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Report to Congressional Requesters

October 2012

# NUCLEAR REGULATORY COMMISSION

# Oversight and Status of Implementing a Risk-Informed Approach to Fire Safety


GAO-13-8

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## Oversight and Status of Implementing a Risk-Informed Approach to Fire Safety

GAO Highlights

Accountability * Integrity * Reliability

Highlights of GAO-13-8, a report to congressional requesters

### Why GAO Did This Study

In 1975, a fire at a nuclear power plant damaged critical control cables and hampered operators' ability to monitor the status of the plant's reactor. NRC subsequently issued deterministic fire safety regulations for plants to follow, but differences in plant design, coupled with changes in NRC guidance, made it difficult for most plants to meet the regulations without seeking numerous exemptions. In 2004, NRC issued a regulation permitting plants to voluntarily transition to risk-informed fire protection requirements. This new approach mirrors NRC's efforts to adopt a more risk-informed regulatory approach to nuclear safety in general. In 2008, GAO reported on three key fire safety issues and recommended NRC take action to address them.

GAO was asked to examine (1) NRC's progress in resolving the long-standing fire safety issues raised in GAO's 2008 report at plants remaining under the deterministic approach and at those plants transitioning to the risk-informed approach; (2) the potential benefits of transitioning to a risk-informed approach and the basis for NRC's decision to make adoption of this approach voluntary; and (3) challenges, if any, in efforts to transition to a risk-informed approach in regulating fire safety. GAO reviewed documents; analyzed responses from operators at a nonprobability sample of 12 nuclear plants and from nine consultants or academic experts on fire safety issues and risk-informed regulations; and interviewed NRC, industry, and public interest group representatives.

GAO is not making recommendations in this report. NRC found the report to be accurate and complete.

View GAO-13-8. For more information, contact Frank Rusco at (202) 512-3841 or ruscof@gao.gov

### What GAO Found

The Nuclear Regulatory Commission (NRC), together with plant operators, has made progress in resolving three fire safety issues raised in GAO's 2008 report by implementing GAO's recommendations or taking other actions. NRC implemented the recommendation on multiple spurious operations (malfunctions caused by fire that could cause safety-related equipment to malfunction) by issuing new guidance or requiring additional modifications at the 36 plants with 57 reactors operating under deterministic regulations. NRC did not implement the recommendations to address the effectiveness of fire wraps or the extended use of interim compensatory measures plants use instead of repairing or replacing damaged safety equipment; however, NRC did take some actions, including (1) evaluating and reporting on corrective actions plants used to mitigate safety concerns associated with fire wraps and (2) developing metrics to gauge the progress of NRC's staff in resolve underlying issues related to the extended use of compensatory measures. According to NRC, plants transitioning to a risk-informed fire safety approach are continuing to resolve these issues through modifications and analyses required as part of the transition process. GAO visited two transitioning plants and observed examples of such modifications.

According to NRC officials, plant operators, and others GAO spoke with, the risk-informed regulatory approach to fire safety offers benefits over the deterministic approach, but NRC made adoption of the risk-informed approach voluntary because it considers plants that meet deterministic requirements to be safe. NRC officials stated that the risk-informed approach (1) will provide plant operators with information to help them quantifiably reduce risk and with flexibility in areas that do not affect risk and (2) allow operators to more easily demonstrate compliance with simplified licensing requirements. According to some of the plant operators, consultants, and experts GAO spoke with, plants will improve their safety using the risk-informed approach. NRC considered mandating the risk-informed approach, but it did not do so because of uncertainties over whether the agency could determine if the approach could improve protection of health and safety enough to impose new regulations. NRC considers plants that meet deterministic requirements to be safe, including plants that do so through approved exceptions to these requirements; thus, it does not plan to further analyze whether the risk-informed approach should be mandatory.

Plant operators, consultants, and experts GAO spoke with identified three challenges that may affect NRC's transition schedule and the number of plants that ultimately transition to the risk-informed approach. First, transition costs have been higher than initially expected, and operators from all of the nontransitioning plants GAO contacted cited this as reason they are remaining under the deterministic approach. Second, according to some operators, consultants, and experts, the absence of fire data may hinder the development of realistic risk assessments and contribute to overly conservative NRC risk assessment guidance, potentially leading to a misallocation of resources. NRC and other stakeholders disagreed with this assessment. Third, few people have expertise in risk analysis and fire modeling, and some operators, consultants, and experts expressed concern that the need for such expertise could compete with other safety-related efforts. However, most consultants and experts GAO spoke with believed that the number of people with expertise will be sufficient to support the transition effort.

# Contents

## Abbreviations

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| NIST | National Institute for Standards and Technology |
| NRC | Nuclear Regulatory Commission |
| NFPA | National Fire Protection Association |
| PRA | probabilistic risk assessment |

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**United States Government Accountability Office**
**Washington, DC 20548**

October 22, 2012

The Honorable Barbara Boxer
Chairman
Committee on Environment and Public Works
United States Senate

The Honorable Edward J. Markey
House of Representatives

On March 22, 1975, a worker testing for air leaks within a building housing a nuclear reactor at the Browns Ferry nuclear power plant in Alabama inadvertently started a fire when the candle he was using ignited nearby electrical cables. The fire burned for 7 hours and damaged cables for electrical power, control systems, and instrumentation, and impaired the reactor's cooling systems. The fire also prevented plant operators from monitoring the reactor's status normally. In the years following this event, the Nuclear Regulatory Commission (NRC), which licenses and regulates nuclear reactors,[1] worked to develop a regulatory approach to fire safety, and in 1980 the agency promulgated fire safety regulations (referred to as "Appendix R") for licensed commercial nuclear power plants that were operating prior to January 1, 1979. These regulations establish the design requirements for nuclear reactors at commercial power plants to mitigate the effects of a fire on power plant operators' ability to shut down a reactor safely. Commercial nuclear power plants that were licensed to operate on or after that date are not subject to these regulations, but NRC included licensing conditions—which we refer to as licensing requirements—that are similar to the regulations in each of the newer plants' operating licenses. These regulations and requirements are considered to be prescriptive (referred to as "deterministic"). In this report, we refer to Appendix R and these similar conditions for operating licenses NRC issued since January 1, 1979, as the deterministic approach. The deterministic approach, which NRC has also used to oversee nuclear

[1]NRC issues licenses for individual nuclear reactors, one or more of which may be located at a particular site, which is generally called a plant. In this report, we use the term "plant" to describe a site with nuclear reactors, because most industry officials we met with discussed operations at the plant level. However, in instances in which we discuss NRC guidance or regulations that relate to individual reactors, we use the term "reactors." When referring to the personnel who operate a reactor or a plant, and who are responsible for implementing regulations, we use the term "plant operators."

power plant safety in areas other than fire protection, establishes a specific set of potential accidents, the consequences of which a nuclear power reactor must be designed to prevent or mitigate to protect public health and safety. It also establishes requirements for engineering safety margins and quality assurance standards for the design, manufacture, and construction of nuclear power reactors.

In the 1990s, NRC's oversight of nuclear reactor safety began moving from the deterministic approach to a risk-informed, performance-based approach to regulatory decision making that was being implemented in phases, according to NRC documents. Since 2000, NRC has worked with the Nuclear Energy Institute,[2] the National Fire Protection Association (NFPA),[3] and others to develop a new risk-informed, performance-based fire safety regulation, which endorsed key aspects of a fire safety standard issued by NFPA. (Hereafter, we will refer to the "risk-informed, performance-based approach" as the "risk-informed approach.") NRC issued this risk-informed regulation in 2004;[4] it represents an alternative approach to the deterministic fire protection regulations. NRC has allowed nuclear power plant operators to voluntarily adopt the fire protection requirements in the new regulation or to continue to comply with the deterministic fire safety regulations and licensing requirements. In 2005, NRC initiated a pilot program at two nuclear power plants that volunteered to transition to the risk-informed fire safety approach.

In June 2008, we reported on NRC's oversight of fire safety at nuclear power plants and described three long-standing fire safety issues facing the agency and the nuclear industry.[5] First, we reported that a fire at a nuclear power plant could cause short circuits resulting in multiple circuit failures, known as multiple "spurious operations," in systems needed to

[2]The Nuclear Energy Institute is the policy organization for the nuclear technologies industry.

[3]An international nonprofit organization, NFPA develops, publishes, and disseminates fire prevention and safety standards.

[4]NRC, in 69 Fed. Reg. 33536 (June 16, 2004)(codified at 10 C.F.R. § 50.48(c)), endorsed the use of key aspects of National Fire Protection Association, NFPA-805, Performance-Based Standard for Fire Protection for Light Water Reactors Electric Generating Plants, 2001 Edition (Quincy, Massachusetts: 2001).

