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Report to Congressional Requesters

April 2012

NUCLEAR REGULATORY COMMISSION

Natural Hazard Assessments Could Be More Risk-Informed

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GAO-12-465

GAO Highlights

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Highlights of GAO-12-465, a report to congressional requesters

April 2012

NUCLEAR REGULATORY COMMISSION

Natural Hazard Assessments Could Be More Risk-Informed

Why GAO Did This Study

On March 11, 2011, an earthquake triggered a tsunami wave that exceeded the seawall at Japan's Fukushima Daiichi nuclear power plant, leading to the release of radioactive material into the environment. The disaster raised questions about the threats that natural hazards, such as earthquakes and floods, may pose to U.S. commercial nuclear power reactors. NRC licenses and regulates U.S. nuclear power reactors. NRC criteria for licensees to assess natural hazards were developed using an approach that required reactors to be designed according to a set of potential accidents using deterministic analysis. Since the 1990s, NRC has been encouraging the use of PRA as part of a risk-informed, performance-based approach.

GAO was asked to (1) determine the extent to which PRA is applied to natural hazards at operating U.S. reactors and (2) describe expert views on and suggested changes, if any, to NRC processes for assessing natural hazards at such reactors. GAO reviewed documents; analyzed responses from 15 experts in assessing nuclear reactor risks and/or natural hazards; visited five selected nuclear power plants; and interviewed NRC officials and industry and public interest group representatives.

What GAO Recommends

GAO recommends that NRC analyze whether licensees of operating reactors should be required to develop PRAs that address natural hazards. NRC agreed with the recommendation and stated it will conduct the analysis in the context of ongoing initiatives.

View GAO-12-465. For more information, contact Frank Rusco at (202) 512-3841 or ruscof@gao.gov.

What GAO Found

The Nuclear Regulatory Commission (NRC) and companies licensed to operate nuclear power reactors (or licensees) apply probabilistic risk assessment (PRA) to natural hazards at operating U.S. nuclear reactors to a limited extent. When the 104 operating reactors were originally licensed before 1997, NRC required licensees to assess natural hazards using deterministic analysis, which—informed by historical experience, test results, and expert judgment—considers a specific set of potential accidents and how the consequences of those accidents can be prevented and mitigated. Subsequent to most of these initial licenses being issued, NRC, through policy statements and other documents, has endorsed PRA—a systematic method for assessing what can go wrong, its likelihood, and its consequences, resulting in quantitative estimates of risk—as a means to enhance and extend traditional deterministic analysis. In 1991, NRC requested that licensees voluntarily examine their reactors' vulnerability to natural hazards and suggested PRA as one of several possible methods for licensees to use in their examinations. However, most licensees opted to use other methods. According to NRC officials and nuclear power industry representatives—and reflected in data GAO obtained from five licensees that together operate 25 reactors—few licensees are likely to have developed or updated since the 1990s PRAs that address natural hazards. NRC would have to conduct an analysis to determine whether or not to require licensees to develop PRAs that address natural hazards. According to agency officials, NRC has not conducted such an analysis.

The experts in assessing natural hazards and/or nuclear reactor risks that GAO interviewed offered a range of views on (1) the overall adequacy of NRC processes for assessing the threats that natural hazards pose to operating U.S. nuclear power reactors and (2) what, if any, changes to those processes are warranted. Several experts said they believe NRC processes are generally adequate for assessing the threats that natural hazards pose to operating reactors. However, more than half of the experts GAO interviewed suggested expanding the use of PRA for assessing natural hazards as a complement to traditional deterministic analyses to provide a more robust approach. Those experts cited a number of advantages to doing so, including that PRA can help identify vulnerabilities that might otherwise be overlooked by relying on traditional deterministic analyses alone. Several experts also identified challenges to expanding the use of PRA for assessing natural hazards, including the limited number of experts qualified to develop PRAs and the costs of doing so.

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Abbreviations

IPEEE	Individual Plant Examination of External Events
NRC	Nuclear Regulatory Commission
PRA	probabilistic risk assessment

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United States Government Accountability Office
Washington, DC 20548

April 26, 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 11, 2011, a 9.0-magnitude earthquake and subsequent tsunami devastated northeast Japan and led to the most extensive release of radioactive material at a nuclear power plant since the 1986 Chernobyl disaster. The Fukushima Daiichi nuclear power plant suffered extensive damage when a tsunami wave that exceeded the plant's seawall flooded the site and caused a prolonged loss of electrical power at several of its reactors. As a result of the loss of power, plant operators were unable to keep three of the reactors cool, which led to fuel melting, hydrogen explosions, and the release of radioactive material into the environment. The disaster displaced tens of thousands of residents and contaminated the surrounding area. The Japanese government expects recovery to take years and cost billions of dollars. In light of the disaster, Japan and other countries have decided to reduce their reliance on nuclear power, which could affect their electricity costs and output of carbon emissions.

In the United States, the Nuclear Regulatory Commission (NRC), an independent federal agency headed by five commissioners, licenses commercial nuclear power reactors and regulates and oversees their safe operation and security.[1] An NRC task force has reviewed the Fukushima Daiichi disaster and determined that the continued operation of existing U.S. nuclear power reactors and the licensing of new reactors do not pose an imminent risk to public health and safety. Nevertheless, the disaster and its origins in a natural hazard—a tsunami—that was more severe than the plant was designed to withstand has raised questions about whether a similar event could happen here. These questions were

[1]Congress created NRC in 1974 to take over the regulatory duties of its predecessor, the Atomic Energy Commission.

further highlighted by natural hazards that affected the sites of several U.S. commercial nuclear power plants and their reactors in 2011,[2] including flooding near two power plants in Nebraska, severe storms at a plant in Alabama, and an earthquake at a plant in Virginia.[3]

NRC's design criteria for nuclear power reactors require that systems, structures, and components important to safety be designed to withstand the effects of natural hazards, such as earthquakes, tornados, hurricanes, floods, and tsunamis, without losing the ability to perform their safety functions.[4] The companies licensed to operate nuclear power reactors, or licensees, are responsible for protecting their reactors against natural hazards by assessing the hazards their reactors may face according to these criteria and designing their reactors to withstand such hazards. NRC is responsible for reviewing assessments and the resulting reactor designs as part of its process for issuing licenses for the construction and operation of nuclear power reactors, as well as for providing continuing oversight of operating reactors.

Most of NRC's regulatory framework—including its criteria for assessing natural hazards for currently-operating reactors—was developed according to a deterministic approach. The deterministic approach 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. Using this approach, NRC developed regulatory requirements primarily based on historical experience, test results, and expert judgment without

[2]In this report, when we use the term power plant, we are referring to an entire site, and nuclear power reactors are the individual units at each site.

[3]Each plant successfully withstood these events, although the ground accelerations of the earthquake that affected the North Anna Power Station in Virginia exceeded the plant's design at several frequencies for a short period of time. This was the first time an operating reactor in the United States exceeded its design limit for ground acceleration. NRC and licensee inspections found minimal earthquake damage to the plant.

[4]10 C.F.R. Part 50, Appendix A, General Design Criterion 2—*Design Bases for Protection Against Natural Phenomena*. According to an NRC document, all currently operating reactors were licensed to or meet the intent of the General Design Criteria, which include General Design Criterion 2.

considering quantitative estimates of risk.[5] According to NRC documents, in developing those requirements, NRC considered the concept of "defense-in-depth"—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.[6] The agency has been moving since the 1990s toward a risk-informed, performance-based approach to regulatory decision making that is being implemented in phases according to NRC documents.[7] This approach extends the traditional deterministic approach in part by incorporating probabilistic risk assessment (PRA). PRA is a systematic method for assessing what can go wrong, its likelihood, and its potential consequences to determine quantitative estimates of risk in order to provide insights into the strengths and weaknesses of the design and operation of a nuclear power reactor. We have previously reported on NRC's use of PRA, its adoption of a risk-informed, performance-based approach, and the challenges involved in implementing that approach.[8]

According to several experts in assessing nuclear reactor risks, risk analysts face challenges in assessing the threats posed by natural hazards, particularly for extreme natural hazards with a low likelihood of occurring but potentially high consequences. These challenges include uncertain knowledge about particular natural hazards due to the limited

[5]According to NRC, the deterministic approach considers implied but unquantified elements of probability in the selection of accidents to be analyzed.

[6]According to NRC, the "defense-in-depth" concept is not defined in NRC regulations, and there is no single, agency-accepted description of the concept. However, it includes the use of access controls, physical barriers, redundant and diverse key safety functions, and emergency response measures.

[7]NRC differentiates between "risk-informed" and "risk-based" regulation, noting that the former uses risk analysis to augment other information used to support regulatory decisions, while the latter approach relies solely on quantitative results of risk assessments. NRC does not endorse a risk-based approach.

[8]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); GAO, *Nuclear Regulatory Commission: Oversight of Nuclear Power Plant Safety Has Improved, but Refinements Are Needed*, GAO-06-1029 (Washington, D.C.: Sept. 27, 2006); GAO, *Nuclear Regulation: Strategy Needed to Regulate Safety Using Information on Risk*, GAO/RCED-99-95 (Washington, D.C.: Mar. 19, 1999); GAO, *Probabilistic Risk Assessment: An Emerging Aid to Nuclear Power Plant Safety Regulation*, GAO/RCED-85-11 (Washington, D.C.: June 19, 1985).

historical record and the rarity of extreme natural hazards, the developing state of knowledge about natural hazards that varies by hazard, and changes to natural hazards over time potentially due to climate change and other causes.

Natural hazard assessments are only one component of NRC's processes for ensuring that nuclear power reactors are protected against such hazards. In addition to requiring licensees to design their reactors using information from such assessments, NRC also requires licensees to have the ability to mitigate the consequence of accidents if they occur to prevent core damage and the uncontrolled release of radioactive material into the environment and, if that fails, to have emergency preparedness procedures in place to mitigate the effects of a radiological release on the public and the environment. Operating a nuclear power reactor is never entirely free of risk; assessments do not eliminate all risk no matter how well the hazards have been assessed but are an important source of information for identifying and mitigating vulnerabilities to events that can occur as a result of natural hazards.

In this context, you asked us to review how NRC assesses the threats that natural hazards pose to operating U.S. commercial nuclear power reactors. This report examines (1) the extent to which PRA is applied to natural hazards at operating U.S. nuclear power reactors and (2) expert views on and suggested changes, if any, to NRC processes for assessing natural hazards at operating U.S. nuclear power reactors.

To describe the extent to which PRA is applied to natural hazards at operating U.S. nuclear power reactors, we reviewed relevant documents and data obtained from NRC and selected licensees. We interviewed knowledgeable officials about the data and found the data to be sufficiently reliable for the purposes of our report. We reviewed NRC policies and procedures, as well as NRC initiatives related to the assessment of natural hazards. We also reviewed the NRC task force report on lessons learned from the Fukushima Daiichi disaster and documented actions NRC has taken on recommendations related to the assessment of natural hazards. In addition, we visited a nonprobability sample of five nuclear power plants to interview licensees about the actions they have taken to assess natural hazards.[9] The five nuclear power plants we visited were the Browns Ferry Nuclear Plant in Alabama, the Diablo Canyon Power Plant in California, the North Anna Power Station in Virginia, the San Onofre Nuclear Generating Station in California, and the Turkey Point Nuclear Plant in Florida. We selected these sites to capture a variety of characteristics, including reactor and containment vessel type, operating license issuance date, license renewal status, and natural hazard activity level. We also interviewed NRC officials and representatives from the nuclear power industry,[10] public interest groups, and the insurance industry to discuss NRC processes for assessing natural hazards. Further, we interviewed officials and reviewed documents from the National Oceanic and Atmospheric Administration, the U.S. Army Corps of Engineers, and the U.S. Geological Survey on the current state of knowledge on natural hazards, how that knowledge has changed over time, and the related uncertainty.

