United States Government Accountability Office

GAO

Report to Congressional Requesters

August 2012

SPENT NUCLEAR FUEL

Accumulating Quantities at Commercial Reactors Present Storage and Other Challenges

GAO

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GAO-12-797

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Highlights

Highlights of GAO-12-797, a report to congressional requesters

Why GAO Did This Study

Spent nuclear fuel, the used fuel removed from nuclear reactors, is one of the most hazardous substances created by humans. Commercial spent fuel is stored at reactor sites; about 74 percent of it is stored in pools of water, and 26 percent has been transferred to dry storage casks. The United States has no permanent disposal site for the nearly 70,000 metric tons of spent fuel currently stored in 33 states.

GAO was asked to examine (1) the amount of spent fuel expected to accumulate before it can be moved from commercial nuclear reactor sites, (2) the key risks posed by stored spent fuel and actions to help mitigate these risks, and (3) key benefits and challenges of moving spent nuclear fuel out of wet storage and ultimately away from commercial nuclear reactors. GAO reviewed NRC documents and studies on spent fuel's safety and security risks and industry data, interviewed federal and state government officials and representatives from industry and other groups, and visited reactor sites.

What GAO Recommends

To help facilitate decisions on storing and disposing of spent nuclear fuel over the coming decades, GAO recommends that NRC develop a mechanism for locating all classified studies. NRC generally agreed with the findings and the recommendation in the report.

View GAO-12-797. For more information, contact Gene Aloise at (202) 512-3841 or aloisee@gao.gov.

August 2012

SPENT NUCLEAR FUEL

Accumulating Quantities at Commercial Reactors Present Storage and Other Challenges

The amount of spent fuel stored on-site at commercial nuclear reactors will continue to accumulate—increasing by about 2,000 metric tons per year and likely more than doubling to about 140,000 metric tons—before it can be moved off-site, because storage or disposal facilities may take decades to develop. In examining centralized storage or permanent disposal options, GAO found that new facilities may take from 15 to 40 years before they are ready to begin accepting spent fuel. Once an off-site facility is available, it will take several more decades to ship spent fuel to that facility. This situation will be challenging because by about 2040 most currently operating reactors will have ceased operations, and options for managing spent fuel, if needed to meet transportation, storage, or disposal requirements, may be limited.

Studies show that the key risk posed by spent nuclear fuel involves a release of radiation that could harm human health or the environment. The highest-consequence event posing such a risk would be a self-sustaining fire in a drained or partially drained spent fuel pool, resulting in a severe widespread release of radiation. The Nuclear Regulatory Commission (NRC), which regulates the nation's spent nuclear fuel, considers the probability of such an event to be low. According to studies GAO reviewed, the probability of such a fire is difficult to quantify because of the variables affecting whether a fire starts and spreads. Studies show that this low-probability scenario could have high consequences, however, depending on the severity of the radiation release. These consequences include widespread contamination, a significant increase in the probability of fatal cancer in the affected population, and the possibility of early fatalities. According to studies and NRC officials, mitigating procedures, such as replacement water to respond to a loss of pool water from an accident or attack, could help prevent a fire. Because a decision on a permanent means of disposing of spent fuel may not be made for years, NRC officials and others may need to make interim decisions, which could be informed by past studies on stored spent fuel. In response to GAO requests, however, NRC could not easily identify, locate, or access studies it had conducted or commissioned because it does not have an agencywide mechanism to ensure that it can identify and locate such classified studies. As a result, GAO had to take a number of steps to identify pertinent studies, including interviewing numerous officials.

Transferring spent fuel from wet to dry storage offers several key benefits, including safely storing spent fuel for decades after nuclear reactors retire—until a permanent solution can be found—and reducing the potential consequences of a pool fire. Regarding challenges, transferring spent fuel from wet to dry storage is generally safe, but there are risks to moving it, and accelerating the transfer of spent fuel could increase those risks. In addition, operating activities, such as refueling, inspections, and maintenance, may limit the time frames available for transferring spent fuel from wet to dry storage. Once spent fuel is in dry storage, there are additional challenges, such as costs for repackaging should it be needed. Some industry representatives told GAO that they question whether the cost of overcoming the challenges of accelerating the transfer from wet to dry storage is worth the benefit, particularly considering the low probability of a catastrophic release of radiation. NRC stated that spent fuel is safe in both wet and dry storage and that accelerating transfer is not necessary given the small increase in safety that could be achieved.