[5]GAO, *Nuclear Safety: NRC's Oversight of Fire Protection at U.S. Commercial Nuclear Reactor Units Could Be Strengthened* GAO-08-747(Washington, D.C.: June 30, 2008).

safely shut down a plant's nuclear power reactor.[6] At the time of our report, plant operators typically accounted only for spurious operations that occur one at a time or in isolation from one another, although industry tests conducted in 2001 demonstrated that spurious operations could occur simultaneously or in rapid succession. Second, we reported that NRC had not resolved uncertainty about the effectiveness of some types of fire-protection barriers (known as fire wraps) used to protect cables that are important for safely shutting down a nuclear reactor. Third, we reported that some plant operators had used temporary measures that that they could take without prior approval to compensate for equipment that needs to be repaired or replaced (compensatory measures) for an extended period of time rather than conducting needed maintenance, a practice that could degrade nuclear fire safety.[7] For example, some plants had adopted fire watches, in which teams of plant employees are either posted continuously in a single location in a plant or rove throughout the plant to detect signs of fires. We reported that, at one nuclear power plant we visited, plant operators used fire watches for more than 5 years instead of replacing faulty seals to cover openings in structural barriers. We made three recommendations to address these long-standing fire safety issues, and we discuss actions NRC took to address them in the report.[8]

In this context, you asked us to follow up on our 2008 report on fire safety. Our objectives were to provide information on (1) NRC's progress in resolving the long-standing fire safety issues raised in our 2008 report at plants remaining under the deterministic approach and at those plants transitioning to the risk-informed approach; (2) the potential benefits of transitioning to a risk-informed approach and the basis for NRC's decision

[6]In our 2008 report, we referred to these as multiple spurious actuations, which is another term to describe the same phenomenon.

[7]NRC considers compensatory measures that are in place longer than 18 months to be extended.

[8]We also made a fourth recommendation based on our finding that NRC did not have a comprehensive database that aggregated information on exemptions (known as exemptions and deviations) to licensing requirements, or the extended use of compensatory measures that could facilitate the study of compliance trends. In response to this recommendation, NRC developed an online document that identifies records of approved exemptions in NRC's public database. We did not conduct additional work for this review on that recommendation.

to make adoption of this approach voluntary; and (3) challenges, if any, in efforts to transition to a risk-informed approach in regulating fire safety.

To obtain information on NRC's progress in resolving the fire safety issues raised in our 2008 report, we reviewed regulations, guidance documents, and periodic reports from NRC and industry. In addition, we interviewed officials from NRC and representatives from industry and public interest groups. We also conducted semistructured interviews with plant operators about conditions at a nonprobability sample of six plants remaining under the deterministic fire safety approach and six plants transitioning to the risk-informed fire safety approach to obtain information about fire protection at both types of plants.[9] Because the plants included in our review are a nonprobability sample that we selected to represent a mix of reactor types and ages, the information gathered from these plants cannot be generalized to the entire population of plants, or the nuclear power industry as a whole, but it does allow us to make qualified comparisons between different groups of plants and to discuss issues faced by each group. To obtain information on the potential benefits of transitioning to a risk-informed approach and the basis for NRC's decision to make adoption of this approach voluntary, we reviewed NRC regulations, standards, and guidance on risk-informed regulation, probabilistic risk assessment and the use of fire modeling at nuclear power plants. We reviewed industry guidance documents and policy statements on the transition. We also conducted a semistructured interview with a total of nine nuclear engineering consultants and academic experts with previous or current experience in the nuclear power industry—six nuclear engineering consultants currently employed at private firms, one consultant currently employed at a Department of Energy national laboratory, and two academic experts with experience in conducting probabilistic risk assessment, fire modeling, or both. Officials from NRC and the National Institute of Standards and Technology (NIST), industry representatives, as well as operators of the 12 plants we consulted, also provided their insights into the strengths and weaknesses of the deterministic and risk-informed approaches to fire safety.[10] We

[9]The 12 plants we contacted house a total of 24 of the nation's 104 nuclear reactors.

[10]NIST developed one of the fire models currently used at nuclear power plants, and provided extensive modeling and experimentation expertise in NRC's evaluation of fire models used at nuclear power plants. Fire models can help determine how the fire may grow in time and affect structures or systems important for the safe shutdown of a plant. Fire modeling is used in conjunction with probabilistic risk assessments in the risk-informed fire safety approach.

conducted site visits to the two nuclear power plants that participated in the pilot program for the risk-informed fire safety approach. To obtain information on challenges, if any, in efforts to transition to a risk-informed approach in regulating fire safety, we reviewed documentation related to NRC's decision to make the adoption of the risk-informed approach voluntary. We reviewed NRC regulations, guidance, and policy documents on the deterministic and risk-informed fire safety approaches. We also summarized the results of our semistructured interviews with the nine nuclear engineering consultants and academic experts we contacted regarding their views on the benefits of the deterministic and risk-informed approaches to fire safety. We also attended relevant presentations at NRC's March 2012 Regulatory Information Conference, and we observed multiple NRC public meetings with industry concerning issues related to the risk-informed approach to fire safety. Appendix I presents a more detailed description of our scope and methodology, and appendix II lists the names and affiliations of the nine consultants and experts we interviewed.

We conducted this performance audit from September 2011 to October 2012 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

# Background

This section discusses the development of NRC's fire safety regulations, NRC's adoption of risk-informed regulation, and the status of the nuclear industry's adoption of the risk-informed fire safety approach.

## NRC's Fire Safety Regulations

NRC's deterministic fire safety approach and its risk-informed fire safety approach contain requirements that plants' fire protection programs have defense-in-depth objectives in areas important to fire safety.[11] Under both approaches, plants must meet the following objectives: (1) prevent fires

[11]According to NRC documents, "defense-in-depth" is a way of designing and operating nuclear power reactors that focuses on creating multiple independent and redundant layers of defense to compensate for potential human and mechanical failures so that no single layer, no matter how robust, is exclusively relied upon.

from starting; (2) detect rapidly, control, and extinguish promptly those fires that do occur; and (3) provide protection for structures, systems, and components important to safety so that a fire that is not promptly extinguished by the fire suppression activities will not prevent the safe shutdown of the plant. The two approaches provide different methods for plants to demonstrate defense-in-depth capabilities. According to NRC officials and nuclear industry representatives, no fire since the Browns Ferry fire in 1975 has threatened a U.S. nuclear reactor's ability to safely shut down.[12]