To obtain expert views on and suggested changes, if any, to NRC processes for assessing natural hazards at operating U.S. nuclear power reactors, we held semistructured interviews with 15 experts in assessing natural hazards, risks to nuclear power reactors, or both. We identified these experts through a literature search, a review of prior GAO reports, and congressional and NRC hearings, as well as expert recommendations. The experts we interviewed included representatives from academia, government, industry, and public interest groups. We analyzed experts' responses across a standard set of questions and summarized the results. We did not independently evaluate the quality of NRC processes for assessing natural hazards and the threats they pose to nuclear power reactors. Appendix I presents a more detailed description of our scope and methodology and appendix II lists the names and affiliations of the 15 experts we interviewed.

We conducted this performance audit from May 2011 to April 2012 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain

[9]Because this was a nonprobability sample, the information we gathered from these site visits is not generalizable to all 65 operating nuclear power plants but provides important illustrative information.

[10]We interviewed officials from the Nuclear Energy Institute, the policy organization of the nuclear energy and technologies industry.

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 U.S. commercial nuclear power reactors, NRC's approach to natural hazard assessments, NRC's endorsement of PRA, and actions NRC has taken on natural hazard assessments since the Fukushima Daiichi disaster.

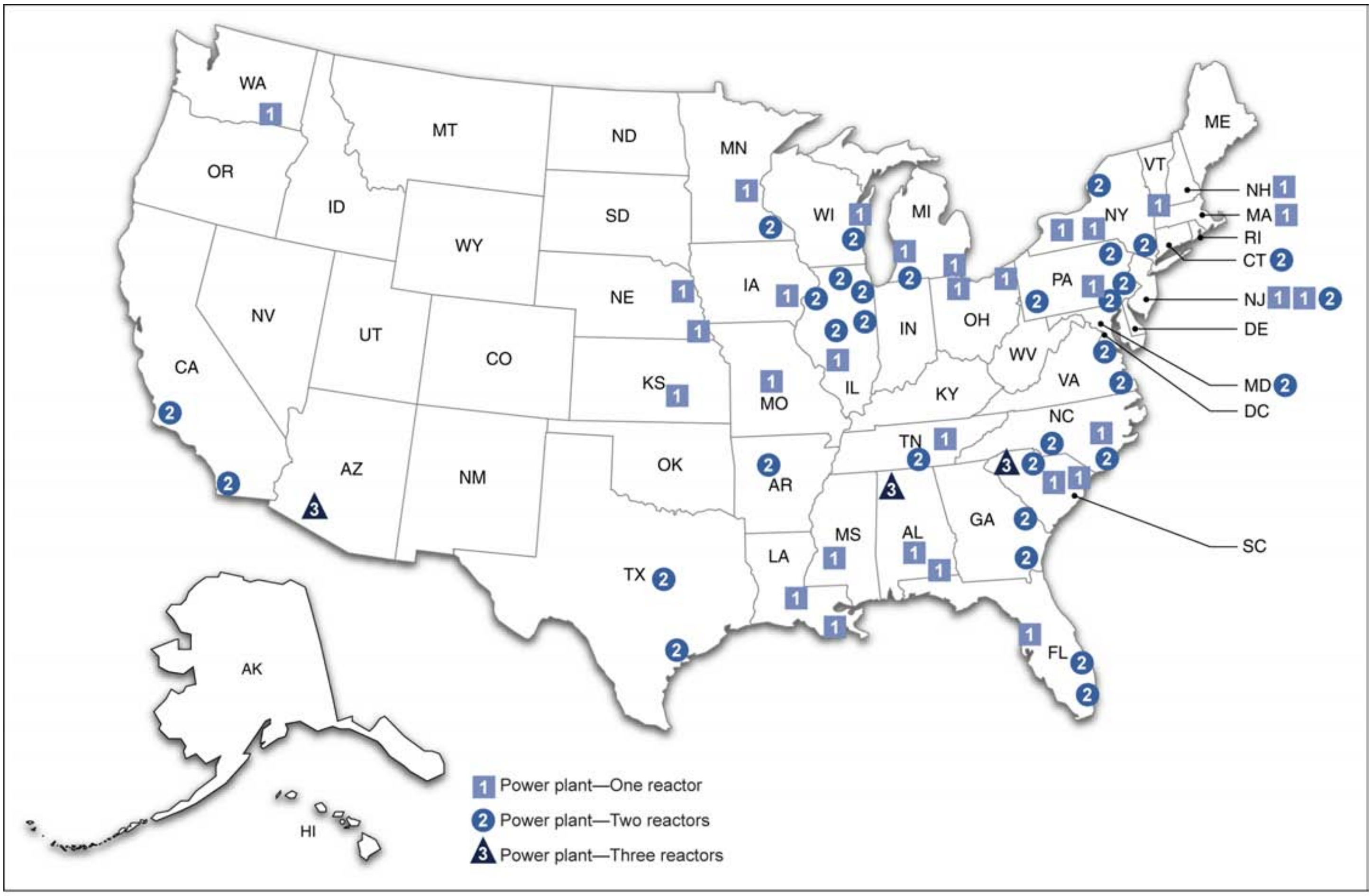
Commercial Nuclear Power Reactors in the United States

Currently, 104 commercial nuclear power reactors operate in the United States. Together, these reactors generated almost 20 percent of our nation's electricity in 2011. These reactors are located at 65 power plants across the country (see fig. 1) and are operated by 26 different companies. All 104 operating reactors received their construction permits in the 1960s and 1970s, with most receiving their operating licenses in the 1970s and 1980s.[11] Many reactors are reaching or have reached the end of their initial 40-year license. As of March 2012, NRC had renewed 71 reactor licenses for an additional 20 years and was currently reviewing 11 license renewal applications.[12] In addition, NRC authorized two new reactors in Georgia in February 2012 and two new reactors in South Carolina in March 2012 and is considering 10 applications for the building and operation of new commercial nuclear power reactors.

[11]One operating reactor received its operating license in 1969, and 6 operating reactors received their operating licenses in the 1990s, with the last of those reactors receiving its operating license in 1996. The other 97 operating reactors received their operating licensees between 1970 and 1989.

[12]NRC issues licenses for commercial nuclear power reactors to operate for 40 years. Under current regulations, licensees may renew their licenses for up to 20 years. License renewal focuses on evaluating and managing the adverse effects of aging on a nuclear power reactor. Current regulations do not include a requirement that licensees of operating reactors reevaluate their design bases pertaining to natural hazards as part of the license renewal process.

Figure 1: U.S. Operating Commercial Nuclear Power Reactors by Power Plant Location



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

NRC's Approach to Assessing Natural Hazards

NRC required licensees of the 104 operating reactors to use deterministic analysis to assess the natural hazards their reactors might face as part of their construction permit and operating license applications.[13] Among other things, NRC required the designs of structures, systems, and

[13]10 C.F.R. Part 50, Appendix A and 10 C.F.R. Part 100—Reactor Site Criteria. NRC requires new nuclear power reactors licensed after January 1997 to be sited and designed with respect to geological and seismic determinations based on an appropriate analysis, such as a probabilistic seismic hazard analysis. 10 C.F.R. Part 100, subpart B.

components important to safety to reflect appropriate consideration of the most severe natural hazards that had been historically reported for a reactor site and the surrounding area, with sufficient safety margin to account for the limited accuracy, quantity, and period over which historical data on natural hazards have been accumulated. NRC staff independently reviewed applicants' natural hazard assessments as part of the application review process to determine whether the assessments were acceptable. When NRC issued an operating license for a nuclear power reactor, these natural hazard assessments became part of the reactors' licensing basis—that is, the collection of documents or technical criteria upon which NRC issues licenses for the construction and operation of nuclear power reactors. NRC does not require licensees to reevaluate their natural hazard assessments on a periodic basis, but through several pieces of regulation it requires that licensees consider new information on natural hazards as they become aware of it to determine if the information may necessitate additional licensee action under NRC requirements. NRC staff also continually evaluate new information on natural hazards through research and oversight processes to assess potential impacts on reactor safety, according to NRC officials, and the agency has initiated several discrete efforts over time that have examined the threats that natural hazards pose to operating nuclear power reactors. For example, in 1991, NRC requested that each licensee identify and report plant-specific vulnerabilities to severe accidents caused by external events, including natural hazards, as part of its Individual Plant Examination of External Events (IPEEE) program.[14] More recently, NRC initiated the Generic Issue-199 program in 2005 to examine the implications of new seismic hazard estimates for the central and eastern United States for operating nuclear power reactors.[15]

[14]NRC, *Individual Plant Examination of External Events (IPEEE) for Severe Accident Vulnerabilities—10 CFR 50.54(f)*, Generic Letter No. 88-20, Supplement 4 (Washington, D.C.: June 28, 1991). Acts of sabotage or terrorism were not included in the set of events considered.

[15]NRC, *Implications of Updated Probabilistic Seismic Hazard Estimates in Central and Eastern United States*, Generic Issue 199 (Washington, D.C.: June 9, 2005).

NRC's Endorsement of PRA

NRC's approach to risk assessment has evolved over time.[16] NRC began endorsing the use of PRA to enhance and extend traditional deterministic analysis as part of the agency's move toward a risk-informed, performance-based regulatory approach. Specifically,

- In 1986, NRC issued a policy statement calling for the use of PRA to measure achievement of the agency's individual and societal safety goals.[17] The policy statement aimed to express NRC policy on "how safe is safe enough" at U.S. nuclear power plants by broadly defining an acceptable level of radiological risk that might be imposed on the public as a result of plant operations.[18]

- 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 deterministic approach and supported NRC's defense-in-depth philosophy.[19]

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[16]Appendix III describes key developments in NRC's approach to probabilistic risk assessment, including its application to natural hazards.

[17]NRC, *Safety Goals for the Operations of Nuclear Power Plants; Policy Statement*, 51 Fed. Reg. 30,028 (Aug. 21, 1986).

[18]The policy statement established two qualitative safety goals—one addressing individual risk and the other addressing societal risk—each supported by a quantitative health effects objective by which the safety goal could be measured. NRC staff subsequently adopted subsidiary numerical objectives of less than 1 core damage event expected per 10,000 years of reactor operation and less than 1 large early radiation release expected per 100,000 years of reactor operation to serve as surrogates for the quantitative health effects objectives. Both the quantitative health effects objectives and the subsidiary numerical objectives are calculated using probabilistic risk assessment. The safety goals, quantitative health effects objectives, and subsidiary numerical objectives are applied at the individual reactor level. NRC officials indicated that NRC does not consider aggregate, industry-wide probabilities that core damage or a large early radiation release would occur somewhere in the United States or set total aggregate, industry-wide objectives because NRC licenses nuclear power reactors on an individual reactor basis and because they do not believe such probabilities would be appropriate.