Contents

Abbreviations

DOE	Department of Energy
EPRI	Electric Power Research Institute
NRC	Nuclear Regulatory Commission

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United States Government Accountability Office
Washington, DC 20548

August 15, 2012

Congressional Requesters

Nuclear fuel that has been used and removed from the reactor core of a nuclear power plant—known as spent nuclear fuel—is one of the most hazardous substances created by humans.[1] If not properly contained or shielded, the intense radioactivity of spent fuel can cause immediate deaths and environmental contamination and, in lower doses, cause long-term health hazards, such as cancer. Some radioactive components of spent fuel remain hazardous for tens of thousands of years. In the United States, the national inventory of commercial spent nuclear fuel amounts to nearly 70,000 metric tons. Concerns were heightened about the vulnerabilities at nuclear power plants to releases of large doses of radiation into surrounding communities after the terrorist attacks of September 11, 2001, and the earthquake and tsunami that struck the Fukushima Daiichi nuclear power plant complex in Japan in March 2011.

Two federal agencies—the Nuclear Regulatory Commission (NRC) and the Department of Energy (DOE)—are primarily responsible for the regulation and disposal of the nation's spent nuclear fuel. NRC regulates the construction and operation of commercial nuclear power plants and spent fuel repositories, as well as the storage and transportation of spent fuel. DOE is charged with investigating sites for a federal geologic repository to dispose of spent nuclear fuel and high-level nuclear waste from commercial nuclear power plants and some defense activities under the Nuclear Waste Policy Act of 1982, as amended.[2] In 1987, however, Congress amended

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[1]Spent (or used) nuclear fuel can no longer efficiently generate power in a nuclear reactor. However, it is potentially a resource because it can be reprocessed to separate out uranium and plutonium to be used as fuel again in a reactor. Reprocessing, however, still results in nuclear waste that requires disposal. The United States does not reprocess its spent nuclear fuel, and this fuel, when it is accepted for disposal, is considered to be high-level waste as defined by the Nuclear Regulatory Commission.

[2]This report does not address the about 13,000 metric tons of spent nuclear fuel and high-level waste DOE manages, which was primarily generated by the nation's nuclear weapons program. For example, DOE manages some former commercial spent fuel, such as spent fuel at a reactor at Fort St. Vrain in Colorado. We reported separately on this issue. See GAO, *DOE Nuclear Waste: Better Information Needed on Waste Storage at DOE Sites as a Result of the Yucca Mountain Shutdown*, GAO-11-230 (Washington, D.C.: Mar. 23, 2011).

the act to direct DOE to focus its efforts only on Yucca Mountain, Nevada. In addition, the act authorized DOE to contract with commercial nuclear reactor operators to take custody of their spent nuclear fuel for disposal at the repository beginning in January 1998, but because of a series of delays due to, among other reasons, state and local opposition to the construction of a permanent nuclear waste repository in Nevada and technical complexities, DOE was unable to begin receiving waste by that time.[3] Currently, the status of the proposed repository at Yucca Mountain is uncertain. DOE and NRC separately suspended their efforts to license this repository in 2010 and 2011, respectively, and several parties have filed a petition in federal court seeking to force NRC to resume the licensing proceeding.[4] In April 2011, we reported on the proposed termination of the Yucca Mountain repository and recommended actions to assist future waste management efforts.[5] In that report, we suggested that Congress might consider a more predictable funding mechanism and an independent organization, outside DOE, for siting and developing a permanent repository. NRC concurred with the facts in a draft of that report, and DOE strongly disagreed with key facts in the draft and our recommendations. No action has been taken to implement our recommendations. Because it did not take custody of the spent fuel starting in 1998, DOE reports that as of September 2011, 76 lawsuits have been filed against it by utilities to recover claimed damages resulting from the delay. These lawsuits have resulted in a cost to taxpayers of about $1.6 billion from the U.S. Treasury's judgment fund. DOE estimates that future liabilities will total about an additional $19.1 billion through 2020 and that they may cost about $500 million each year after that.[6]

Spent nuclear fuel consists of thumbnail-sized pellets of uranium dioxide fitted into 12- to 15-foot hollow metal rods, which are bundled together

[3]Some technical complexities, such as DOE's assessment of how heat from the spent nuclear fuel might affect the performance of the repository, became the focus of years of scientific inquiry.