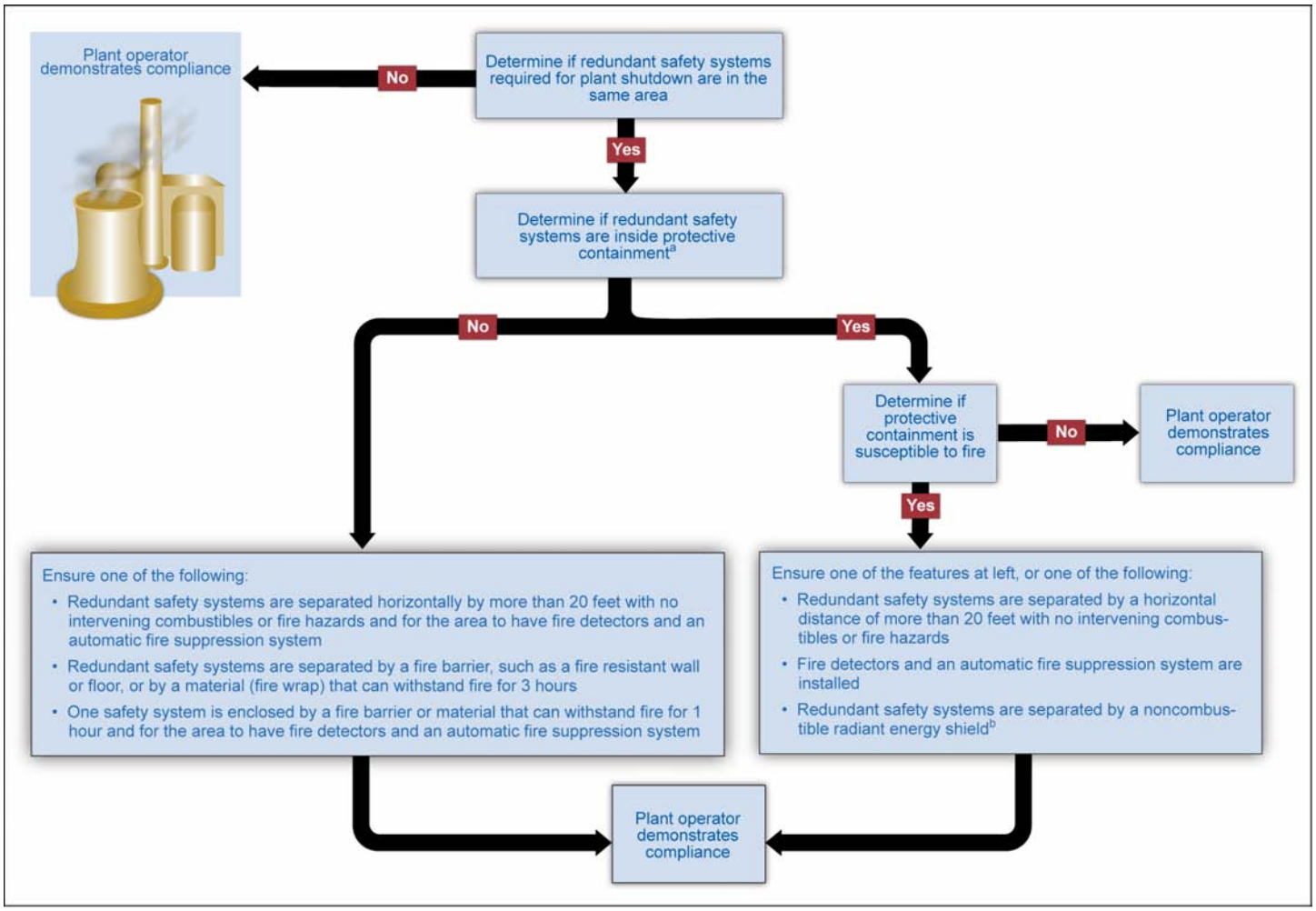
## NRC's Deterministic Approach

NRC's deterministic fire safety approach requires that power plant operators ensure that at least one system of electric cables and equipment is available to safely shut down a reactor if a fire occurs. To meet requirements under the deterministic approach, these operators must, among other things, separate redundant systems, either by distance or fire resistant barriers, such as a fire resistant wall or floor, or by a material (fire wrap) that protects important cables and, in some cases, operators must install fire detection and automatic suppression systems. The requirements also specify the amount of space between redundant systems or how long fire barriers should be able to withstand fire.[13] For example, fire barriers must also be able to withstand fire for at least 1 hour in areas with automatic fire suppression systems and fire detectors or for at least 3 hours where such features are not present. If these requirements are not met or if a redundant system required for shutdown could be damaged by fire suppression activities or operation of the fire suppression system, NRC requires an alternative dedicated shutdown capability. Figure 1 shows the process a plant operator uses to demonstrate fire safety compliance under the deterministic approach.

[12]In our 2008 report, we reported that from January 1995 through December 2007, operators at 54 plants had informed NRC of 125 fires at their plants. From January 2008 through November 2011, operators at 22 plants reported an additional 27 fires to NRC.

[13]Specifically, the deterministic fire safety approach requires nuclear reactors to have at least one redundant system of electric cables and equipment available to safely shut down the reactor. When two systems are in the same area of a nuclear reactor building, the regulations require that they be (1) separated horizontally by more than 20 feet with no intervening combustibles or fire hazards and for the area to have fire detectors and automatic fire suppression systems, or (2) separated by a fire barrier, such as a fireproof wall or floor, or by a material (fire wrap) that can withstand fire for 3 hours, or (3) enclosed by a fire barrier or material that can withstand fire for 1 hour and for the area to have fire detectors and an automatic fire suppression system.

**Figure 1: Process for Demonstrating Fire Safety Compliance under the Deterministic Approach**




Sources: GAO analysis of NRC regulations and NFPA guidance.

[a]"Containment" refers to structures, systems, or components provided to prevent or mitigate the release of radioactive materials.

[b]A "radiant energy shield" is a device used to protect components from the effects of radiant heat generated by a fire.

Over the years, NRC has approved exemptions or deviations from this deterministic approach for units that could not meet the fire safety requirements if the units could otherwise demonstrate the ability to safely shut down. Plants follow the following processes, as applicable:

- *Exemption process.* Under this process, plant operators could obtain an exemption from the deterministic requirements if they could demonstrate fire safety through methods or features other than those explicitly stated in the regulations.

- *Deviation process.* Some of the reactors that came online after NRC had defined the deterministic approach still could not meet the requirements. In such cases, NRC allowed operators to seek deviations from their licensing requirements if they could demonstrate an acceptable alternate approach to fire safety.

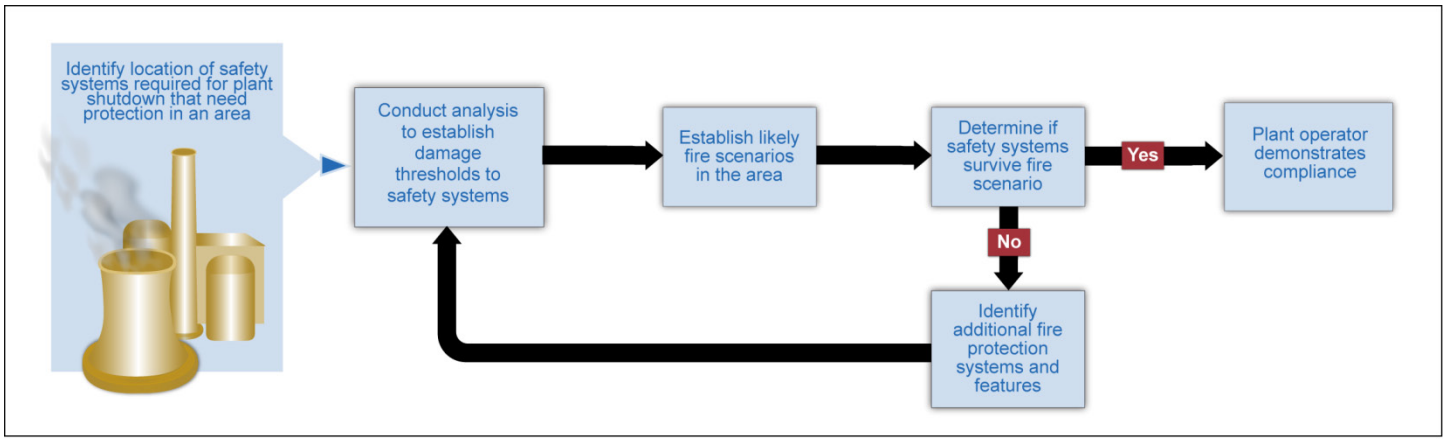
In part because of variations among plant designs and different interpretations of fire safety regulations between industry and NRC, the agency continued to issue updated guidance related to the deterministic regulations, according to NRC and industry documents. However, in 2004, NRC reported that the processing of exemption and deviation requests had placed a "significant" burden on the resources of the agency and the nuclear industry.[14] NRC also acknowledged that industry representatives and some members of the public described the deterministic requirements as an "unnecessary regulatory burden." As of April 2012, NRC had granted more than 900 exemptions and deviations from the deterministic fire safety approach, according to NRC documents and officials.

## Risk-Informed Approach

In response to charges that the processes for granting exemptions and deviations under the deterministic approach were burdensome, NRC issued a regulation in 2004 permitting plants to voluntarily transition to risk-informed fire protection requirements. Under this approach, a plant operator adopts performance goals, objectives, and criteria for fire safety that are defined by the fire protection standard issued by NFPA. The operator can use probabilistic risk assessments (PRA) and fire models, among other tools, to meet the performance criteria. A PRA is a systematic assessment of what can go wrong, its likelihood, and its potential consequences to determine quantitative estimates of a particular risk, such as a fire safety risk. Fire models are mathematical predictions of fire growth, environmental conditions, and potential effects on structures or systems. Figure 2 illustrates how a plant demonstrates fire safety compliance under the risk-informed approach.

[14]69 Fed. Reg. 33536, 33537 (June 16, 2004).

**Figure 2: Process for Demonstrating Fire Safety Compliance under the Risk-Informed Approach**




Source: GAO analysis of NFPA guidance.

Note: Plant operators use fire probabilistic risk assessments and fire models, among other risk analysis tools, throughout the process to demonstrate compliance.

Nuclear power plant operators can choose to make a transition from using the deterministic approach to the risk-informed approach. In doing so, they can conduct a PRA that is subsequently reviewed by teams of experts from other plant operators and consulting firms that are not involved in developing the PRA under review. After the PRA is reviewed, the transitioning plant requests that NRC amend the plant's operating license. NRC staff review the amendment request and, if necessary, request additional information from plant operators and conduct audits of transition documents to ensure that the plant has conducted the necessary tasks. If NRC approves the license amendment request, it will issue a final report evaluating the safety of the plant, after which the transition is considered complete. According to NRC documents and officials, the agency expects the approval process for each plant to take about 2 years after the plant submits its request for a license amendment.

## NRC's Adoption of a Risk-Informed Approach

NRC's change to a risk-informed approach to fire safety is part of a larger NRC effort to move toward accepting or adopting a risk-informed approach to nuclear safety in general. Examples are as follows.

- In 1995, NRC issued a policy statement encouraging the increased use of PRA in all regulatory matters to the extent supported by the state of the art in PRA methods and data and in a manner that

complemented NRC's existing deterministic approach and supported NRC's defense-in-depth philosophy.[15]

- In 2007, NRC issued regulations requiring applicants for combined licenses for new nuclear power reactors to submit a description and the results of a plant-specific PRA to NRC as part of their applications.[16] NRC also began requiring recipients of combined licenses to develop, maintain, and periodically upgrade a plant-specific PRA. Among other things, NRC required the PRA to cover initiating events—that is, events that can lead to a reactor accident—for which there are NRC-endorsed consensus standards for PRA.[17]

- In 2011, NRC commissioned a risk management task force to develop a strategic vision and options for adopting a more comprehensive risk-informed, performance-based regulatory approach. In its April 2012 report, the task force identified goals and objectives that could be the framework for NRC regulatory activities 10 to 15 years in the future and addressed changes that would be needed to ensure that the framework is implemented.[18] The task force reported, "NRC has recognized that purely deterministic and prescriptive approaches can limit the flexibility of both the regulated industries and the NRC to respond to lessons learned from operating experience and support the adoption of improved designs or processes." The task force went on to recommend, among other things, "the goal to adopt risk-informed and performance-based approaches, where practical, should continue and should be incorporated into the revised regulatory framework."

