking and validation
4	Fire risk assessment guidance development
5	Fire protection rulemaking support
6	Fire protection for nuclear power plants
7	Fire protection for gaseous diffusion plants
8	Fire significance determination process support
9	Fire risk assessment tools for precursor analysis

Appendix B - FRA Research Areas

Ref. 7 identifies 42 potential FRA research topics, i.e., areas where work may be needed to achieve the objectives of the fire risk research program. A number of issues address specific elements of FRA. The remainder deal with either: a) problem-specific, integrated treatments of fire initiation, equipment damage, and plant response, or b) activities relevant to but not required by the FRA analysis process. Ref. 7 further groups these 42 potential topics into 17 broader topic areas.

Table B.1 provides the FY 2001-2002 fire risk research program tasks (or other RES program activities) associated with these topics and topic areas. The topic areas (and the topics within each topic) are presented in the order of priority established for the FY 1998-2000 research program.

Note that, although it was not discussed in the FY 1998-2000 fire risk research program plan [1], the prioritization is based upon input from cognizant staff in the user offices. The process involved two NRR fire protection engineers, one NRR PRA analyst responsible for the development of the fire risk SDP, one engineer from the Office of Analysis and Evaluation of Operational Data (AEOD) with a strong background in fire safety, one NMSS fire protection engineer and one RES PRA analyst with a strong background in fire risk assessment. Following discussions regarding the topics and topic areas listed in Table B.1, the participants independently ranked the topic areas. The integrated prioritization of topic areas shown in Table B.1 was developed through the use of a uniform weighting scheme, i.e., the opinions of all participant were treated as being equally important. The prioritization of topics within a topic area was not addressed by most of the participants; the prioritization shown is therefore based upon the RES participant's judgment.

<u>Notes for Table B.1</u>

1. This topic is addressed in NFPA 805.

2. Generic Issue 57, "Effects of Fire Protection System Actuation on Safety-Related Equipment" (see NUREG/CR-5580), assesses the risk significance of this issue.

3. Elements of the proposed program discussed in NUREG-1547 (L.Y. Cooper and K.D. Steckler, "Methodology for Developing and Implementing Alternative Temperature-Time Curves for Testing the Fire Resistance of Barriers for Nuclear Power Plant Applications," 1996) are addressed by Task 3 of the fire risk research program.

4. Nuclear Electric Insurance Limited (NEIL) is currently developing a database for NPP fire events. RES is incorporating the results from this database into an update of the analysis documented in Ref. 41.

5. Improved accident precursor analysis methods for external events contributors may be addressed under the RES Accident Sequence Precursor program. Discussions of recent work can be found in NUREG/CR-6544 (R.J. Budnitz, et al, "A Methodology for Analyzing Precursors to Earthquake-Initiated and Fire-Initiated Accident Sequences," 1998).

Table B.1. Potential FRA Topic Areas and Related RES Activities (Page 1 of 2)

Priority	Topic Area	Topic	Associated RES Activity [Notes]
1	Circuit failure mode and likelihood	Circuit failure mode and likelihood	Fire risk research program Task 1
2	Detection and suppression analysis	Fire protection system reliability/availability	Fire risk research program Task 1
		Suppression effectiveness (automatic, manual)	Fire risk research program Task 1
		Effect of compensatory measures on suppression	Fire risk research program Task 1
		Scenario-specific detection and suppression analysis	Fire risk research program Tasks 1, and 3
		Adequacy of detection time data	Fire risk research program Task 1
3	Fire PRA applications issues	Comparison of methodologies	IPEEE review program; Fire risk research program Task 2
		Multiple unit interactions	IPEEE review program; Fire risk research program Task 2
		Availability of safe shutdown equipment	IPEEE review program; Fire risk research program Task 2
		Seismic/fire interactions	IPEEE review program; Fire risk research program Task 2
		Non-power and degraded conditions	[1]
		Flammable gas lines	IPEEE review program; Fire risk research program Task 2
4	Impact of fires on operator performance	Fire scenario cognitive impact	Project ATHEANA; Fire risk research program Task 2
		Impact of fire induced environment on operators	Project ATHEANA; Fire risk research program Task 2
		Role of fire brigade in plant response	Project ATHEANA; Fire risk research program Task 2
		Scenario dynamics	Project ATHEANA; Fire risk research program Task 2
4	Risk significance of main control room fires	Main control room fires	Project ATHEANA; Fire risk research program Tasks 1 and 2
		Circuit interactions	Fire risk research program Tasks 1 and 2
6	Fire initiation analysis	Likelihood of severe fires	Fire risk research program Task 1
		Scenario frequencies	Fire risk research program Task 1
		Effect of plant operations, including compensatory measures	Fire risk research program Tasks 1 and 2

Table B.1. Potential FRA Topic Areas and Related RES Activities (Page 2 of 2)