[4]NRC responded to the parties' petition by stating that it does not have sufficient appropriated funds to complete action on the license application. On August 3, 2012, the federal court reviewing the parties' petition issued an order holding the case in abeyance pending updates by the parties on the status of fiscal year 2013 appropriations with respect to the issues presented in the case.

[5]GAO, *Commercial Nuclear Waste: Effects of a Termination of the Yucca Mountain Repository Program and Lessons Learned*, GAO-11-229 (Washington, D.C.: Apr. 8, 2011).

[6]These costs are in constant 2011 dollars.

into assemblies. Operators of commercial nuclear power reactors use two methods to store spent nuclear fuel: wet storage in pools of water or dry storage in steel and concrete casks. When reactor operators first remove spent fuel from a reactor, it is thermally hot and intensely radioactive and must be immersed in deep pools of water, which cools the spent fuel and shields the environment from the spent fuel. As the inventory of spent fuel has grown, reactor operators have increased the number of assemblies stored in the pools—generally 40 feet deep—by replacing existing storage racks with newer racks holding denser arrangements of assemblies. Despite the denser arrangements, which can sometimes hold thousands of assemblies, spent fuel pools have limited capacity. Beginning in the 1980s, reactor operators began to transfer spent fuel to dry cask storage systems to free space in the pools for fuel removed from the reactor. Spent fuel can be transferred to dry storage once it has aged sufficiently to be cooled by passive air ventilation—generally after about 5 years. Dry cask storage typically consists of a stainless steel canister placed inside a larger stainless steel or concrete cask, which isolates it from the environment. Dozens of community action and environmental groups have advocated that reactor operators accelerate the transfer of spent fuel from pools to dry storage cask systems, believing the risks of dry storage are lower than that of wet storage. NRC maintains that spent fuel is safe and secure in both wet and dry storage systems.

In light of concerns over the nation's growing quantities of stored spent nuclear fuel, ongoing security threats, and safety concerns raised by events in Japan, you asked us to review the safety and security of spent fuel. Specifically, our objectives were to examine (1) the amount of spent fuel that is expected to accumulate before it can be moved from commercial nuclear reactor sites, (2) the key safety and security risks posed by spent fuel stored at reactor sites and actions to help mitigate these risks, and (3) key benefits and near- and long-term challenges of transferring spent nuclear fuel out of wet storage and ultimately away from reactor sites.

To answer these objectives, we reviewed pertinent NRC documents; analyzed studies on the safety and security of spent fuel; interviewed officials from federal and state regional organizations and representatives from industry, academia, and various community action and environmental groups; and visited selected decommissioned and operating reactor sites.[7] Specifically, to determine the amount of spent fuel projected to accumulate before it can be moved from individual reactor sites, we obtained a database on spent fuel projections from the Nuclear Energy Institute, an industry advocacy organization. We based our estimates for when centralized storage and permanent disposal facilities might become available on assumptions from our November 2009 report and on additional analysis based on reports from various sources, including DOE and the Electric Power Research Institute (EPRI, a nonprofit research entity) on centralized storage and permanent disposal.[8] To determine key safety and security risks of spent fuel and potential mitigation actions, we reviewed studies from NRC and other groups, including Sandia National Laboratories, the National Academy of Sciences, and community action groups. We also reviewed NRC requirements addressing the safety and security of spent fuel and directives from the nuclear power industry. We interviewed officials from NRC and DOE and representatives from industry, academia, and various community groups. We visited the Haddam Neck decommissioned reactor site and the Millstone reactor in Connecticut, the Hope Creek and Salem reactors in New Jersey, and the Susquehanna reactor in Pennsylvania, and we spoke with NRC officials and industry representatives about spent fuel storage issues at these sites. To determine the benefits and challenges of transferring spent fuel from wet to dry storage, we reviewed documents from NRC, DOE, industry, and community groups. We also interviewed officials from NRC, DOE, and state regional organizations, and representatives of industry, academia, the Blue Ribbon Commission on America's Nuclear Future,[9] and community groups. Appendix I presents our scope and methodology in more detail.