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

- In 2007, NRC issued regulations requiring applicants for combined licenses[20] for new nuclear power reactors to submit a description and the results of a reactor-specific PRA to NRC as part of their application.[21] NRC also began requiring licensees of new nuclear power reactors that will operate those reactors under a combined license to develop, maintain, and periodically upgrade a reactor-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 were NRC-endorsed consensus standards for PRA quality.[22]

- In 2009, NRC issued a regulatory guide that endorsed national consensus standards for PRA quality.[23] Effective April 2010, licensees of operating reactors who choose to submit risk-informed licensing applications are expected to meet the NRC-endorsed guidelines, including a quality standard that addresses the assessment of natural hazards.

- In 2011, the Chairman of the NRC commissioned a task force to develop a strategic vision and assess options for a more holistic risk-informed, performance-based regulatory approach, with one option being better incorporation of risk management concepts into NRC's regulatory programs.

[20]In 1989, NRC promulgated 10 C.F.R. Part 52, which established a new combined license for electric power companies to obtain a license to build and operate a new reactor. 54 Fed. Reg. 15,372 (Apr. 18, 1989). While NRC has revised its regulatory process, the technical bases for its decisions to make findings have generally remained the same. The 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. The combined license process provides a one-step approval process that authorizes a licensee to construct and operate a nuclear power reactor; as such, it is intended to provide predictability and early resolution of issues in the review process.

[21]10 C.F.R. § 52.79(a)(46).

[22]10 C.F.R. § 50.71(h).

[23]NRC, *An Approach for Determining the Technical Adequacy of Probabilistic Risk Assessment Results for Risk-Informed Activities*, Regulatory Guide 1.200 (Washington, D.C.: March 2009).

NRC policy statements, training manuals, and other documents cite numerous advantages of using PRA to enhance the agency's traditional deterministic approach. Specifically, PRA

- can enhance safety decision making with risk insights, allowing for the more efficient use of NRC resources and reducing unnecessary burdens on licensees;
- explicitly considers a broader set of potential challenges to safety;
- provides a logical means for prioritizing challenges based on risk significance, operating experience, and engineering judgment;
- explicitly identifies, evaluates, and quantifies sources of uncertainty;
- provides a means to test the sensitivity of assessment results to key assumptions;
- provides a rigorous, systematic tool for analyzing complex systems and enables information integration; and
- provides qualitative insights into plant vulnerabilities and quantitative results for use in decision making.

NRC has encouraged the increased use of PRAs in all regulatory matters but generally does not require licensees to develop or maintain PRAs for currently operating reactors. However, licensees may choose to submit license amendment requests so they can transition to less prescriptive, risk-informed approaches for particular issues allowed by NRC regulations, such as NRC's risk-informed approach to fire protection.[24] According to NRC officials, if licensees choose to apply to use a risk-informed approach, licensees must develop a PRA to the extent required

[24]In 2004, NRC issued a regulation that allowed the transition of nuclear reactors from its existing, prescriptive fire safety regulations to a less prescriptive, risk-informed, performance-based approach, under which licensees can use tools, such as fire modeling and risk analysis, to determine which areas of the nuclear power plant are most at risk from fire. According to NRC officials, these analyses could enable units to focus their resources on addressing these higher-risk areas and reduce the number of future exemptions in areas that are no longer considered to be at high risk from fire. Reductions in exemptions would, thus, simplify the units' licenses. For more information, see GAO-08-747.

for the application.[25] In contrast, applicants for combined licenses to build and operate new nuclear power reactors are required to develop a PRA in addition to a deterministic analysis.[26] For combined licenses, NRC expects those PRAs to address natural hazards except for natural hazards that licensees determine are an insignificant contributor to risk, based on NRC-endorsed screening criteria. For example, a nuclear power reactor that is distant from a coast will likely be able to omit tsunami hazards from its PRA. Further, NRC requires licensees of new nuclear power reactors who will operate their reactors under a combined license to develop, maintain, and periodically upgrade their PRAs over the operating life of their reactors.[27] PRAs are used to evaluate several categories of initiating events, including internal events, which start inside the nuclear power plant or the electric system serviced by the power plant (e.g., random hardware failures and operator actions), and external events, which typically start outside the nuclear power plant, such as natural hazards (e.g., earthquakes, external floods, external fires, and high-wind events). According to NRC documents, PRA can estimate three different levels of risk—one focused on reactor core damage, one focused on containment release, and one focused on radiological

[25]Regulatory activities that use PRA include (1) risk-informed licensing change applications; (2) categorization and treatment of structures, systems, and components under 10 C.F.R. § 50.69; (3) fire protection programs under 10 C.F.R. § 50.48(c); and (4) licenses, certifications, and approvals for nuclear power plants under 10 C.F.R. Part 52. NRC staff have prepared guidance to assist licensees in developing risk-informed changes to their licensing bases. See NRC, *An Approach to Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis*, Regulatory Guide 1.174 (Washington, D.C.: July 1998).

[26]10 C.F.R. § 52.79(a)(46).

[27]Specifically, NRC requires licensees who will operate reactors under a combined license to develop, maintain, and periodically upgrade a Level 1 and Level 2 PRA. 10 C.F.R. § 50.71(h).

consequences to the public.[28] For information on developing a PRA, see appendix IV.

Actions NRC Has Taken on Natural Hazard Assessments Since the Fukushima Daiichi Disaster

In March 2011, NRC chartered a staff task force to review its processes and regulations in light of the Fukushima Daiichi disaster and to recommend whether NRC should make near-term improvements to its regulatory system.[29] The task force issued its final report in July 2011. Among other things, the task force found that NRC regulations and guidance provide a robust approach for assessing natural hazards, but it noted that NRC's processes for assessing natural hazards had evolved over time. As a result, the licensing bases, design, and level of protection from natural hazards differ among operating reactors depending on when the reactors were built and when they were licensed for operation. Based on these findings, the task force recommended, among other things, that NRC order licensees to reevaluate the seismic and flooding hazards at their sites against current NRC requirements and guidance and, if necessary, update their reactor design bases. The task force further recommended that NRC initiate rulemaking to require licensees to confirm seismic and flooding hazards every 10 years, address any new and significant information and, if necessary, update their reactor design bases. In addition, the task force recommended that, while these longer term actions are being completed, NRC order licensees to check their seismic and flood protection features to identify and address any plant-

[28]Specifically, Level 1 PRAs evaluate events that can lead to plant accidents and examine reactor systems and operators' responses to calculate "core damage frequency"—the frequency of the combinations of initiating events, hardware failures, and human errors leading to the uncovering of the reactor core such that reflooding of the core is not imminent. Level 2 PRAs start with Level 1 core damage accidents and assess the frequencies of various categories of containment releases. The results for operating reactors are typically reported in terms of "large early release frequency"—the frequency of those accidents leading to significant, unmitigated releases from the reactor's containment in a time frame prior to effective evacuation of the nearby population such that there is a potential for early health effects. Level 3 PRAs start with Level 2 radiological release accidents and assess the public health consequences of a radiological release in terms of injury to the public and damage to the environment. Because core damage and large early release estimates are easier to calculate than public health consequences, the results of Level 1 and Level 2 PRAs are often used as surrogates for the results of a Level 3 PRA. NRC has plans to perform a new Level 3 PRA (including Level 1 and Level 2 PRAs) for a single operating power plant that will include assessment of natural hazards and be completed within 4 years.

[29]Appendix V describes actions that NRC has taken in response to the Fukushima Daiichi disaster that relate to natural hazard assessments.

specific vulnerabilities and verify the adequacy of monitoring and maintenance for protection features such as watertight barriers and seals.

In response to the task force report, in August 2011, NRC directed agency staff to identify the task force recommendations that could and, in the staff's view, should be implemented without unnecessary delay. The staff submitted a report to NRC in October 2011 with their proposed prioritization of the recommendations. In this report, the staff recommended that NRC move forward with requiring licensees to reevaluate the seismic and flooding hazards at their sites and to check their seismic and flood protection features. However, the staff recommended that NRC wait to initiate rulemaking requiring licensees to confirm their sites' seismic and flooding hazards every 10 years in order to gain experience from the implementation of the initial reevaluation. In December 2011, NRC approved the staff's proposals and supported actions on several recommendations. That same month, Congress passed, and the President signed, the 2012 Consolidated Appropriations Act, which included a provision directing NRC to require that licensees reevaluate external hazards at their sites, including seismic and flooding hazards, as expeditiously as possible.[30] In February 2012, NRC staff proposed issuing a request for information that, among other things, would ask licensees to reevaluate the seismic and flooding hazards at their sites.[31] The staff suggested PRA as one of two acceptable methods for licensees to use in reevaluating seismic hazards. The staff did not exclude, but also did not suggest, PRA as a method for assessing flooding hazards because, according to NRC officials, NRC currently uses a deterministic approach for assessing flooding hazards. NRC staff also proposed addressing other natural hazards, such as wind and missile loads from tornados and hurricanes, at a later date once sufficient resources are available for the reevaluations. According to NRC officials, it is not clear yet whether agency staff will suggest licensees use PRA or other methods to reevaluate those other natural hazards. In March 2012,

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[30]Consolidated Appropriations Act, 2012, Pub. L. No. 112-74, Div. B, § 402 (Dec. 23, 2011).

[31]NRC, *Proposed Orders and Requests for Information in Response to Lessons Learned from Japan's March 11, 2011, Great Tohoku Earthquake and Tsunami*, SECY-12-0025 (Washington, D.C.: Feb. 17, 2012).

NRC issued the request for information proposed by agency staff in February.[32]

PRA Is Applied to Natural Hazards to a Limited Extent

Licensees and NRC apply PRA to natural hazards at operating U.S. nuclear power reactors to a limited extent, according to information provided by nuclear power industry representatives, NRC officials, and several experts in assessing nuclear reactor risks that we interviewed and data we obtained. While NRC has endorsed PRA as a means to enhance and extend traditional deterministic assessments, the agency has not conducted the analyses to determine whether or not it should require licensees of operating reactors to develop and maintain PRAs that address natural hazards.