[15]NRC, *Use of Probabilistic Risk Assessment Methods in Nuclear Regulatory Activities;* Final Policy Statement, 60 Fed. Reg. 42,622 (Aug. 16, 1995).

[16] 10 C.F.R. § 52.79(a)(46). In 1989, NRC promulgated regulations that allowed electric power companies to obtain a single license to build and operate a new reactor. This "combined license" is NRC's response to the nuclear industry's concerns about the length and complexity of NRC's former two-step process of issuing a construction permit followed by an operating license.

[17]10 C.F.R. § 50.71(h).

[18]NRC, NUREG 2150, *A Proposed Risk Management Regulatory Framework* (Washington, D.C.: April 2012).

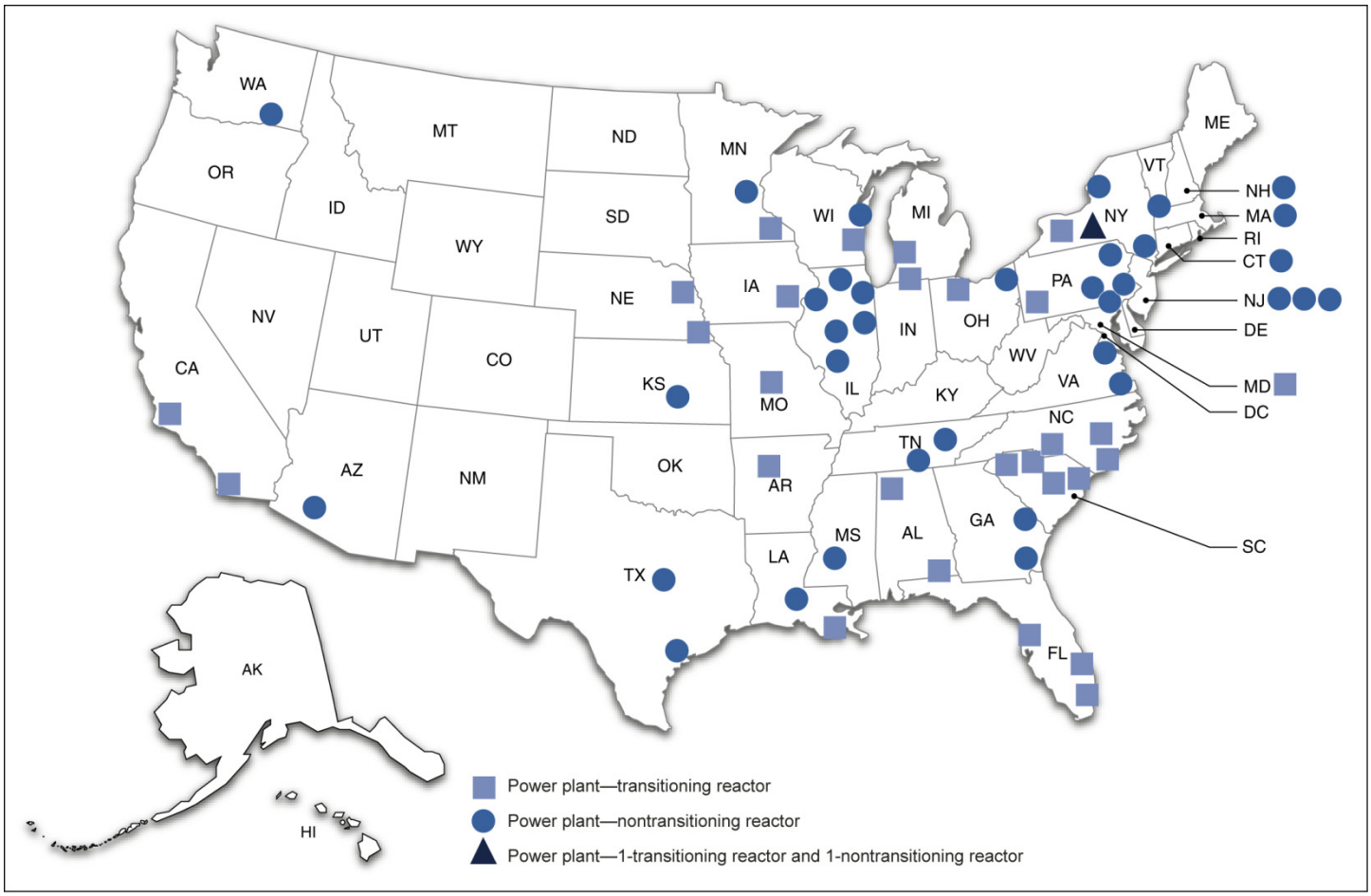
## Status of Industry's Adoption of the Risk-Informed Fire Safety Approach

According to NRC documents, the 65 commercial nuclear power plants operating in the United States house 104 reactors that incorporate 80 different designs. Furthermore, operators for 47 of these reactors, located at 29 plants, plan to or are in the process of transitioning to the risk-informed approach to fire safety. NRC has adopted a staggered schedule for such plants to submit license amendment requests seeking approval to transition to the risk-informed approach. This schedule anticipates that the agency will receive amendment requests from all of the plants by 2014 and will decide on all of the requests by 2016. (Appendix III contains a list of transitioning plants and the dates they are scheduled to submit their license amendment requests to NRC.) According to NRC officials, the agency has implemented a discretionary enforcement policy under which inspection findings related to the transition will not automatically result in violations or penalties. The period of enforcement discretion is tied to each plant's committed date for submitting its license amendment request and, according to NRC documents, provides incentive for plants to adhere to their transition schedule. Plants that elect not to complete the transition process must then seek exemptions or deviations or conduct the modifications necessary to comply with the deterministic approach.

To assist the transition process, operators at two plants—including a plant with three reactors in South Carolina and a plant with one reactor in North Carolina—participated in a pilot program for the risk-informed approach. These plants began the transition in August 2005 and, by December 2010, both plants had completed it. In 2011, NRC issued a report on lessons learned from the pilot experience for other plant operators interested in making the transition.[19] Figure 3 shows the location of the 65 power plants and identifies those with nuclear reactors that will transition to the risk-informed approach and those that remain under the deterministic approach.

[19]NRC, *Lessons-Learned from Pilot Plant Transition to a Risk-Informed, Performance-Based Fire Protection Licensing Basis,* SECY-11-0068 (Washington, D.C.: May 2011).

**Figure 3: Nuclear Power Plants with Reactors Transitioning to the Risk-Informed Approach or Remaining under the Deterministic Approach**




Sources: NRC (data); Map Resources (map).

Note: The 65 operating commercial nuclear power plants are located in 31 states. Some plants house multiple nuclear reactors.

## NRC Has Taken Steps to Resolve Long-standing Fire Safety Issues

NRC, in conjunction with plant operators, has made progress in resolving the three long-standing fire safety issues raised in our 2008 report at nuclear power plants remaining under the deterministic approach and those transitioning to the risk-informed approach. NRC implemented one of our three recommendations and took actions to resolve issues we had identified in making the other two recommendations but did not specifically implement these recommendations.

For the plants remaining under the deterministic approach, NRC has done the following in response to our 2008 recommendations:

- We recommended that NRC commit to a specific date for developing guidelines that reactors should meet to prevent multiple spurious operations. In November 2009, NRC issued a document in which it endorsed industry guidance for methodologies that operators might use to mitigate multiple spurious operations that could occur because of a fire. [20] NRC also set a November 2012 deadline for power plant operators to implement this guidance. Furthermore, as part of this mitigation effort, NRC required corrective actions at the 36 plants that have a total of 57 reactors remaining under deterministic regulations (hereafter referred to as nontransitioning plants).[21] Information gathered by industry, as well as statements to us by selected plant operators, indicate that most operators expect to implement the guidance by NRC's deadline. According to a January 2012 industry survey of operators at plants housing 46 of the 57 nontransitioning reactors, seven of the responding operators reported that they did not expect to mitigate the effects of multiple spurious operations by the deadline; the plants where these operators work at were not identified. We subsequently interviewed operators at 6 nontransitioning plants, and operators at 4 of these plants told us they expect to resolve issues associated with multiple spurious operations by NRC's deadline. Operators at the fifth plant told us that an unexpected maintenance period requiring the plant to go off-line pushed back their mitigation of multiple spurious operations until its next maintenance period, which will occur after November 2012; operators at the sixth plant told us that their efforts to resolve other safety-related issues may delay their mitigation of multiple spurious operations until 2014. In August 2012, NRC officials told us that they may issue a generic letter requesting information from plant operators regarding the specific actions taken to mitigate multiple spurious operations because, under current guidance, operators are not required to provide such information unless requested during NRC plant

[20]NRC, Regulatory Guide 1.189, *Fire Protection for Nuclear Power Plants,* Revision 2 (Washington, D.C.: October 2009). According to NRC officials, power plants that are transitioning, or planning to transition to, the risk-informed approach are currently not subject to this November 2012 deadline.