[7]Our selection of sites was a judgmental sample based on reactor sites that met specific criteria, including the type of operating reactor, the type of dry storage systems used, and whether the reactor was operating or decommissioned. We found a group of reactors in the Northeast meeting these criteria, enabling us to visit sites in a single 1-week trip. Although our observations on the methods and risks of spent fuel storage are similar at all reactor sites, each site is sufficiently different that our specific observations at one site cannot be generalized to all reactor sites.

[8]GAO, *Nuclear Waste Management: Key Attributes, Challenges, and Costs for the Yucca Mountain Repository and Two Potential Alternatives*, GAO-10-48 (Washington, D.C.: Nov. 4, 2009).

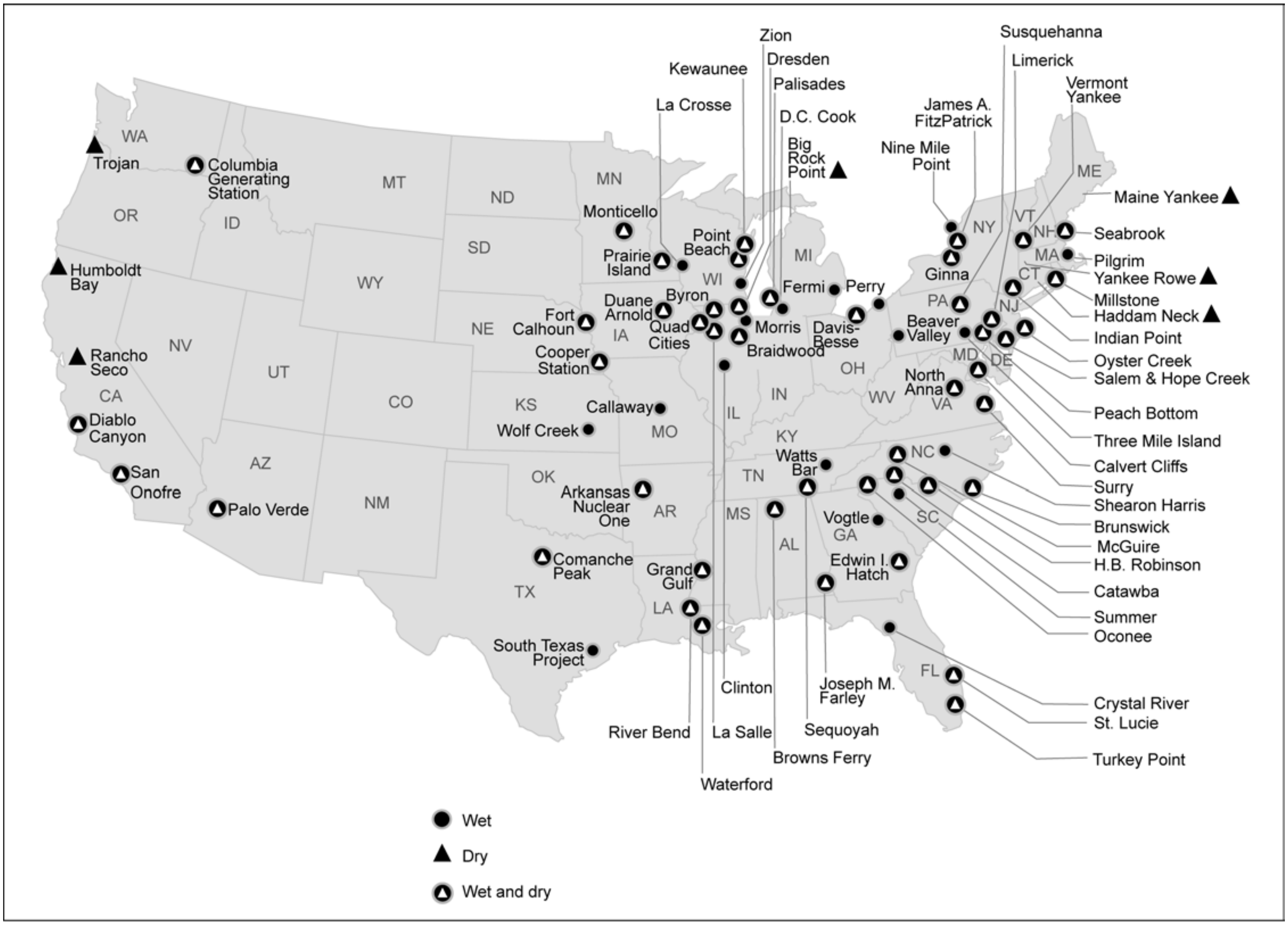
[9]In 2010, the administration directed DOE to establish this Blue Ribbon Commission of recognized experts to study nuclear waste management alternatives. The commission issued a report in January 2012.