Licensees and NRC Apply PRA to Natural Hazards to a Limited Extent

Nuclear power industry representatives, NRC officials, and several experts in assessing nuclear reactor risks we interviewed, as well as data we obtained, indicate that licensees and NRC apply PRA to natural hazards at operating nuclear power reactors to a limited extent. Prior to its response to the Fukushima Daiichi disaster, the last time NRC requested licensees to assess natural hazards was in 1991 when the agency initiated the IPEEE program. For the IPEEE, NRC requested each licensee to voluntarily identify and report plant-specific vulnerabilities to severe accidents caused by external events, including natural hazards. Although PRA was suggested by NRC as one of several possible methods for licensees to use in their examinations, most licensees opted to use methods other than PRA. Specifically, NRC received 70 IPEEE submissions from licensees covering all operating reactors. According to NRC's summary of the 70 submissions, about 40 percent applied PRA to seismic hazards, and about 15 percent applied PRA to high winds, floods, and other external events. NRC reported that almost no licensees identified vulnerabilities with respect to seismic hazards, and none identified vulnerabilities related to high winds, flooding, or other external events. Nonetheless, according to NRC's summary, 70 percent of the IPEEE submissions identified plant improvements related to seismic hazards, and about 50 percent identified plant improvements related to high winds and flooding. NRC performed a review of all IPEEE

[32]NRC, *Staff Requirements—SECY-12-0025—Proposed Orders and Requests for Information in Response to Lessons Learned From Japan's March 11, 2011, Great Tohoku Earthquake and Tsunami* (Washington, D.C.: Mar. 9, 2012).

submissions to assess the technical adequacy of the methods and data used and noted that the quality of licensees' submissions varied. NRC did not attempt to verify or validate licensees' results. NRC staff proposed in 2011 that licensees reevaluate seismic hazards under the agency's Generic Issue-199 program. Similar to the IPEEE, the proposal cited PRA as one—but not the only—possible method for assessing seismic hazards. The NRC staff has now proposed to pursue the reevaluation of seismic hazards as part of the implementation of the Fukushima Daiichi task force recommendations and has identified PRA as one of the methods that licensees can choose to use.

Nuclear Energy Institute representatives told us that, if data were to be collected on licensees' current application of PRA to natural hazards, they believe the data would likely show little difference since the IPEEE in the 1990s. They also stated that they believe few of those PRAs developed for the IPEEE would have been updated since then. Likewise, senior NRC officials told us that were NRC to obtain current data on licensees' application of PRA to natural hazards, the results would likely show limited application, substantial variability, and few new or updated assessments since the IPEEE. According to several experts in assessing nuclear reactor risks we spoke with, few of the nation's operating reactors currently have PRAs in place that address natural hazards. For example, one expert stated that some reactors have PRAs that address seismic hazards, and a few have PRAs that address external floods, but the rest do not have PRAs that address natural hazards at all.

NRC does not collect comprehensive data on the extent of licensees' voluntary application of PRA to natural hazards at operating reactors. NRC officials stated that, because PRAs are not required for operating reactors, NRC does not have comprehensive data on their use. NRC officials told us that where licensees voluntarily undertake risk-informed applications or license amendments, the information licensees submit to NRC may include results on natural hazards. For example, when a licensee chooses to use a risk-informed approach to request a change to its licensing basis, the licensee must determine whether natural hazards are a significant contributor to risk and provide that information to NRC.[33] To make this determination, the licensee may use a PRA. Apart from these circumstances, however, NRC does not have data on operating reactor licensees' PRA use. NRC officials could not tell us, therefore, which licensees of operating reactors have voluntarily undertaken PRAs that address natural hazards, what natural hazards are addressed, when existing PRAs were first developed and last updated, or the extent to which they meet NRC-endorsed quality standards. Nuclear Energy Institute representatives similarly told us that they do not collect data on PRA use and do not have a plant-by-plant listing of which reactors have PRAs in place that address natural hazards. NRC officials said that they do not collect comprehensive PRA information because licensees of operating reactors are not required to have a PRA. Further, they told us that, if NRC decided to collect this information, the agency would likely issue a "generic communication"—NRC's primary method of communicating information to licensees and interested stakeholders or requesting information from them. NRC officials told us that a generic communication to obtain comprehensive PRA information would take NRC a significant amount of time to develop and issue.[34]

According to representatives of five licensees we interviewed, 12 of the 25 reactors those licensees operate have PRAs in place that address seismic hazards, and none have PRAs in place that address high winds or external floods (see table 1).[35] The representatives told us that, in some instances, a reactor does not have a PRA in place for a given natural hazard because a screening analysis indicated that the hazard's contribution to risk was sufficiently low that it could be eliminated from

[33]NRC licenses nuclear power reactors on an individual reactor basis. Therefore, licensees' natural hazard assessments—including voluntary PRAs—and NRC's review of those assessments are at the individual reactor level and generally do not take into account other nuclear power reactors on the same site, or other nuclear power plants in the region or nationwide. An event that affects multiple reactors can potentially have greater consequences than an event that affects a single reactor.

[34]Some generic communications request information or actions relative to NRC regulations and require responses. Others suggest methods for meeting NRC requirements on which licensees may voluntarily act or communicate related technical or regulatory information.

[35]We requested data from the companies that operate the five nuclear power plants we visited regarding their application of PRA to seismic hazards, floods, high winds, and other external events at the reactors we toured, as well as the other reactors operated by the companies.

further consideration; in other instances, licensees have performed margin studies instead or rely on traditional deterministic assessments of the hazard. Of the seismic PRAs in place at 12 of the 25 reactors for which we obtained information, 10 have not been updated since they were first developed. The seismic PRAs at 6 of the 12 reactors were developed in the 1990s under NRC's IPEEE program. The seismic PRAs at the other reactors were developed between 1983 and 2010 for a variety of reasons. For example, two were developed as part of voluntary licensee efforts to better understand seismic risk. Another was developed as part of a plant's long-term seismic monitoring program created as a condition of its operating license due to discovery during construction of a new fault line.

Table 1: Natural Hazard PRAs at Selected Nuclear Power Reactors

			Natural hazards included				
Licensee	**Plant name (state)**	**Reactor number**[a]	**Seismic**	**High winds**	**External floods**	**Developed**	**Last updated**
Dominion	Kewaunee Power Station (WI)	Data not applicable	Yes	No	No	1994	1994
	Millstone Power Station (CT)	2	No	No	No	Data not applicable	Data not applicable
		3	Yes	No	No	1995	1995
	North Anna Power Station (VA)	1	No	No	No	Data not applicable	Data not applicable
		2	No	No	No	Data not applicable	Data not applicable
	Surry Nuclear Power Station (VA)	1	Yes	No	No	2010	2010
		2	Yes	No	No	2010	2010
NextEra Energy	Duane Arnold Energy Center (IA)	Data not applicable	Yes	No	No	1997	2005
	Point Beach Nuclear Plant (WI)	1	Yes	No	No	1995	1995
		2	Yes	No	No	1995	1995
	Seabrook Station (NH)	1	Yes	No	No	1983	2004
	St. Lucie Plant (FL)	1	No	No	No	Data not applicable	Data not applicable
		2	No	No	No	Data not applicable	Data not applicable
	Turkey Point Nuclear Plant (FL)	3	No	No	No	Data not applicable	Data not applicable
		4	No	No	No	Data not applicable	Data not applicable

Licensee	Plant name (state)	Reactor number[a]	Natural hazards included: Seismic	High winds	External floods	Developed	Last updated
Pacific Gas & Electric	Diablo Canyon Power Plant (CA)	1	Yes	No	No	1988	1988
		2	Yes	No	No	1988	1988
Southern California Edison	San Onofre Nuclear Generating Station (CA)	2	Yes	No	No	1995	1995
		3	Yes	No	No	1995	1995
Tennessee Valley Authority	Browns Ferry Nuclear Plant (AL)	1	No	No	No	Data not applicable	Data not applicable
		2	No	No	No	Data not applicable	Data not applicable
		3	No	No	No	Data not applicable	Data not applicable
	Sequoyah Nuclear Plant (TN)	1	No	No	No	Data not applicable	Data not applicable
		2	No	No	No	Data not applicable	Data not applicable
	Watts Bar Nuclear Plant (TN)	1	No	No	No	Data not applicable	Data not applicable

Sources: GAO analysis of data provided by Dominion, NextEra Energy, Pacific Gas & Electric, Southern California Edison, and Tennessee Valley Authority.

[a]One or more reactors may be located at a single power plant. Generally, individual reactors are numbered. Where only one reactor is located at a plant, however, the reactor may or may not have a number associated with it.

NRC has also applied PRA to natural hazards to a limited extent. For example, NRC officials told us that the agency has developed 16 external event risk analysis models of limited detail that address some natural hazards at 19 operating reactors.[36] These models are available to NRC staff for internal use in providing risk insights to various agency initiatives such as NRC's inspection and incident investigation programs. According to NRC officials, NRC staff use the models to a limited extent. The models rely on licensee information, such as that derived from the IPEEE, that could be out-of-date. NRC officials told us they have plans to validate

[36]In 1995, NRC began developing these models, called Standardized Plant Analysis Risk models. As of December 2011, NRC had 78 Standardized Plant Analysis Risk models that address internal events at all 104 operating reactors and 16 Standardized Plant Analysis Risk models that address some external events at 19 operating reactors. Specifically, of the 16 external event Standardized Plant Analysis Risk models, all 16 include seismic events among the natural hazards assessed, 5 include high winds, and 2 include external floods.

the models in the future to improve confidence among agency staff in their use. According to the officials, there has also recently been renewed interest in the agency in resuming development of these models for the remaining operating reactors. The officials told us NRC is finalizing the first in a series of such models that include more recent plant information and improved validation.[37] In a separate initiative, according to NRC documents and officials, NRC has plans to perform a new full-scope PRA for a single operating power plant that will calculate off-site risk and its contributors, including natural hazards.[38] NRC staff identified several reasons for doing so, including technical advances that had taken place since the last similar NRC effort in the late 1980s,[39] scope considerations that had not previously been addressed such as multiunit site effects, and potential future uses for these models such as verifying or revisiting regulatory requirements and guidance and developing NRC's in-house PRA technical capability.

NRC Has Not Analyzed Whether It Should Require PRAs That Address Natural Hazards

While NRC has endorsed PRA as a means to enhance and extend traditional deterministic assessments, the agency has not conducted the analyses to determine whether or not it should require licensees of operating reactors to develop and maintain PRAs that address natural hazards. NRC's "backfit rule" generally requires NRC to assure licensees that requirements placed on them will change only when warranted from

[37]NRC officials told us the 19 reactors that the existing Standardized Plant Analysis Risk external event models were developed for were selected on the basis of convenience and availability of information. NRC's initial plans to develop additional external event Standardized Plant Analysis Risk models for the remaining reactors were not carried out due to an agency determination that resources would be better allocated to internal event Standardized Plant Analysis Risk model development.

[38]In September 2011, the NRC directed agency staff to plan for and perform a new full-scope comprehensive site Level 3 PRA for a single operating power plant that will include assessment of natural hazards and be completed within 4 years. A full-scope comprehensive site Level 3 PRA is a PRA that includes a quantitative assessment of the public risk from accidents involving all site reactor cores and spent nuclear fuel that can occur during any plant operating state, and that are caused by all initiating event hazards (internal events, fires, flooding, seismic events, and other site-specific external hazards).

[39]NRC, *Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants*, NUREG-1150 (Washington, D.C.: December 1990).

a public health and safety standpoint.[40] As such, to require that licensees of operating reactors apply PRA to natural hazards, NRC officials told us NRC would have to determine that the advantages of doing so are necessary to ensure that protection of the public health and safety is adequate or that the added increase in overall protection is at least substantial and justifies the cost of implementation. Senior NRC officials told us that it may be difficult to meet either of these criteria in order to justify the imposition of a new PRA requirement on licensees of operating reactors.[41] NRC officials we spoke with were unaware of any formal determinations by the agency regarding whether or not requiring PRA of operating reactors meets the backfit rule or exceptions thereto. Additionally, an official from the agency's Office of General Counsel told us that the NRC has the authority to "administratively except" a new

[40]NRC's backfit rule requires that NRC determine that new requirements would result in a substantial increase in the overall protection of public health and safety or common defense and security and that this increased protection justifies the cost of implementation. 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." The backfit rule requires a backfit analysis demonstrating that the new or changed requirement is a substantial increase in overall protection unless NRC finds that a backfit is needed to ensure that protection of public health and safety is adequate, or in other limited situations. 10 C.F.R. § 50.109(a)(4).