[21]This number includes the sole plant that has one transitioning reactor and another remaining under the deterministic approach.

inspections.[22] According to these officials, NRC plans to capture information on the methodologies plants are using to mitigate multiple spurious operations, including any instances in which plants are using methodologies not endorsed in NRC's guidance document. The NRC officials told us that the information request must go through NRC's review process and public comment period, and that they did not expect that it would be released until November 2013 at the earliest. These officials stated that the information request could result in the need for additional work by licensees to fully mitigate multiple spurious operations.

- NRC did not implement our recommendation that it analyze the effectiveness of existing fire wraps and undertake efforts to ensure that fire endurance tests have been conducted to qualify fire wraps as approved fire barriers but, according to agency documents, NRC addressed the concerns about fire wraps that we had raised. In an April 2009 letter to Congress on its actions related to our recommendations, NRC reported that nontransitioning plants had resolved this issue by taking some of the following actions: obtaining amendments to their license from NRC, receiving approved exemptions and deviations from deterministic requirements, or completing plant modifications to achieve compliance. Furthermore, in May 2010, NRC reported on compensation strategies used at plants to resolve fire wrap issues. NRC reported that plant operators' efforts included removing deficient fire wrap, installing alternate fire wrap materials, and modifying areas where the wrap had been located to reduce fire risk.[23] Based on information provided by plant operators, NRC's report concluded that there is reasonable assurance that the fire wraps currently used in nuclear power plants to provide protection for the safe shutdown of a power plant adequately protect public health and safety. Operators from four of the six nontransitioning

[22]According to NRC, generic letters request that addressees (1) perform analyses or submit descriptions of proposed corrective actions regarding matters of safety, safeguards, or the environment and submit in writing that they have completed the requests with or without prior NRC approval of the action; (2) submit technical information that NRC needs to perform its functions; or (3) submit proposed changes to technical specifications. By a generic letter, the NRC may also provide the addressees (1) staff technical or policy positions not previously communicated or broadly understood or (2) solicit participation in voluntary pilot programs.

[23]NRC, NUREG-1924, *"Electric Raceway Fire Barrier Systems in U.S. Nuclear Power Plants"* (Washington, D.C.: May 2010).

plants we interviewed told us that they have deficient fire wrap in their plants but have resolved the associated safety issues through modifications approved by NRC or by obtaining exemptions from deterministic requirements. According to these plant operators, they have done so by demonstrating to NRC that other safety features compensate for the wraps, such as by installing upgrades to the wraps to meet deterministic requirements,[24] or by conducting additional testing to demonstrate that the wraps are adequate as configured in the plants.

- NRC did not implement our recommendation that it address safety concerns related to extended use of interim compensatory measures[25] but, in April 2009, the agency reported that it had committed its staff to resolving the issues that underlie the need for compensatory measures and developing metrics to gauge the progress of this effort. Beginning in 2009, NRC and the Electric Power Research Institute gathered data from nontransitioning plants on the use of "long-term compensatory measures"—measures that have been in place for longer than 18 months.[26] NRC reported that the total number of areas within plants where long-term compensatory measures are used increased from June 2011 through December 2011. NRC officials stated their belief that the current use of extended interim compensatory measures is associated with plant operator efforts to mitigate multiple spurious operations, but that they had not conducted an analysis to confirm this. Operators of five of the six nontransitioning plants we contacted told us that they had implemented interim compensatory measures while they work to mitigate multiple spurious operations. NRC officials told us in April

[24]Under the deterministic approach, fire wraps must meet requirements to act as barriers to fire for 1 or 3 hours, depending on whether they are located in an area with fire detection and suppression devices.

[25]Specifically, we recommended that NRC define how long an interim compensatory measure can be used and identify the interim compensatory measures in place at nuclear units that exceed that threshold; assess the safety significance of such extended compensatory measures and define how long a safety-significant interim compensatory measure can be used before NRC requires the unit operator to make the necessary repairs or replacements or request an exemption or deviation from its fire safety requirements and develop a plan and deadlines for units to resolve those compensatory measures.

[26]The Electrical Power Research Institute is a nonprofit company that performs research and development in the electricity sector.

2012 that they expected that the number of long-term compensatory measures would decline following NRC's deadline for mitigating multiple spurious operations by November 2012. However, NRC officials informed us in August 2012 that they were no longer certain that the number of long-term interim compensatory measures would decline as expected. According to these officials, the agency's planned information request related to multiple spurious operations could potentially uncover issues that would require operators to perform additional work to mitigate spurious operations. If this occurs, the NRC officials told us, operators may need to use additional extended compensatory measures at nuclear power plants as they work to finally mitigate these issues after the information request is released as planned in November 2013.

For the plants transitioning to the risk-informed approach to fire safety, NRC officials and plant operators told us that they are continuing to resolve the fire safety issues through modifications and analyses required to comply with the risk-informed approach. Following are examples.

- At one of the transitioning plants we visited, operators showed us a new control facility that is being developed to shut down the plant's reactors from a separate building if a fire affects the primary shutdown circuits. Such a capability allows the plant to mitigate multiple spurious operations at a reactor.

- At that same transitioning plant, operators told us that the modifications and their use of PRA will eliminate their use of long-term compensatory measures, which predominately consisted of fire watches.

- At a plant we visited that had completed the transition, operators stated that they had significant amounts of degraded fire wrap but had made upgrades to areas where the fire wrap was located, including adding additional fire detection devices. Figure 4 shows an example of a fire detection device—called an incipient fire detector alarm—installed at this plant in an area with degraded fire wrap to comply with the risk-informed approach. According to industry documents, the device detects combustion particles that overheating electrical cables produce before any smoke, flames, or heat. An operator at this plant told us that the PRA and other analysis performed as part of the transition had demonstrated that the wrap, in conjunction with upgrades, provide sufficient protection.

**Figure 4: Incipient Fire Detection Device**


Source: Shearon Harris Nuclear Power Plant.

## Benefits Cited in the Risk-Informed Fire Safety Approach, but NRC Considers Plants That Meet the Deterministic Approach to Be Safe

The risk-informed regulatory approach to fire safety offers benefits over the deterministic approach, according to NRC documents we reviewed, and NRC officials, consultants and experts, plant operators, and industry representatives we spoke with, but NRC made the adoption of the risk-informed approach voluntary instead of mandatory because it considers plants that meet deterministic requirements to be safe. NRC officials stated that plant operators will have greater knowledge of plant risk and simpler licensing conditions under the risk-informed approach, and some consultants, experts, and power plant operators we interviewed stated to us that the approach improves plant safety. NRC ultimately elected to make the transition voluntary because of uncertainty over whether agency

staff could make the required determination regarding the approach's protection of health and safety to impose new requirements. NRC considers plants that meet deterministic requirements to be safe, including plants that do so through approved exemptions and deviations.

## NRC Officials, Plant Operators, and Consultants and Experts Cited Various Benefits of the Risk-Informed Approach

NRC documents and agency officials identified two major benefits of transitioning to the risk-informed approach. First, according to NRC officials, the modifications and risk assessments that plant operators perform as part of the transition process will help them identify and devote resources to activities that quantifiably reduce risk while allowing them greater flexibility in areas that do not significantly affect risk. For example, in its April 2012 risk management task force report, NRC stated that the risk-informed approach includes performance-based methods for evaluating plant configurations that would not meet the deterministic requirements, and that these methods allow engineering analyses to demonstrate that changes in overall plant risk that result from these plant configurations are acceptably small and that fire protection defense-in-depth is maintained.[27] To illustrate the difference between the risk-informed and deterministic approaches, NRC officials told us that, in 2008, operators of a nontransitioning plant notified NRC that they had found 17-½ feet of separation between safety systems in a single area, rather than at least 20 feet as required by deterministic regulations. The plant had to submit an exemption request—which NRC approved 8 months later—for what NRC officials characterized as a possibly minor or nonexistent safety issue. These officials told us that obtaining a single exemption—which could include engineering assessments or other work to demonstrate safety—could cost a plant tens of thousands of dollars. According to NRC documents, if the agency does not approve an exemption, a plant could be required to make safety-related modifications that are more expensive than obtaining an exemption but that do not quantifiably reduce risk. Operators from all six of the transitioning plants we contacted said they expected that the risk-informed approach would allow them to avoid making expensive modifications or seeking exemptions to comply with deterministic guidelines. According to NRC guidance and other information provided to us by NRC officials, the approach would also allow plant operators to have the flexibility to change aspects of their approved fire protection programs for reasons other than

[27]NRC, *A Proposed Risk Management Regulatory Framework (*April 2012).

fire safety concerns—such as administrative controls, maintenance procedures, and physical plant modifications if they wished to do so—without prior NRC review and approval if those modifications would not increase risk beyond a certain threshold.[28] An NRC official told us that he was not aware of any operator of a plant meeting deterministic rules making the changes listed above for any reason.