Priority	Topic Area	Topic	Associated RES Activity [Notes]
7	**Fire modeling toolbox: assessment & development**	**Source fire modeling**	**Fire risk research program Tasks 1-3**
		Compartment fire modeling	**Fire risk research program Task 3**
		Thermal fragilities	**Fire risk research program Task 1**
		Uncertainty analysis	**Fire risk research program Tasks 1, 2, and 3**
		Smoke fragilities	**Fire risk research program Task 1**
		Smoke generation and transport modeling	**Fire risk research program Tasks 1 and 3**
		Multi-compartment fire modeling	**Fire risk research program Task 3**
		Suppressant-related fragilities	**IPEEE review program; [2]**
7	**Risk significance of turbine building fires**	**Turbine building fires**	**Fire risk research program Task 1**
9	**Experience from major fires**	**Learning from experience**	**Fire risk research program Task 1**
10	**Fire barrier qualification and thermal analysis**	**Barrier performance analysis tools**	**Fire risk research program Task 1**
		Barrier qualification	**[3]**
		Penetration seals	**Fire risk research program Task 1**
11	**Fire events database**	**Adequacy of fire events database**	**[4]**
11	**Fire barrier reliability analysis**	**Adequacy of data for active and passive barriers**	**Fire risk research program Task 1**
11	**Precursor analysis methods**	**Precursor analysis methods**	**Fire risk research program Task 9**
11	**Fire PRA guidance and standardization**	**Standardization of methods**	**Fire risk research program Task 4; [1]**
15	**International cooperation**	**Learning from others**	**[5]**
16	**Risk significance of containment fires**	**Containment fires**	**IPEEE review program; [1]**
16	**Non-core damage issues in fire risk assessment**	**Fire-induced non-reactor radiological releases**	**[1]**
		Decommissioning and decontamination	**[1]**

Appendix C - Resolution of ACRS Comments on Draft Plan

In April 2001, the staff received comments from the ACRS on the overall NRC safety research program [60], including comments on the fire risk research program (as documented in a publicly available draft version of the fire risk research program plan issued November 22, 2000 [61]). Table C.1 provides a consolidated, paraphrased summary of those comments that suggest revisions to the program. The table also indicates how the comments are addressed in this report.

Table C.1. ACRS Comments and Treatment

Summary of ACRS Comment(s)	Discussion
A systematic assessment of NRC FRA needs should be performed. This assessment should identify FRA information needed to support the regulatory process, and specific staff roles and responsibilities regarding the performance of FRA. The assessment should consider FRA needs for GDPs and mixed-oxide (MOX) fuel fabrication facilities.	This activity will need to be coordinated with the user offices (NRR and NMSS) and will be brought to the attention of the FRCC. In the meantime, the Task 4 (FRA Guidance Development) user needs survey activity (see Section 3.5.2), which was originally scheduled in Ref. 61 to start following completion of Task 2 (Fire Risk Requantification Study), will be initiated in FY 2002 (see Section 3.5.4).
Quantitative goals for improvement (to help identify productive paths and stopping rules for research activities) should be considered.	Possible approaches that are relevant to the development of FRA methods, tools, and data will be formulated and discussed with the ACRS (see Section 4.1).
The development of public domain models for fire behavior and related phenomena (e.g., transport of smoke and toxic products) should be considered. The identification of issues to be addressed by the development activity should not solely rely upon collaborative research activities.	As described in Ref. 61 and in this report, fire model development activities will be considered in the planning of post FY-2002 fire risk research activities (see Section 5). The planning process will use the FRA needs information discussed in the first comment above. Section 3.4 of the research plan has been modified to clarify the role of independent NRC activities under Task 3 (Fire Model Benchmarking and Validation).
Fire detection methods development should be placed in context of FRA.	The current plan now addresses this issue under Task 1 (Fire Risk Assessment Methods, Tools, and Data Development), rather than under Task 6 (Fire Protection for Nuclear Power Plants).
The fire SDP activity should provide a technically defensible basis and minimize dependence on subjective evaluations.	The current scope of Task 8 (Fire Significance Determination Process Support) directly addresses an NRR user need [31] (see Section 3.9). It is anticipated that follow-on activities will be identified following the completion of the work identified.

Table C.1. ACRS Comments and Treatment (cont.)

Summary of ACRS Comment(s)	Discussion
A technical basis for defining prototypic fires for use in experiments is needed.	One of the key Task 1 (Fire Risk Assessment Methods, Tools, and Data Development) objectives is the development of estimates of the frequencies of challenging fires (see Sections 3.2.1 and 3.2.2). If successful, this work should provide an important component of the needed technical basis.
Separate confirmatory experiments may be needed to support current efforts in the circuit analysis arena.	The possibility of additional confirmatory experiments is now discussed in Section 3.7.2.
A systematic method to assess the effect of smoke on fire fighters, and to assess the effect of the Occupational Safety and Health Administration (OSHA) two-in and two-out rule on fire fighting effectiveness, is needed.	Manual fire fighting effectiveness is now included in the discussion on potential post FY-2002 research topics (see Section 5).