[41]We reported in 1999 that similar difficulties had been expressed by the NRC staff in the 1990s, during which time NRC was considering whether and to what extent it should revise its regulations pertaining to operating reactors to make them risk-informed. In 1998, agency staff proposed to the NRC a phased approach to risk-informing its regulations. The staff also recommended that implementation of revised regulations be voluntary. The staff noted that it would be difficult to make the backfit determination needed to require implementation and further that doing so could create the impression that current plants were less safe. In response, the Chairman suggested a more aggressive approach that would entail a risk-informed approach for all relevant regulations across the board and stated that the revised regulations should be mandatory, unless the staff found that backfit provisions could not be met. Also, the Commissioners expressed concern about a voluntary approach, believing that it would create two classes of plants operating under two different sets of regulations. Ultimately, however, the NRC adopted the staff's proposed phased approach to risk-informing its regulations of operating reactors and determined that compliance would be voluntary.

requirement from the backfit rule.[42] NRC officials stated that it generally takes several years to conduct and document the regulatory analyses to determine whether a new requirement should be implemented and then to complete the rulemaking process necessary before a requirement can become law.[43]

Experts Offered a Range of Views on NRC Assessment Processes

The 15 experts in assessing natural hazards and/or nuclear reactor risks that we interviewed offered a range of views on (1) the adequacy of NRC processes for assessing the threats that natural hazards pose to operating U.S. nuclear power reactors and (2) what, if any, changes to those processes are warranted. Experts had varied views on the overall adequacy of NRC natural hazard assessment processes and identified a number of strengths and limitations of those processes. More than half of the experts we interviewed suggested expanding the use of PRA for assessing natural hazards as a complement to traditional deterministic analyses, and several experts cited a number of challenges to doing so. Some experts we interviewed suggested other changes to NRC processes for assessing natural hazards. Appendix II lists the names and affiliations of the 15 experts we interviewed.

Experts Noted Strengths and Limitations of NRC Assessment Processes

The 15 experts we interviewed had varied views on the overall adequacy of NRC processes for assessing the threats that natural hazards pose to operating U.S. nuclear power reactors and identified a number of strengths and limitations of those processes. Several experts said they believe NRC processes are generally adequate. One of those experts noted that, in his view, NRC's processes for assessing natural hazards work well due to the conservative approach NRC takes to assessing and designing against natural hazards. Another expert who agreed that NRC processes are adequate overall explained that natural hazards are well

[42]The official told us that the NRC did this when it adopted the Aircraft Impact Assessment Rule in 2009. *See* 74 Fed. Reg. 28,112, 28,143 (June 12, 2009). The official stated that an administrative exception must be the subject of notice and public comment for rulemakings, but is not required with respect to the issuance of orders.

[43]Officials from NRC's Office of General Counsel believe that a requirement to perform a PRA would not be subject to the backfit rule because such a requirement would constitute an information collection (and possibly reporting) requirement that NRC has deemed not to be subject to the backfit rule. However, according to the same officials, if the requirement is implemented by rule, the NRC would prepare—as part of that rulemaking—a regulatory analysis to support the adoption of such a requirement.

accounted for in reactor designs and that NRC does as good of a job as any other federal agency in ensuring that its regulated community protects against natural hazards. Several other experts expressed mixed views on the adequacy of NRC processes. Some of these experts stated that they had more confidence in NRC's approach for assessing the threats that natural hazards pose to proposed new reactors than its approach for operating nuclear power reactors because the former requires licensees to use PRA in addition to traditional deterministic assessments when assessing natural hazards. Two experts stated that NRC processes for assessing natural hazards are inadequate. One of those experts noted that NRC and licensees need to consider other possibilities that may affect natural hazard assessments, such as the potential effects of climate change on the natural hazards a reactor may face over its operating life.

Experts we interviewed identified a number of strengths of NRC processes for assessing the threats posed by natural hazards to operating nuclear power reactors. Four strengths were identified by more than two experts. First, about half of the experts identified as a strength the structured and thorough process NRC follows in reviewing licensee assessments of natural hazards. A few of these experts noted the stringency of NRC's review of licensee assessments, and a few others said that the agency has done an effective job defining a comprehensive set of natural hazards that licensees are responsible for assessing. Second, several experts identified as a strength what they said was NRC's conservative approach to licensee assessments and reactor designs for natural hazards, including NRC's emphasis on (1) defense-in-depth principles, (2) engineering safety margins, and (3) reactor designs based on the worst credible natural hazards a site is expected to face. Some of these experts said that, because NRC's approach to assessing natural hazards is conservative, they believe that U.S. nuclear power reactors are well-designed and well-protected from natural hazards. Third, a few experts pointed to the expertise of NRC's staff in assessing natural hazards as another strength of the agency's processes. These experts said that NRC staff are diligent in trying to understand natural hazards and are proactive in identifying new information for assessing natural hazards. Several experts indicated that NRC is effective at identifying and considering new natural hazard data, although one of those experts also noted that it can take the agency time to incorporate new data into agency regulations. Fourth, a few experts identified as a strength what they said was NRC's global leadership in developing the latest tools and methods for assessing the threats posed by natural hazards to nuclear power reactors.

Experts we interviewed also identified a number of limitations of NRC processes for assessing the threats posed by natural hazards to operating nuclear power reactors. Three limitations were identified by more than two experts. First, about half of the experts identified as a limitation that NRC has not required licensees of operating reactors to assess natural hazards using PRA and that licensees generally have not done so. One of these experts noted that while NRC generally has good information on natural hazards, the use of PRA would allow NRC to better quantify the adequacy and uncertainty of that information. Another of these experts stated that deterministic assessments of natural hazards alone can provide a false sense of security with regard to the certainty of the information that has been assessed. Second, several experts identified as an additional limitation of NRC processes for assessing natural hazards that some existing assessments are not as robust or up-to-date as they could be. One of these experts noted that NRC generally does not require licensees of operating reactors to systematically reevaluate their natural hazard assessments, and some experts highlighted external flooding and high-wind hazards in particular as warranting further review. Third, a few experts identified as a limitation that NRC's processes for assessing natural hazard threats are overly bureaucratic and slow and can lead to overly conservative results. One of those experts noted that NRC's conservatism can potentially lead to the costly overdesign of nuclear power reactors. Another of these experts stated that NRC processes are bureaucratic and time-consuming and undermine the agency's ability to identify actions that need to be taken promptly in response to new information.

More Than Half of Experts Suggested Expanded Use of PRA

More than half of the 15 experts we interviewed suggested expanding the use of PRA for assessing natural hazards at operating nuclear power reactors as a complement to traditional deterministic assessments, and several experts cited a number of advantages, as well as challenges to doing so. The experts' suggestion was similar to a lesson learned from the Fukushima Daiichi disaster identified by a team from the International Atomic Energy Agency, which found a need for the nuclear power community to increase efforts to develop PRAs for external events.[44] Of the experts who suggested expanding the use of PRA, more than half

[44]International Atomic Energy Agency, *Mission Report: The Great East Japan Earthquake Expert Mission* (Vienna, Austria: June 16, 2011).

noted that such risk assessments should not be the sole basis for decision making but should be used to complement traditional deterministic assessments in order to provide a more robust approach to assessing natural hazards. A few experts noted that NRC has already moved in this direction by requiring that licensees of new reactors develop and maintain PRAs that address natural hazards. Some experts emphasized the importance of NRC better integrating PRA into agency processes for assessing natural hazards, and others said that such risk assessments of natural hazards should be comprehensive, periodically updated, and integrated with licensees' PRAs of internal events.

The experts who suggested expanding the use of PRA for natural hazards cited a number of advantages of using it to complement traditional deterministic assessments, including the following:

- PRA takes a broader look at hazards than traditional deterministic assessment by systematically examining all potential causes of an accident for any particular hazard, including events beyond those accounted for in a reactor's original design.

- PRA considers and quantifies the likelihood of events and can help inform regulatory priorities by identifying more significant contributors to a reactor's risk profile.

- PRA provides a structure for explicitly addressing and presenting uncertainty and attempts to account for unknowns.

- PRA can help identify design vulnerabilities that might otherwise be overlooked by relying on traditional deterministic assessments alone.

- PRA can support improved safety decision making by providing risk insights.

Several experts also identified challenges to expanding the use of PRA for natural hazards, including the following:

- More than half of the experts we interviewed noted that uncertain knowledge about natural hazards, particularly the frequency of large hazards, presents a challenge in evaluating those hazards. Some experts noted the difficulty of identifying the frequency of large natural hazards for use in a PRA given the limited data resulting from the brief historical record and rarity of the hazards. One of these experts said he believes the uncertainties associated with low-probability, high-consequence natural hazards are too large for a PRA to produce an accurate risk estimate, and two other experts said the information generated by a PRA would be useful to inform but not determine decisions.

- About half of the experts said another key challenge is the limited number of experts qualified to develop PRAs for natural hazards. One expert noted the number of practitioners that can do this type of risk assessment is small and that it is important that more people be trained to conduct them. Another expert said that finding people to do these analyses, more so than the cost involved in conducting them, represents the primary challenge to expanding the use of PRA. He further noted that this is even more the case now given the actions NRC and industry are taking in response to the Fukushima Daiichi disaster. In June 2008, we noted a similar challenge to NRC's efforts to transition to a risk-informed approach to fire protection.[45] At that time, numerous NRC, industry, and academic officials we spoke with expressed concern regarding the limited number of personnel with the necessary skills and training to design, review, and inspect against PRAs. Those officials told us that the shortage of skilled personnel was due in part to an increased demand for individuals with critical skills under NRC's risk-informed approach. We have reported on this challenge of the limited number of PRA practitioners as far back as 1985.[46] NRC and industry officials we interviewed agreed that the limited number of experts qualified in PRA remains a challenge today.

- A few experts identified other challenges to expanding the use of PRA for natural hazards, including the cost of developing those risk assessments, the regulatory hurdles to NRC requiring licensees of operating reactors to use PRA, and the care that must be taken when deciding which natural hazards to include in a PRA and which to screen out of the analysis.

Some Experts Suggested Other Changes to NRC Assessment Processes

Some of the 15 experts we interviewed suggested changes to NRC processes for assessing the threats posed by natural hazards to operating U.S. nuclear power reactors that were unrelated to expanding

[45] GAO-08-747.

[46] GAO/RCED-85-11.

the use of PRA. Five such changes were suggested by at least two experts as follows:

- Several experts suggested that NRC should have licensees revisit their existing natural hazard assessments to incorporate current knowledge on natural hazards or ensure that the assumptions used in the assessments have not changed. Some of these experts noted that the state of knowledge on natural hazards such as earthquakes, floods, and high-wind events had changed since licensees completed their assessments. More than half of the experts we interviewed said the NRC Fukushima Daiichi task force's recommendations that NRC require licensees to reevaluate their seismic and flooding hazards and confirm them on a periodic basis in the future were useful, and some of those experts suggested that the reevaluation should include all natural hazards, as it will, according to NRC officials.[47] One expert said it would be better if NRC required licensees to perform a comprehensive assessment of natural hazards rather than a reevaluation of existing assessments against current requirements. A few experts said the reevaluations proposed by the task force would be of only limited utility. Two of those experts indicated that resources would be better devoted to having licensees enhance their reactors' abilities to mitigate natural hazards and to reevaluate natural hazards as significant new information becomes available rather than on a set periodic basis.