Second, according to NRC officials, under the risk-informed approach, plant operators can obtain licensing amendments that correspond to a single fire safety standard issued by NFPA, rather than be subject to the dozens of guidance documents, communications, and regulatory issue summaries that NRC has issued under the deterministic approach. NRC officials— including regional inspectors responsible for conducting fire safety inspections—told us they expect that simplified licensing requirements will enable plants to more easily demonstrate compliance and allow NRC inspectors to focus on technical issues significant to risk rather than on reading and interpreting complex licensing documents before conducting plant inspections. Operators from two of the six transitioning plants we contacted cited the prospect of clarifying or simplifying their license requirements as a major factor in their decision to adopt the risk-informed approach. For example, under this approach, operators at one plant expected to resolve long-standing issues dating from the 1980s, including differences in interpretation by the plant operator and NRC on how to implement deterministic requirements.

An NRC webpage updated in March 2012 states that the adoption of the risk-informed approach "can absolutely improve an already safe operating environment… [and] fire risk analysis and fire science has evolved in the last two decades, and we now know how to make already safe plants safer." The webpage also notes that early fire protection regulations were developed without the benefit of quantitative estimates of risk and before recent advances in performance-based methods such as fire modeling.

[28]NRC, Regulatory Guide 1.205: *Risk-informed, Performance-based Fire Protection for Existing Light-Water Nuclear Power Plants* (Washington, D.C.: December 2009). Specifically, prior NRC review and approval is not required for individual changes that result in a risk increase less than $1\times10^{-7}$/year (yr) for CDF [core damage frequency] and less than $1\times10^{-8}$/ yr for LERF [large early release frequency]. The proposed change must also be consistent with the defense-in-depth philosophy and must maintain sufficient safety margins. The change may be implemented following completion of the plant change evaluation.

Operators from the six transitioning plants and five of the nine consultants and experts we contacted said that they believed that transitioning plants will be safer than they were under the deterministic approach. Operators at the six transitioning plants said that the transition has improved plant safety because of the extensive fire safety analyses or modifications required during the transition process. For example, operators at one plant stated that they had added fire detection capabilities and that through safety analysis were able to determine that actions that operators were required to do manually in 70 areas throughout the plant to ensure safe shutdown under the deterministic approach were not needed. At the time of our review, the plant operators had yet to submit their license amendment request to NRC, and the agency had not formally evaluated the plant's safety analysis.

## NRC Made the Risk-Informed Approach Voluntary Because It Considers Plants Meeting Deterministic Regulations to Be Safe

NRC officials told us that the agency considers plants that meet deterministic requirements to be safe and, therefore, it decided not to require these plants to transition to the risk-informed approach. Furthermore, as we previously noted, under the deterministic approach there has not been a fire at a U.S. plant that has prevented a plant's reactor from safely shutting down. Also, in the late 1990s, NRC conducted an analysis of selected plants and determined that the cumulative effects of multiple exemptions at plants under the deterministic approach did not pose a significant risk.[29]

Before deciding to make the risk-informed approach voluntary, NRC's commissioners and staff considered two other options. Specifically, as documented in NRC's 1998 policy statement, [30] NRC considered whether to replace the deterministic regulation with the new risk-informed

[29]Specifically, NRC analyzed the risk assessments from 13 of the 103 reactors then in operation and found that only 5 of the 169 exemptions granted to these reactors were potentially risk-significant. NRC reported that it could not project its findings to the 90 other reactors, although NRC staff stated that the risk significance of the combined exemptions would be small because the estimated accident frequency at those reactors were lower than for the reactors that had been examined. See GAO, *Fire Protection: Barriers to Effective Implementation of NRC's Safety Oversight Process*, GAO/RCED-00-39 (Washington, D.C.: Apr. 19, 2000).

[30]NRC, *Development of a Risk-Informed, Performance-Based Regulation for Fire Protection at Nuclear Power Plants,* SECY-98-058 (Washington, D.C.: March 1998). This document outlines three options that NRC staff considered, with industry input, related to adopting a risk-informed approach.

regulation or to maintain the existing deterministic framework without adopting risk-informed regulation. According to the policy statement, NRC staff recommended to allow plant operators to either voluntarily adopt the risk-informed approach or remain under the deterministic approach because it was unclear at that time whether NRC staff would be able to determine if the risk-informed approach improved safety over the deterministic approach. Such a determination would be needed for NRC to comply with its "backfit rule." Under this rule, NRC is generally prohibited from imposing new regulatory requirements on plants unless it determines that the requirements (1) are necessary to provide adequate protection to the health and safety of the public; (2) are necessary to bring a facility into compliance with a license or the agency's rules or orders, or into conformance with plant operators' written commitments; or (3) would substantially increase protection of public health and safety and the implementation costs would be justified in view of the increased protection.[31] The NRC commissioners subsequently directed the staff to proceed with rulemaking to make adoption of the risk-informed approach voluntary. Similarly, in 1998, NRC staff recommended that the implementation of revised regulations pertaining to a wide range of reactor operations should be voluntary.[32] At that time, the staff noted that it would be difficult to make the backfit determination needed to require mandatory implementation and further stated that doing so could create the impression that plants operating under the current regulations were less safe. Ultimately, the NRC commissioners determined that compliance would be voluntary.

As we reported in April 2012,[33] NRC officials told us that it generally takes several years to conduct and document the regulatory analyses needed

[31]10 C.F.R. § 50.109(a)(3). Backfit is defined in 10 C.F.R. § 50.109(a)(1) as "the modification of or addition to systems, structures, components, or design of a facility; or the design approval or manufacturing license for a facility; or the procedures or organization required to design, construct or operate a facility; any of which may result from a new or amended provision in the Commission's regulations or the imposition of a regulatory staff position interpreting the Commission's regulations that is either new or different from a previously applicable staff position."

[32]We reported on this decision in 1999. See GAO, *Nuclear Regulation: Strategy Needed to Regulate Safety Using Information on Risk*, GAO/RCED-99-95 (Washington, D.C.: Mar. 19, 1999).

[33]GAO, *Nuclear Regulatory Commission: Natural Hazard Assessments Could Be More Risk-Informed*, GAO-12-465 (Washington, D.C.: Apr. 26, 2012).

to determine whether a new requirement should be implemented. Similarly, NRC officials we interviewed stated that conducting a backfit analysis for fire safety approaches requires extensive staff resources. These officials told us that plants that meet the deterministic requirements—including those that do so through approved exemptions or deviations—are considered by definition to be safe in that they provide a reasonable assurance of adequate protection. Therefore, the agency does not plan to consider further the need for a mandatory adoption of the risk-informed approach.

## Plants Transitioning to the Risk-Informed Approach Face Three Key Challenges

NRC documents we reviewed and some of the plant operators, industry representatives, consultants and experts we spoke to identified three primary challenges that may affect plants' ability to transition to the risk-informed approach by 2014, when NRC expects to have received requests for license amendments from all of the plants that have currently committed to make the transition. These challenges may also limit the number of plants that ultimately transition to the risk-informed approach beyond those that have already committed to doing so.

First, transition costs have been higher than expected. Operators from 7 of the 12 plants we contacted told us that initial estimates for costs and resources for transition activities were relatively low (from several hundred thousand dollars to a few million dollars for each plant), and these estimates were based on projections that the activities could be conducted relatively easily. As information from the pilot program became available, however, cost estimates began to rise, according to plant operators we spoke with. For example, operators from one pilot plant told us that they had originally estimated transition costs of $5 to 10 million, but ultimately the plant spent $20 million because plant operators identified the need for more modifications than planned, and conducting the PRA was more costly than expected. Operators from all of the nontransitioning plants we contacted cited the cost of the transition as a reason why they are remaining under the deterministic approach, and five of the nine consultants and experts we spoke with stated that cost was a basis for plants not to transition to the risk-informed approach.

According to the lessons learned report prepared by NRC staff after the two pilot plants completed the transition,[34] both NRC and industry

[34]NRC, SECY-11-0068.

representatives underestimated the complexity of the analyses and level of resources needed for the pilot plants to transition to the risk-informed approach. NRC officials told us that none of the currently transitioning plants have officially informed the agency why their transition costs have been higher than expected, but that the officials believe that many of the plant operators did not know the precise location of important cables in their plants; thus, they had to spend substantial resources to pinpoint the location of the cables before conducting their PRA. NRC's risk management task force characterized the transition in its 2012 report as a "high-cost, high-payback" endeavor. The task force also acknowledged the high cost of developing high-quality PRAs and implementing fire protection changes; nevertheless, it stated that the cost of the alternative—continuing with the deterministic approach or allowing plants to shut down—is "even more prohibitive" for the industry. Moreover, one plant operator—whose plant was not involved in the pilot program—stated that the results of the pilot program confirmed his plant's original decision not to commit to the transition process.