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

Background

In the United States, the national inventory of commercial spent nuclear fuel amounts to nearly 70,000 metric tons, which is stored at 75 sites in 33 states (see fig. 1).

Figure 1: Commercial Spent Nuclear Fuel Storage Sites



Source: NRC.

Note: Of the 75 sites, 65 have currently operating reactors, 7 have decommissioned reactors, 2 have reactors being decommissioned, and 1 site was constructed as a storage pool for spent fuel awaiting reprocessing.

Commercial Nuclear Reactor Operations and Storage of Spent Fuel

Fuel for commercial nuclear power reactors is typically made from low-enriched uranium fashioned into thumbnail-size ceramic pellets of uranium dioxide.[10] These pellets are fitted into 12- to 15-foot hollow rods, referred to as cladding, made of a zirconium alloy.[11] The rods are then bound together into a larger assembly. A typical reactor holds about 100 metric tons of fuel when operating—generally from 200 to 800 fuel assemblies. The uranium in the assemblies undergoes fission—a process of splitting atoms into fragments and neutrons that then bombard other atoms—resulting in a sustainable chain reaction that creates an enormous amount of heat and radioactivity. The heat is used to generate steam for a turbine, which generates electricity. The fragments created when fission splits atoms, or when bombarding neutrons bond with atoms, include hundreds of radioisotopes, or radioactive substances, such as krypton-90, cesium-137, and strontium-90. Furthermore, the neutron bombardment of uranium can also create heavier radioisotopes, such as plutonium-239. The radioisotopes produced in a reactor can remain hazardous from a few days to many thousands of years; these radioisotopes remain in the fuel assemblies and as components of the resulting spent fuel.