- A few experts suggested that NRC should examine the criteria that licensees use to decide whether to assess a natural hazard or screen it out of their assessment. One expert suggested that NRC create a special category of assessments to consider low probability, high-consequence natural hazards that otherwise might be screened out.

- Two experts suggested that NRC should devote additional resources to researching natural hazards in order to inform agency assessments and guidance relating to those hazards.

[47]In October 2011, NRC's Advisory Committee on Reactor Safeguards recommended that agency staff consider additional external hazards beyond seismic and flooding hazards as part of the lessons learned from the Fukushima Daiichi disaster. After we completed our interviews with experts, the 2012 Consolidated Appropriation Act was enacted with a provision that, among other things, directed NRC to require licensees to reevaluate the seismic, tsunami, flooding, and other external hazards at their sites against current requirements and guidance as expeditiously as possible, and thereafter when appropriate, as determined by the NRC.

- Two experts suggested that NRC should do more work to assess how natural hazards might affect sites with multiple reactors. One expert expressed the view that there has not been a systematic enough examination of the potential consequences of a natural hazard that might affect multiple reactors.

- Two experts suggested that NRC should consider how potential future changes in natural hazards are addressed in assessments. One expert noted, for example, that climate change could potentially lead to changes in natural hazards over reactors' operating lives.

In addition, two experts said that they do not believe NRC needs to make changes to its processes for assessing the threats posed by natural hazards beyond what NRC is already undertaking in response to the Fukushima Daiichi disaster. One expert said that NRC and licensees should focus on enhancing reactors' ability to cope with and respond to natural hazards rather than devote those resources to further assessing natural hazard threats.

Conclusions

Operating a nuclear power reactor is never entirely free of risk, but comprehensive assessments of that risk and various contributing risk factors—including natural hazards—can help identify vulnerabilities that might otherwise be overlooked. Actions taken to mitigate such risks could decrease the chance of an accident that could have serious public health, environmental, and economic consequences. NRC documents and most experts we spoke with indicate that PRA offers NRC and licensees a number of advantages that, as a complement to traditional deterministic assessments, can provide a more robust approach to assessing natural hazards.

Because NRC and licensees of operating reactors continue to rely primarily on deterministic assessments of natural hazards, they are realizing PRA's advantages to a limited extent. We recognize that NRC must undertake a thorough review to require licensees of operating reactors to develop and maintain PRAs that address natural hazards. In particular, we acknowledge the difficulty that NRC officials anticipate in reaching a determination that a PRA requirement is warranted for operating reactors under existing regulations. Further, we understand there are a limited number of experts qualified to develop PRAs for natural hazards, and that there is a cost to developing PRAs. However, we also note NRC's overall endorsement of the use of PRA to enhance and extend traditional deterministic assessments, as well as the significant advantages cited by the experts we interviewed who suggested expanding the use of PRA for assessing natural hazards at operating nuclear power reactors. Moreover, we note that a team from the International Atomic Energy Agency has identified a need to increase efforts to develop PRAs for external events as a lesson learned from the Fukushima Daiichi disaster. While NRC suggested PRA in the 1990s as one potential option for licensees to use to assess natural hazards, most licensees opted not to do so, and agency officials and industry representatives told us they believe that licensees today have only applied PRA to natural hazards to a limited extent. Given all this, PRAs' potential benefits in the natural hazard context may not be realized without efforts by NRC to promote its use. Without conducting the analyses necessary to determine whether a PRA requirement is warranted for operating reactors, however, NRC does not have a strong basis to judge whether or not such a requirement should be implemented.

Recommendation for Executive Action

To improve safety decision making by NRC in carrying out its responsibility under the Atomic Energy Act to ensure that the operation of nuclear power plants is consistent with the common defense and security and public health and safety, we recommend that the NRC Commissioners direct agency staff to conduct and document any needed analyses to determine whether the agency should require licensees of operating reactors to develop and maintain PRAs that address natural hazards.

Agency Comments and Our Evaluation

We provided a draft of this report to the NRC Commissioners and the Secretaries of Commerce, Defense, and the Interior for their review and comment. The Secretaries of Commerce, Defense, and the Interior had no comments. NRC provided written comments on April 13, 2012, which are reproduced in appendix VI, and technical comments, which we incorporated into the report as appropriate.

NRC agreed with the report recommendation. The agency stated it would conduct and document the analysis recommended by GAO in the context of follow-on actions for related ongoing agency initiatives after sufficient information has been gathered from those activities to better inform the analysis. In addition, NRC asserted that it will continue to evaluate its processes and policies regarding the enhanced use of PRA and risk insights as part of its overall regulatory framework. As we noted in our report, NRC documents and most experts we spoke with indicate that PRA offers NRC and licensees a number of advantages that, as a complement to traditional deterministic assessments, can provide a more robust approach to assessing natural hazards. We also noted that officials we interviewed and data we obtained indicate that NRC and licensees apply PRA to natural hazards at operating nuclear power reactors to a limited extent. We continue to believe that until NRC completes the analysis necessary to determine whether a PRA requirement is warranted for operating reactors, NRC will not have a strong basis to judge whether or not such a requirement should be implemented, and PRAs' potential benefits in the natural hazard context may not be realized.

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 the NRC, the Secretaries of Commerce, Defense, and the Interior, the appropriate congressional committees, and other interested parties. In addition, this 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 VII.

Frank Rusco
Director, Natural Resources and Environment

Appendix I: Objectives, Scope, and Methodology

Our review provides information on: (1) the extent to which probabilistic risk assessment (PRA) is applied to natural hazards at operating U.S. nuclear power reactors and (2) expert views on and suggested changes, if any, to Nuclear Regulatory Commission (NRC) processes for assessing natural hazards at operating U.S. nuclear power reactors. To address both of these objectives, we reviewed relevant literature and NRC documents and met with officials from NRC, the nuclear power industry, public interest groups, and others to understand NRC processes for assessing natural hazards at nuclear power reactors.

Specifically, to address the first objective, we reviewed relevant documents and data obtained from NRC and selected licensees on the extent to which PRA has been applied to natural hazards. We interviewed knowledgeable officials about the data and found the data to be sufficiently reliable for the purposes of our report. We reviewed NRC policies and procedures, as well as NRC initiatives related to the assessment of natural hazards. We also reviewed the NRC near-term task force's report on insights gained from the Fukushima Daiichi disaster and documented the actions taken by NRC on recommendations related to the assessment of natural hazards. In addition, we visited a nonprobability sample of five nuclear power plants to interview licensees about the actions they have taken to assess natural hazards.[1] The five nuclear power plants we visited were the Browns Ferry Nuclear Plant in Alabama, the Diablo Canyon Power Plant in California, the North Anna Power Station in Virginia, the San Onofre Nuclear Generating Station in California, and the Turkey Point Nuclear Plant in Florida. We selected these sites to capture a variety of characteristics, including reactor and containment vessel type, operating license issuance date, license renewal status, and natural hazard activity level.

To address the second objective, we summarized the results of semistructured interviews with experts in assessing natural hazards, risks to nuclear power reactors, or both. We first reviewed NRC documentation about processes used to assess natural hazards at nuclear power reactors and confirmed our understanding of those processes with NRC. Then, we identified 43 experts from our review of the literature, prior GAO reports, congressional and NRC hearings, and recommendations from

[1]Because this was a nonprobability sample, the information we gathered from these site visits is not generalizeable to all 65 operating nuclear power plants but provides important illustrative information.

NRC, the Nuclear Energy Institute, the Union of Concerned Scientists, and experts in assessing risks to nuclear power reactors. From this list, we selected 15 experts based on (1) the relevance of their expertise as reflected in publications, testimonies, and their biographies; (2) the relevance and extent of their publications; (3) the relevance and extent of their testimonies before Congress and NRC; and (4) recommendations from others in the field. Finally, to ensure coverage and a range of perspectives, we selected experts who came from academia, government, industry, public interest groups, and other affiliations; provided perspectives from both those inside NRC or the nuclear power industry and from those outside of those two groups; and provided perspectives from those publicly supportive, publicly critical, and those without a public position on nuclear power. Appendix II lists the experts we interviewed. 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. We did not independently evaluate the quality of NRC processes for assessing natural hazards and the threats they pose to nuclear power reactors.

During the course of our review, we interviewed NRC officials from the Office of General Counsel, Office of New Reactors, Office of Nuclear Reactor Regulation (including the Japan Lessons Learned Project Directorate), Office of Nuclear Regulatory Research, and Risk Management Task Force in headquarters, as well as NRC officials in Region II and Region IV and the resident inspectors at the five nuclear power plants we visited. We also interviewed officials and reviewed documents from the National Oceanic and Atmospheric Administration, the U.S. Army Corps of Engineers, and the U.S. Geological Survey on the current state of knowledge on natural hazards, how that knowledge has changed over time, and the related uncertainty. Further, we interviewed representatives from American Nuclear Insurers, the Nuclear Energy Institute, and the Union of Concerned Scientists to discuss their views on NRC processes for assessing natural hazards and the threats those hazards pose to nuclear power reactors.

We conducted this performance audit from May 2011 to April 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 Experts

- Dennis C. Bley, Buttonwood Consulting, Inc., Member of NRC's Advisory Committee on Reactor Safeguards
- Biff Bradley, Nuclear Energy Institute
- Robert J. Budnitz, Lawrence Berkeley National Laboratory
- Thomas B. Cochran, Natural Resources Defense Council
- Karl N. Fleming, KNF Consulting Services LLC
- B. John Garrick, U.S. Nuclear Waste Technical Review Board
- Michael W. Golay, Massachusetts Institute of Technology
- N. Prasad Kadambi, Consultant
- William Leith, U.S. Geological Survey
- William Levis, PSEG Power LLC
- Stuart Lewis, Electric Power Research Institute
- David A. Lochbaum, Union of Concerned Scientists
- Mohammad Modarres, University of Maryland
- Ali Mosleh, University of Maryland
- Doug True, ERIN Engineering & Research, Inc.

Appendix III: Key Developments in NRC's Approach to Probabilistic Risk Assessment

According to NRC documents, NRC is moving toward a risk-informed, performance-based approach to decision making that is being implemented in phases. This approach extends the traditional deterministic approach in part by incorporating PRA—a systematic method for assessing what can go wrong, its likelihood, and its potential consequences to determine quantitative estimates of risk. The timeline below describes some of the key developments in NRC's approach to PRA, including its application to natural hazards.

1975

NRC publishes the first PRA of nuclear power reactors.[1] According to an NRC document, this study marks the first U.S. attempt to systematically evaluate a large spectrum of accidents and to use quantitative techniques to evaluate severe accident probabilities and off-site radiological consequences in an integrated manner to obtain a more realistic estimate of public risk. The study challenged the concept that conservative safety analysis of design-basis accidents could establish an upper limit of public risk.