Second, it may be difficult to develop realistic PRAs, according to industry documents and some of the plant operators, consultants, and experts we interviewed. Five of the nine consultants and 5 of the 12 plant operators we contacted expressed concern that NRC's guidance for fire PRAs produces overly conservative results. Some of these individuals said that the assumptions underlying the guidance suggest that damage caused by fire is much more likely to occur than has actually been observed in nuclear power plants and that overly conservative risk assessments could cause plant operators to misallocate the resources available to reduce risk of fire. According to 4 of the 12 plant operators and two of the nine consultants and experts who discussed this issue with us, the specific reason for overly conservative PRAs is that sufficient data are not available to develop realistic calculations supporting fire models and PRAs because no major fire incidents—in which a fire threatens a plant's ability to safely shut down—have occurred at nuclear power plants since the 1975 Browns Ferry fire. These individuals stated that, in the absence of sufficient data, NRC and its consultants used overly conservative assumptions in developing NRC's guidance for conducting PRAs. NRC officials and two of the consultants we spoke with agreed that some aspects of NRC's guidance are conservative, but not overly so. These consultants stated that overly conservative risk assessments could result from plant operators' incorrect application of fire modeling, rather than conservative guidance by NRC. NRC is scheduled to release new guidance for fire modeling in October 2012 that is intended to help plant operators identify how to apply such modeling correctly. In addition, NRC

officials told us that they are working with industry to identify areas where NRC's PRA guidance can be improved as more fire data become available from ongoing research.

Third, the number of people experienced in fire modeling and probabilistic risk assessment is relatively small compared with the potential need, according to plant operators, consultants, and experts we spoke with. These individuals differed on the extent to which the number of experts in the field would affect the transition effort. The experts needed to help with the transition include consultants who develop risk assessments and fire models for transitioning power plants, peer reviewers commissioned by industry who review PRAs, and NRC employees or contractors who assist in approving license amendments. Industry representatives we spoke with characterized the PRA field as barely able to keep up with the demands of the transition, and they noted that many individuals with relevant expertise are nearing retirement age. In addition, we identified only three universities that support accredited degree programs in fire protection engineering in the United States.

We have reported on the challenge posed by the limited number of consultants for conducting PRAs as far back as 1985.[35] For example, in June 2008, we noted that numerous NRC officials, industry representatives, and academic experts expressed concern about the limited number of personnel with the necessary skills and training to develop and review PRAs. More recently, in April 2012, we reported that experts in PRAs had said that a key challenge to the use of these assessments is the limited number of experts qualified to develop PRAs.[36] We recognize that our April 2012 report discussed PRAs for natural hazards and that fires in nuclear plants are not natural hazards, but the same pool of individuals conduct PRAs for both types of risk. One of the experts we consulted for our April 2012 report noted that finding individuals with PRA expertise has become more difficult because NRC and industry are conducting PRAs for natural hazards in response to the Fukushima Daiichi nuclear power plant disaster. For this review, operators at 5 of the 12 plants we interviewed expressed concern about

[35]See GAO, *Probabilistic Risk Assessment: An Emerging Aid to Nuclear Power Plant Safety Regulation*, GAO/RCED-85-11 (Washington, D.C.: June 19, 1985); GAO-08-747; and GAO-12-465.

[36]GAO-12-465.

the limited numbers of individuals skilled in PRA and the effect that these numbers may have on plant costs and PRA quality. Operators at one plant estimated that they had paid twice as much in contractor fees as originally planned. Seven of the nine consultants and experts we contacted acknowledged that the current demand for expertise could, in the short term, limit the ability of PRA or fire modeling experts to meet all of the needs of industry or NRC. For example, one expert observed that it has been very difficult to get the number of experts needed to conduct peer reviews of plants' PRAs. However, six of the nine consultants and experts stated that enough people with expertise will ultimately be available to meet the modeling and review needs of both industry and NRC to meet the transition schedule, in part because of increased demand, training, and new practitioners entering the field. For its part, NRC has taken some steps to manage resource needs, including contracting with experts from the Department of Energy's national laboratories and obtaining additional staff for the NRC team responsible for overseeing the transition. In October 2011, NRC identified the transition effort as a high-priority safety activity that would not be delayed by work related to the agency's Fukushima response.[37]

## Agency Comments and Our Evaluation

We provided a draft of this report to the Chairman of the Nuclear Regulatory Commission for review and comment. NRC provided written comments on October 12, 2012, stating that it found the draft report to be accurate, complete, and appropriate in its handling of sensitive information. NRC also provided technical comments, which we incorporated into our report as appropriate. NRC's comments are reproduced in appendix IV.

[37]NRC, *Prioritization of Recommended Actions to Be Taken in Response to Fukushima Lessons Learned*. SECY-11-0137 (Washington, D.C.: Oct. 3, 2011).

As agreed with your offices, unless you publicly announce the contents of this report earlier, we plan no further distribution until 30 days from the report date. At that time, we will send copies to the Chairman of NRC, the appropriate congressional committees, and other interested parties. In addition, the report will be available at no charge on the GAO website at http://www.gao.gov.

If you or your staff members have any questions about this report, please contact me at (202) 512-3841 or ruscof@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. Key contributors to this report are listed in appendix V.

Frank Rusco
Director, Natural Resources and Environment

# Appendix I: Objectives, Scope, and Methodology

Our review provides information on: (1) the Nuclear Regulatory Commission's (NRC) progress in resolving the long-standing fire safety issues raised in our 2008 report at plants remaining under the deterministic approach and at those plants transitioning to the risk-informed approach;[1] (2) the potential benefits of transitioning to a risk-informed approach and the basis for NRC's decision to make adoption of this approach voluntary; and (3) challenges, if any, in efforts to transition to a risk-informed approach in regulating fire safety.

For all of these objectives, we reviewed relevant literature and NRC documents and interviewed NRC officials, representatives from the nuclear power industry, consulting organizations, public interest groups, and others to understand NRC's efforts to oversee fire safety at nuclear power plants. In addition, we summarized the results of semistructured interviews from a nonprobability sample of operators of 12 nuclear power plants—housing a total of 24 of the nation's 104 nuclear reactors— to obtain information about fire protection at plants that are remaining under the deterministic approach, as well as those that are transitioning to the risk-informed approach. Six of the plants we contacted are remaining under the deterministic approach, and the remaining six plants plan to or are in the process of transitioning to a risk-informed approach. These plants were Arkansas Nuclear One in Arkansas, Braidwood Nuclear Generating Station in Illinois, Browns Ferry Nuclear Plant in Alabama, Catawba Nuclear Station in South Carolina, Comanche Peak Nuclear Power Plant in Texas, Diablo Canyon Power Plant in California, Dresden Generating Station in Illinois, Edwin I. Hatch Nuclear Plant in Georgia, Indian Point Energy Center in New York, Joseph M. Farley Nuclear Plant in Alabama, Nine Mile Point Nuclear Station in New York, and Wolf Creek Generating Station in Kansas. We selected these plants to capture a variety of characteristics, including whether they are transitioning to a risk-informed approach to fire safety, the year their operating license was issued, and reactor type. The information gathered from these plants cannot be used to make inferences about the entire population of plants, or the nuclear power industry as a whole, but it does allow us to make qualified comparisons between different groups of plants and to discuss issues faced by each group. We also visited two plants, housing a total of four reactors, that participated in a pilot program for the risk-informed

[1] GAO-08-747.

approach to fire safety. These reactors are the Oconee Nuclear Station in South Carolina and the Shearon Harris Nuclear Plant in North Carolina.

We also interviewed NRC officials from the Office of General Counsel, Office of Nuclear Regulatory Research, the Office of Nuclear Reactor Regulation (including the team overseeing the transition of plants to the risk-informed fire safety approach), as well as NRC officials in Region II and Region IV. We also interviewed officials from the National Institute of Standards and Technology regarding their development of fire models used at nuclear power plants and their role in providing modeling and experimentation expertise in NRC's evaluation of fire models.[2] Furthermore, we interviewed representatives from the Nuclear Energy Institute, the Union of Concerned Scientists, Beyond Nuclear, and NC WARN to discuss their views on NRC's oversight of fire safety at U.S. nuclear power plants.

To obtain information on NRC's progress in resolving the long-standing fire safety issues raised in our 2008 report at plants remaining under the deterministic approach and at those plants transitioning to the risk-informed approach, we reviewed relevant documents obtained from NRC and selected plant operators related to NRC's progress in resolving fire safety issues raised in our 2008 report. We reviewed NRC and industry guidance to plant operators on mitigating issues associated with multiple spurious operations at plants remaining under the deterministic approach to fire safety, as well as those transitioning to the deterministic approach to fire safety. We also reviewed NRC reports and guidance on the use of fire wraps at nuclear power plants and documentation on how operators resolved issues associated with the use of fire wraps. We reviewed joint NRC and industry periodic reports on the extended use of interim compensatory measures at nontransitioning and transitioning plants.

To obtain information on the potential benefits of transitioning to a risk-informed approach and the basis for NRC's decision to make adoption of this approach voluntary, we reviewed relevant documents obtained from NRC and industry on NRC's efforts to transition to a risk-informed approach to regulating fire safety at 29 plants. We reviewed NRC regulations, standards, and guidance on risk-informed regulation,

[2]Fire models can help determine how the fire may grow in time and affect structures or systems important for the safe shutdown of a plant. Fire modeling is used in conjunction with PRAs in the risk-informed fire safety approach.

probabilistic risk assessment (PRA), and the use of fire modeling at nuclear power plants. We reviewed industry guidance documents and policy statements on the transition. We also summarized the results of semistructured interviews with nuclear engineering consultants and academic experts with experience in PRA, fire modeling, or both. To identify consultants and experts to interview, we conducted a review of journal articles, prior GAO reports, NRC guidance documents, industry conference publications, and congressional and NRC hearings. We then solicited recommendations from NRC, the Nuclear Energy Institute, and public interest groups on possible interview subjects. We also asked consultants and experts we contacted for our initial interviews to identify others whom we should interview. Out of a list of 23 potential interview contacts, we ultimately selected a total of nine nuclear engineering consultants and academic experts based on (1) the relevance of their publications, testimony, and background to our review and (2) the extent to which these individuals were recommended to us by NRC, industry representatives, public interest groups, and their peers. Of these nine individuals, six nuclear engineering consultants are currently employed by private consulting firms, one nuclear engineering consultant is currently employed by a Department of Energy national laboratory, and two academic experts are currently employed by universities. Appendix II lists the experts we interviewed. [3] We contacted these nuclear engineering consultants or academic experts by telephone and e-mail, informed them about the nature of our review, and requested their participation in our semistructured interviews. The number of individuals with the relevant expertise to address our questions is limited and, as a result, all of the individuals we interviewed are currently working or have in the past worked for or consulted with the nuclear industry or NRC. We conducted a content analysis to assess experts' responses to a standard set of questions and grouped responses into overall themes. The views expressed by experts do not necessarily represent the views of GAO. Not all of the experts provided their views on all issues.

[3]We attempted to select nuclear engineering consultants and academic experts who were affiliated with different companies or institutions if possible; however, two of the consultants recognized as having extensive expertise relevant to our study are employed by the same parent company. On another occasion, one of the nuclear engineering consultants we contacted included a coworker with relevant experience in the interview; we have identified the coworker in appendix II, but given the similarity of his views with that of his colleague we count both consultants as a single interview respondent.

To obtain information on challenges, if any, in efforts to transition to a risk-informed approach in regulating fire safety, we reviewed documentation related to NRC's decision to make the adoption of the risk-informed approach voluntary. We reviewed NRC regulations, guidance, and policy documents on the deterministic and risk-informed fire safety approaches, as well NRC's 2012 risk management task force report and other documentation related to the agency's expected future use of risk management principles in the regulation of nuclear safety. We reviewed NRC inspection reports from plants that are remaining under the deterministic approach to fire safety and those that are transitioning to a risk-informed approach. We summarized the results of our semistructured interviews with the nine nuclear engineering consultants and academic experts we contacted regarding their views on the benefits of the deterministic and risk-informed approaches to fire safety. We also attended relevant presentations at NRC's March 2012 Regulatory Information Conference, and we observed multiple NRC public meetings with industry concerning issues related to the risk-informed approach to fire safety.

We conducted this performance audit from September 2011 to October 2012 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

# Appendix II: List of Consultants and Experts Contacted for This Report

- Paul J. Amico, Science Applications International Corporation
- Sean Hunt, Hughes Associates, Inc.
- Francisco J. Joglar, KGRS/Hughes Associates, Inc.
- Robert Kalantari, Engineering Planning and Management, Inc.
- Mardy Kazarians, Kazarians & Associates, Inc.
- Mohammad Modarres, University of Maryland
- Frederick W. Mowrer, California Polytechnic State University
- Steven P. Nowlen, Sandia National Laboratories
- Mark Schairer, Engineering Planning and Management, Inc.
- Clarence L. Worrell, Westinghouse Electric Company, LLC

# Appendix III: Schedule for Plants Transitioning to a Risk-Informed Approach to Fire Safety

| Plant | Owner | State | Number of units | License amendment request submittal date |
|---|---|---|---|---|
| Shearon Harris | Duke Energy | North Carolina | 1 | 05/29/2008[a] |
| Oconee | Duke Energy | South Carolina | 3 | 05/30/2008[b] |
| D.C. Cook | Indiana Michigan Power Company | Michigan | 2 | 07/01/2011 |
| Callaway | AmerenUE | Missouri | 1 | 08/29/2011 |
| Duane Arnold | NextEra Energy | Iowa | 1 | 07/29/2011 |
| Fort Calhoun | Omaha Public Power District | Nebraska | 1 | 09/29/2011 |
| VC Summer | SC Electric and Gas | South Carolina | 1 | 11/15/2011 |
| Waterford—Unit 3 | Entergy Nuclear Operations | Louisiana | 1 | 11/17/2011 |
| Arkansas Nuclear One—Unit 2 | Entergy Nuclear Operations | Arkansas | 1 | 03/27/2012[c] |
| Cooper | Nebraska Public Power District | Nebraska | 1 | 04/25/2012 |
| Nine Mile Point— Unit 1 | Constellation Energy | New York | 1 | 06/29/2012 |
| Turkey Point | NextEra Energy | Florida | 2 | 06/30/2012 |
| Arkansas Nuclear One—Unit 1 | Entergy Nuclear Operations | Arkansas | 1 | 08/31/2012[d] |
| Beaver Valley | First Energy Nuclear | Pennsylvania | 2 | 09/30/2012[e] |
| Brunswick | Duke Energy | North Carolina | 2 | 09/30/2012 |
| Farley | Southern Nuclear Operating Company | Alabama | 2 | 09/30/2012 |
| Prairie Island | Northern States Power | Minnesota | 2 | 09/30/2012 |
| Palisades | Entergy Nuclear Operations | Michigan | 1 | 12/31/2012 |
| Browns Ferry | Tennessee Valley Authority | Alabama | 3 | 03/29/2013[f] |
| Ginna | Constellation Energy | New York | 1 | 03/29/2013 |
| St. Lucie | NextEra Energy | Florida | 2 | 03/30/2013 |
| San Onofre | Southern California Edison | California | 2 | 03/31/2013 |
| Diablo Canyon | Pacific Gas and Electric | California | 2 | 06/28/2013 |
| Point Beach | NextEra Energy | Wisconsin | 2 | 06/30/2013 |
| Calvert Cliffs | Constellation | Maryland | 2 | 09/30/2013 |
| Catawba | Duke Energy Power | South Carolina | 2 | 09/30/2013 |
| McGuire | Duke Energy Power | North Carolina | 2 | 09/30/2013 |
| Robinson | Duke Energy | South Carolina | 1 | 09/30/2013 |
| Davis Besse | First Energy Nuclear | Ohio | 1 | 07/01/2014 |
| Crystal River 3 | Duke Energy | Florida | 1 | 07/01/2014 |

Source: NRC.

[a]Shearon Harris was a pilot plant for the risk-informed approach transition. NRC approved the plant's license amendment request on June 28, 2010.

[b]Oconee was a pilot plant for the risk-informed approach transition. NRC approved the plant's license amendment request on December 29, 2010.

[c]On September 7, 2012, NRC notified Arkansas Nuclear One, Unit 2 that it did not accept the reactor's license amendment request, and the reactor is no longer under enforcement discretion. Plant operators may resubmit an amendment request at an unspecified future date.

[d]Arkansas Nuclear One, Unit 1 submitted an extension request to delay submittal of its license amendment request to August 2013. NRC staff are currently reviewing the extension request.

[e]Beaver Valley submitted an extension request to delay submittal of its license amendment request to December 2013. NRC staff are currently reviewing the extension request.

[f]Browns Ferry originally committed to submit its License Amendment Request in March 2012 but was granted an extension by NRC to March 2013.

# Appendix IV: Comments from the Nuclear Regulatory Commission

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

October 12, 2012

Mrs. Kim Gianopoulos, Assistant Director
Natural Resources and Environment
U.S. Government Accountability Office
441 G Street, NW
Washington, D.C. 20548

Dear Mrs. Gianopoulos:

Thank you for providing the U.S. Nuclear Regulatory Commission (NRC) with the opportunity to review and comment on the U.S. Government Accountability Office's (GAO's) draft report GAO-13-8, "Nuclear Regulatory Commission: Oversight and Status of Implementing a Risk-Informed Approach to Fire Safety." The NRC staff has reviewed the draft report and found it to be accurate, complete, and appropriate in its handling of sensitive information.

If you have any questions regarding this response, please contact Jesse Arildsen. Mr. Arildsen can be reached by telephone at (301) 415-1785.

Sincerely,

R. W. Borchardt

R. W. Borchardt
Executive Director
for Operations

# Appendix V: GAO Contact and Staff Acknowledgments

## GAO Contact

Frank Rusco, (202) 512-3841, or ruscof@gao.gov

## Staff Acknowledgments

In addition to the individual named above, Kim Gianopoulos and Ernie Hazera, Assistant Directors; Steve Carter; and Stephanie Gaines made key contributions to this report. R. Scott Fletcher, Cindy Gilbert, Amanda Manning, Armetha Liles, Cynthia Norris, Carol Herrnstadt Shulman, Jeanette Soares, and Kiki Theodoropoulos provided technical assistance.