1979

An accident occurs at the Three Mile Island nuclear power plant, resulting in a partial meltdown of a reactor core. According to an NRC document, the accident substantiated risk insights generated through the 1975 study and led to the increased use of PRA to identify vulnerabilities in the nuclear industry.

1986

NRC issues its Safety Goal Policy Statement in which it broadly defines an acceptable level of radiological risk that might be imposed on the public as a result of nuclear power reactor operations and calls for the use of PRA to measure achievement of the agency's individual and societal safety goals.[2]

[1]NRC, *Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants*, WASH-1400(NUREG 75/014) (Washington, D.C.: October 1975).

[2]NRC, *Safety Goals for the Operations of Nuclear Power Plants; Policy Statement*, 51 Fed. Reg. 30,028 (Aug. 21, 1986).

1988	NRC initiates the Individual Plant Examination program and requests that each licensee perform an examination to identify plant-specific vulnerabilities to severe accidents that could be fixed with low-cost improvements.[3] One of several program objectives is for each licensee to gain a more quantitative understanding of the overall probability of core damage and radioactive material releases. NRC identifies PRA as one acceptable approach for licensees to use in conducting their examination but limits the scope of the effort to internal events.
1990	NRC publishes a follow-on study to its original 1975 study that advances the state of the art in PRA, particularly the analysis of uncertainty.[4]
1991	NRC initiates the Individual Plant Examination of External Events program and requests that each licensee identify and report to the agency all plant-specific vulnerabilities to severe accidents caused by external events, including natural hazards such as seismic events, floods, and high-wind events.[5] NRC suggests PRA as one possible method for licensees to use in responding to NRC's request.
1994	NRC develops a PRA implementation plan that aims to ensure PRA is implemented in a consistent and predictable manner in regulatory activities.[6]

[3]NRC, *Individual Plant Examination for Severe Accident Vulnerabilities, 10 CFR 50.54(f)*, Generic Letter No. 88-20 (Washington, D.C.: Nov. 23, 1988).

[4]NRC, *Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants*, NUREG-1150 (Washington, D.C.: December 1990).

[5]NRC, *Individual Plant Examination of External Events for Severe Accident Vulnerabilities—10 CFR 50.54(f)*, Generic Letter No. 88-20, Supplement 4 (Washington, D.C.: June 28, 1991).

[6]NRC, *Proposed Agency-Wide Implementation Plan for Probabilistic Risk Assessment*, SECY-94-219 (Washington, D.C.: Aug. 19, 1994).

1995	NRC issues a policy statement regarding the expanded use of PRA.[7] In its approval of the policy statement, the NRC stated its expectation that "the use of PRA technology should be increased in all regulatory matters to the extent supported by state-of-the-art in PRA methods and data and in a manner that complements the NRC's deterministic approach and supports the NRC's traditional defense-in-depth philosophy."
1996	NRC requires new nuclear power reactors licensed after January 1997 to be sited and designed with respect to geological and seismic determinations based on an appropriate analysis, such as a probabilistic seismic hazard analysis.[8]
1998	NRC establishes a structure for risk-informed decision making to improve consistency in regulatory decisions where PRA results are used to supplement traditional deterministic and defense-in-depth approaches.[9] The structure consists of five key principles: proposed changes must (1) meet current regulations, (2) be consistent with the defense-in-depth philosophy, and (3) maintain sufficient safety margins; (4) when proposed changes result in an increase in risk, the increases should be small and consistent with the intent of NRC's Safety Goal Policy Statement; and (5) the impact of the proposed changes should be monitored using performance management strategies. The structure acknowledges that assurance of adequate protection of public health and safety encompasses more than simply demonstrating an acceptable level of overall risk.

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

[8]10 C.F.R. Part 100, subpart B.

[9]NRC, *An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis*, Regulatory Guide 1.174 (Washington, D.C.: July 1998).

2000

NRC develops a strategy[10] for implementing risk-informed regulation in response to a GAO recommendation.[11]

2007

NRC issues regulations requiring that applicants for combined licenses for new nuclear power reactors submit a description and the results of a reactor-specific PRA to NRC as part of their license application.[12] NRC also requires licensees of new nuclear power reactors that will operate their reactors under a combined license to develop by the scheduled date of their initial fuel loading a Level 1 and Level 2 reactor-specific PRA that covers, among other things, initiating events for which there are NRC-endorsed consensus quality standards 1 year prior to the scheduled date for initial fuel loading.[13] Licensees are required to maintain their PRA and upgrade it every 4 years over the operating life of the reactor, as well as when the licensee submits a license renewal application.[14] Also, NRC develops its risk-informed and performance-based implementation plan.[15] The plan provides guidance and direction regarding activities the agency undertakes to integrate risk information and performance measures into its regulations, regulatory guidance, and oversight processes.

2009

NRC issues a regulatory guide that provides guidance to licensees to use in determining the technical adequacy of a PRA for regulatory decision making and endorses certain American Society of Mechanical Engineers and American Nuclear Society national consensus standards for PRA

[10]NRC, *Risk-Informed Regulation Implementation Plan*, SECY-00-0213 (Washington, D.C.: Oct. 26, 2000).

[11]GAO/RCED-99-95. GAO recommended that "the Commissioners of NRC direct the staff to develop a comprehensive strategy that includes but is not limited to objectives, goals, activities, and time frames for the transition to risk-informed regulation; specifies how the Commission expects to define the scope and implementation of risk-informed regulation; and identifies the manner in which it expects to continue the free exchange of operational information necessary to improve the quality and reliability of risk assessments."

[12]10 C.F.R. § 52.79(a)(46).

[13]10 C.F.R. § 50.71(h)(1).

[14]10 C.F.R. § 50.71(h)(2), (3).

[15]NRC, *Update on the Improvements to the Risk-Informed Regulation Implementation Plan*, *Enclosure 1 - Risk-Informed and Performance-Based Plan*, SECY-07-0074 (Washington, D.C.: Apr. 26, 2007).

quality.[16] Among other things, those standards address the application of PRA to natural hazards.[17]

2011

The Chairman of the NRC charters a task force to develop a strategic vision and assess options for a more comprehensive and holistic risk-informed, performance-based regulatory approach, with one option being better incorporating risk management concepts into NRC's regulatory programs.[18] Later that year, in response to the Fukushima Daiichi disaster, NRC charters a staff task force to review its processes and regulations and to recommend whether NRC should make near-term improvements to its regulatory system.[19] The task force makes several recommendations in its final report, including requiring that licensees reevaluate the seismic and flooding hazards at their sites against current NRC guidance and requirements.[20] With policy direction from the NRC, the agency staff moves forward with actions to implement the task force recommendations.[21]

[16]NRC, *An Approach for Determining the Technical Adequacy of Probabilistic Risk Assessment Results for Risk-Informed Activities*, Regulatory Guide 1.200 (Washington, D.C.: March 2009).

[17]American Society of Mechanical Engineers and American Nuclear Society, *Addenda to ASME/ANS RA-S-2008: Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment Results for Nuclear Power Plant Applications*, ASME/ANS RA-Sa-2009 (ASME, New York, NY; ANS, La Grange Park, IL: February 2009).

[18]NRC, *Charter for Task Force for Assessment of Options for More Holistic Risk-Informed, Performance-Based Regulatory Approach* (Washington, D.C.: Feb. 11, 2011).

[19]NRC, *Charter for the Nuclear Regulatory Commission Task Force to Conduct a Near-Term Evaluation of the Need for Agency Actions Following the Events in Japan* (Washington, D.C.: Mar. 30, 2011).

[20]NRC, *Recommendations for Enhancing Reactor Safety in the 21st Century: The Near-Term Task Force Review of Insights From the Fukushima Dai-ichi Accident* (Washington, D.C: July 12, 2011).

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

2012

NRC issues three orders and a request for information in response to lessons learned from the Fukushima Daiichi disaster.[22] As part of the request for information, the staff asks licensees to reevaluate the seismic and flooding hazards at their sites and suggests PRA as one possible method to address the seismic hazard reevaluation.

[22] NRC, *Staff Requirements—SECY-12-0025—Proposed Orders and Requests for Information in Response to Lessons Learned From Japan's March 11, 2011, Great Tohoku Earthquake and Tsunami* (Washington, D.C.: Mar. 9, 2012).

Appendix IV: Information on Developing a Probabilistic Risk Assessment

Probabilistic risk assessments are used to evaluate several categories of initiating events—that is, events that can lead to a reactor accident—including internal events, which start inside the nuclear power plant or the electric system serviced by the power plant (e.g., random hardware failures and operator actions), and external events, which typically start outside the nuclear power plant, such as natural hazards (e.g., earthquakes, external floods, external fires, and high-wind events). According to NRC documents, external events are of significant concern since they can both initiate core damage accidents and negate or compromise the safety systems or procedures used to prevent or mitigate such accidents.

According to NRC documents, PRA can estimate three different levels of risk—one focused on reactor core damage, one focused on containment release, and one focused on radiological consequences to the public. Specifically, Level 1 PRAs evaluate events that can lead to plant accidents and examine reactor systems and operators' responses to calculate "core damage frequency"—the frequency of the combinations of initiating events, hardware failures, and human errors leading to the uncovering of the reactor core such that reflooding of the core is not imminent. A Level 1 PRA consists of six major steps: (1) identifying a comprehensive list of events that can lead to accidents and grouping those events into categories based on their potential impact on accident response systems; (2) establishing success criteria based on traditional engineering analyses; (3) modeling accident sequences; (4) estimating parameters for the analysis such as initiating event frequencies and the failure rates of particular components; (5) quantifying accident sequences; and (6) documenting and evaluating the results. To accomplish these steps, a PRA employs several specific techniques, including event trees, fault trees, human reliability analyses, and Monte Carlo methods (see table 2). Analysts use these methods to estimate the core damage frequency for each accident sequence. Those frequencies are then totaled to calculate the total core damage frequency for a reactor.

Table 2: Selected Techniques Used in PRA

Technique	Description
Accident sequence analysis (event trees)	Model responses to each event that can initiate an accident. For any given initiating event, there are various accident sequences resulting from whether systems operate properly or fail and what actions operators take. Some accident sequences will result in a safe recovery, and some will result in reactor core damage. Event trees graphically represent accident sequences.
System analysis (fault trees)	Model systems in detail. Many events in an event tree represent a system that is needed to respond to the initiating event. An analysis is performed for each such event, which is graphically represented with a fault tree that identifies the combination of failures that cause the overall system to fail. The fault tree logic is then used to calculate overall failure probability.
Human reliability analysis	Used to evaluate human errors that are important to the outcome of an event. Analysts assess the probability of a human error in light of factors like training, procedures, and expected conditions during an event.
Monte Carlo methods	Used to compute risks. Allows analysts to consider variations in each analysis factor, imperfect knowledge, as well as many possible ways that factors can interact.

Source: NRC.

Level 2 PRAs start with Level 1 core damage accidents and assess the frequencies of various categories of containment releases. The results for operating reactors are typically reported in terms of "large early release frequency"—the frequency of those accidents leading to significant, unmitigated releases from the reactor's containment in a time frame prior to effective evacuation of the nearby population such that there is a potential for early health effects. Level 3 PRAs start with Level 2 radiological release accidents and assess the public health consequences of a radiological release in terms of injury to the public and damage to the environment.[1]

[1]Because core damage and large early release estimates are easier to calculate than public health consequences, the results of Level 1 and Level 2 PRAs are often used as surrogates for the results of a Level 3 PRA. NRC has plans to perform a new Level 3 PRA for a single operating power plant that will include assessment of natural hazards and be completed within 4 years.

Appendix V: NRC Actions on Natural Hazard Assessment in Response to the Fukushima Daiichi Disaster

NRC has taken a number of actions in response to the Fukushima Daiichi disaster. The timeline below describes actions that relate to natural hazard assessments.

March 2011

A 9.0 magnitude earthquake and subsequent tsunami lead to a prolonged loss of alternating current electrical power at several reactors at Japan's Fukushima Daiichi nuclear power plant. As a result of the loss of power, plant operators are unable to keep three of the reactors cool, which leads to fuel melting, hydrogen explosions, and the release of radioactive material into the environment. Among several actions, NRC charters a staff task force to review its processes and regulations in light of the Fukushima Daiichi disaster and to recommend whether NRC should make near-term improvements to its regulatory system.[1]

July 2011

The NRC task force issues its final report.[2] The task force finds that NRC regulations and guidance provide a robust approach for assessing natural hazards but notes that NRC's processes for assessing natural hazards have evolved over time. As a result, the licensing bases, design, and level of protection from natural hazards differ among operating reactors depending on when the reactors were built and when they were licensed for operation. Based on these findings, the task force recommends actions to, among other things, clarify and strengthen NRC's regulatory framework for protection against natural hazards. Three of these recommended actions relate to the assessment of natural hazards. Specifically, the task force recommends that (1) NRC order licensees to reevaluate the seismic and flooding hazards at their sites against current NRC requirements and guidance and, if necessary, update their reactor design bases; (2) NRC initiate rulemaking to require licensees to confirm their seismic and flooding hazards every 10 years, address any new and significant information and, if necessary, update their reactor design bases; and (3) NRC order licensees to check their seismic and flood protection features to identify and address any plant-specific

[1]NRC, *Charter for the Nuclear Regulatory Commission Task Force to Conduct a Near-Term Evaluation of the Need for Agency Actions Following the Events in Japan* (Washington, D.C.: Mar. 30, 2011).

[2]NRC, *Recommendations for Enhancing Reactor Safety in the 21st Century: The Near-Term Task Force Review of Insights from the Fukushima Dai-ichi Accident* (Washington, D.C.: July 12, 2011).

vulnerabilities and verify the adequacy of monitoring and maintenance for protection features such as watertight barriers and seals.

August 2011	The NRC directs agency staff, among other things, to engage stakeholders on the task force recommendations and to identify and prioritize the recommendations that in the staff's view can and should be implemented without unnecessary delay.[3]
September 2011	Agency staff report to the NRC Commissioners on the task force recommendations that in their view can and should be implemented without unnecessary delay.[4] Among other things, the staff recommends that the NRC move forward on requiring licensees to reevaluate the seismic and flooding hazards at their sites against current NRC requirements and guidance. The staff also recommends that the NRC move forward on requiring licensees to check their seismic and flood protection features.
October 2011	Agency staff propose a prioritization of the task force recommendations to the NRC Commissioners and describe the actions necessary to implement the recommendations.[5] The staff suggests deferring the task force recommendation that NRC initiate rulemaking to require licensees to confirm their seismic and flooding hazards every 10 years until the related recommendation for licensees to reevaluate seismic and flooding hazards is implemented. Later in the month, the NRC approves the staff's proposal on the task force recommendations that can and should be implemented without unnecessary delay and says that the agency should

[3]NRC, *Staff Requirements—SECY-11-0093—Near-Term Report and Recommendations for Agency Actions Following the Events in Japan* (Washington, D.C.: Aug. 19, 2011).

[4]NRC, *Recommended Actions to be Taken Without Delay From the Near-Term Task Force Report*, SECY-11-0124 (Washington, D.C.: Sept. 9, 2011).

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

strive to complete and implement the lessons learned from the Fukushima Daiichi disaster by 2016.[6]

December 2011

The NRC approves the agency staff's proposals on implementing task force recommendations and supports actions on several, including the recommendations that licensees reevaluate their seismic and flooding hazards against current NRC requirements and guidance and check their seismic and flood protection features.[7] Later in the month, Congress passes and the President signs the 2012 Consolidated Appropriations Act, which includes a provision directing NRC to require that licensees reevaluate external hazards at their sites, including seismic and flooding hazards, as expeditiously as possible.[8]

January 2012

NRC announces that it is accelerating its plans for implementing the task force recommendations. According to NRC officials, agency staff will propose expanding licensee reevaluations beyond seismic and flooding hazards to include all natural hazards that are relevant to a site, but they expect to recommend that the reevaluation of seismic and flooding hazards take priority over other natural hazards.

February 2012

The NRC staff proposes issuing three orders and a request for information in response to lessons learned from the Fukushima Daiichi disaster.[9] The staff's stated goal is for the orders and request for information to be issued before the first anniversary of the earthquake and tsunami that led to the Fukushima Daiichi disaster. As part of the proposed request for information, the staff plans to ask licensees to

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[6]NRC, *Staff Requirements—SECY-11-0124—Recommended Actions to be Taken Without Delay From the Near-Term Task Force Report* (Washington, D.C.: Oct. 18, 2011).

[7]NRC, *Staff Requirements—SECY-11-0137—Prioritization of Recommended Actions to Be Taken in Response to Fukushima Lessons Learned* (Washington, D.C.: Dec. 15, 2011).

[8]Consolidated Appropriations Act, 2012, Pub. L. No. 112-74, Div. B, § 402 (Dec. 23, 2011).

[9]NRC, *Proposed Orders and Requests for Information in Response to Lessons Learned from Japan's March 11, 2011, Great Tohoku Earthquake and Tsunami*, SECY-12-0025 (Washington, D.C.: Feb. 17, 2012).

reevaluate the seismic and flooding hazards at their sites. NRC staff propose addressing other natural hazards, such as wind and missile loads from tornados and hurricanes, at a later date once sufficient resources are available for the reevaluations. The staff also plans to ask licensees to check their seismic and flood protection features.

March 2012	NRC issues the three orders and the request for information proposed by agency staff in February.[10]

[10]NRC, *Staff Requirements—SECY-12-0025—Proposed Orders and Requests for Information in Response to Lessons Learned From Japan's March 11, 2011, Great Tohoku Earthquake and Tsunami* (Washington, D.C.: Mar. 9, 2012).

Appendix VI: Comments from the Nuclear Regulatory Commission

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

April 13, 2012

Mr. Frank Rusco, Director
Natural Resources and Environment Division
U.S. Government Accountability Office
441 G Street, NW.
Mail Stop: 2T23
Washington, DC 20548

Dear Mr. Rusco:

Thank you for the opportunity to review and submit comments on the draft U.S. Government Accountability Office (GAO) report GAO-12-465, "Nuclear Regulatory Commission – Natural Hazard Assessments Could Be More Risk-Informed," which the U.S. Nuclear Regulatory Commission (NRC) received on March 15, 2012. The NRC appreciates the time and effort that you and your staff have taken to review this topic.

The GAO concludes that probabilistic risk assessment (PRA) offers the NRC and licensees a number of advantages that, as a complement to traditional deterministic assessments, can provide a more robust approach to assessing natural hazards at operating nuclear power plants. The GAO further notes the NRC's overall endorsement of the use of PRA to enhance and extend traditional deterministic assessments. In addition, the GAO provided one recommendation:

> To improve safety decision making by NRC in carrying out its responsibility under the Atomic Energy Act to ensure that the operation of nuclear power plants is consistent with the common defense and security and public health and safety, we recommend that the [Commission] direct agency staff to conduct and document any needed analyses to determine whether the agency should require licensees of operating reactors to develop and maintain PRAs that address natural hazards.

The NRC agrees that it could analyze whether licensees of operating reactors should be required to develop and maintain PRAs that address natural hazards. In fact, the NRC has several ongoing initiatives that are directly relevant to this issue. The NRC's Office of Nuclear Regulatory Research is currently conducting a pilot plant Level 3 PRA effort, as discussed in SECY-11-0089, "Options for Proceeding with Future Level 3 Probabilistic Risk Assessment Activities," dated July 7, 2011, and the corresponding staff requirements memorandum, dated September 21, 2011. The scope of this Level 3 PRA effort, which will be performed by NRC staff for the Vogtle Electric Generating Plant, Units 1 and 2, encompasses natural hazards typically considered in previous external event PRAs (e.g., seismic events, tornadoes, hurricanes, and external flooding). The pilot study will address the impact of these natural hazards on one or both operating reactors at the site, as well as the spent fuel pools. This study will offer insights regarding the potential benefits of applying this expanded tool and will enable the NRC to better assess the NRC and licensee resources required to develop and maintain a Level 3 PRA.

F. Rusco - 2 -

The NRC continues to evaluate the further application of PRA to its regulatory programs and requirements. Commissioner Apostolakis is currently leading a task force to enhance risk-informed regulation through a more structured consideration of risk management. Separately, the NRC's Fukushima near-term task force recommended (Recommendation 1) that the agency establish a logical, systematic, and coherent regulatory framework for adequate protection that appropriately balances defense-in-depth and risk considerations. One of the issues the NRC will consider is whether we should further evaluate the insights gained from the earlier Individual Plant Examination and Individual Plant Examination for External Events efforts, to identify potential generic regulations or plant-specific regulatory requirements.

Additionally, on March 12, 2012, the NRC issued a request for information to all power reactor licensees and holders of construction permits, in response to the Fukushima near-term task force's Recommendation 2.1, and recent Congressional direction (the Consolidated Appropriations Act; Section 402 of Public Law 112-074, December 2011). This request for information includes a request that licensees reevaluate both the seismic and flooding hazards at nuclear power plant sites using updated seismic and flooding hazard information and present-day regulatory guidance and methodologies, including risk assessment approaches, as appropriate. The NRC staff will evaluate the licensees' responses to this request for information, and will determine whether additional regulatory actions are necessary to provide additional protection against the updated hazards.

The NRC will conduct and document the analysis recommended by GAO in the context of the agency's follow-on actions for one or more of these ongoing initiatives, after sufficient information has been gathered from these activities to better inform such an analysis. In addition, the NRC will continue to evaluate its processes and policies regarding the enhanced use of PRA and risk insights as part of its overall regulatory framework. Enclosed are additional NRC comments intended to provide a more comprehensive perspective on the conclusions and recommendations in the draft GAO report.

Should you have any questions about these comments, please contact Jesse Arildsen of my staff at 301-415-1785.

Sincerely,

R. W. Borchardt
Executive Director
for Operations

Enclosure:
As stated

Appendix VII: 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, Kimberly Gianopoulos, Assistant Director; David Marroni; Emmy Rhine; and Ashley Vaughan made key contributions to this report. Important contributions were also made by R. Scott Fletcher, Cindy Gilbert, Jonathan Kucskar, Alison O'Neill, Timothy Persons, Kiki Theodoropoulos, and Jack Wang.

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