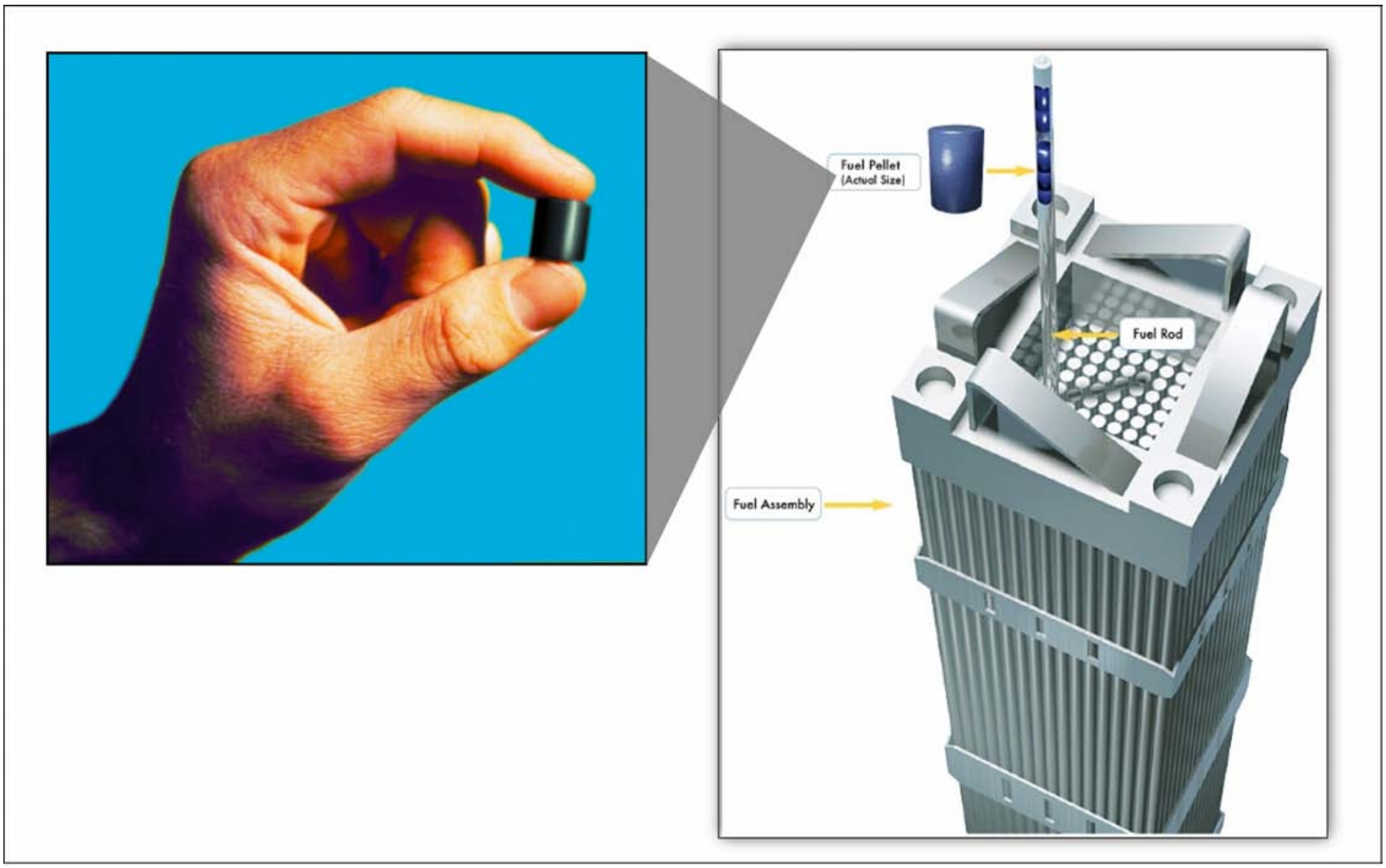
Each fuel assembly is typically used in the reactor for 4 to 6 years, after which most of the fuel it contains is spent, and the uranium dioxide is no longer cost-efficient at producing energy. Reactor operators typically discharge about one-third of the fuel assemblies every 18 months to 2 years and place this spent fuel in a pool to cool. Water circulates in the pool to remove the enormous heat generated from the radioactive decay of some of the radioisotopes. As long as circulating water continues to remove this heat, pool water temperature is maintained well below boiling, typically below 120 degrees Fahrenheit. If exposed to air, however, recently discharged spent fuel could rise in temperature by hundreds or thousands degrees Fahrenheit. A pool is needed to ensure

[10]Uranium is found naturally in the ground, consisting of about 99.3 percent of the nonfissile uranium-238, with only 0.7 percent fissile uranium-235. In its natural state, uranium is only slightly radioactive and can be handled without shielding. To make fuel for a commercial power reactor, the proportion of uranium-235—which is responsible for a sustainable nuclear chain reaction—must be enriched to 3 to 5 percent, but even this enrichment requires little shielding from heat or radioactivity. It is not until after the uranium is irradiated in a reactor and is bombarded with neutrons that it becomes hazardous because of production of other radioisotopes.

[11]A zirconium alloy is used because of its resistance to corrosion and low absorption of neutrons, meaning it does not interfere with the nuclear chain reaction.

that heat generated from the decay of radioisotopes, particularly immediately after discharge from a reactor, does not damage fuel rods and release radioactive material. Figure 2 shows a fuel pellet for a commercial nuclear reactor and a fuel rod in an assembly.

Figure 2: Fuel Pellet and Fuel Rod Assembly for a Commercial Nuclear Power Reactor



Source: Nuclear Energy Institute.

The pools of water are typically about 40 feet deep, with at least 20 feet of water covering the spent fuel, and the water is cooled and circulated to keep the assemblies from overheating. These pools are constructed according to NRC's requirements, typically 4- to 6-feet thick with steel-reinforced concrete and a steel liner. The pools must be located inside what is known as the vital area of a nuclear power reactor, protected by armed guards, physical barriers, and limited access. Within the vital area, pools may be in one of two locations, depending on the type of reactor. In a pressurized water reactor, spent fuel is stored in a pool at or below ground level,[12] but in a typical boiling water reactor, spent fuel is stored in a pool well above ground level, near the reactor vessel, as high as three stories above ground.[13] Figure 3 shows the location of a spent fuel pool for a boiling water reactor, and figure 4 shows a typical spent fuel pool.

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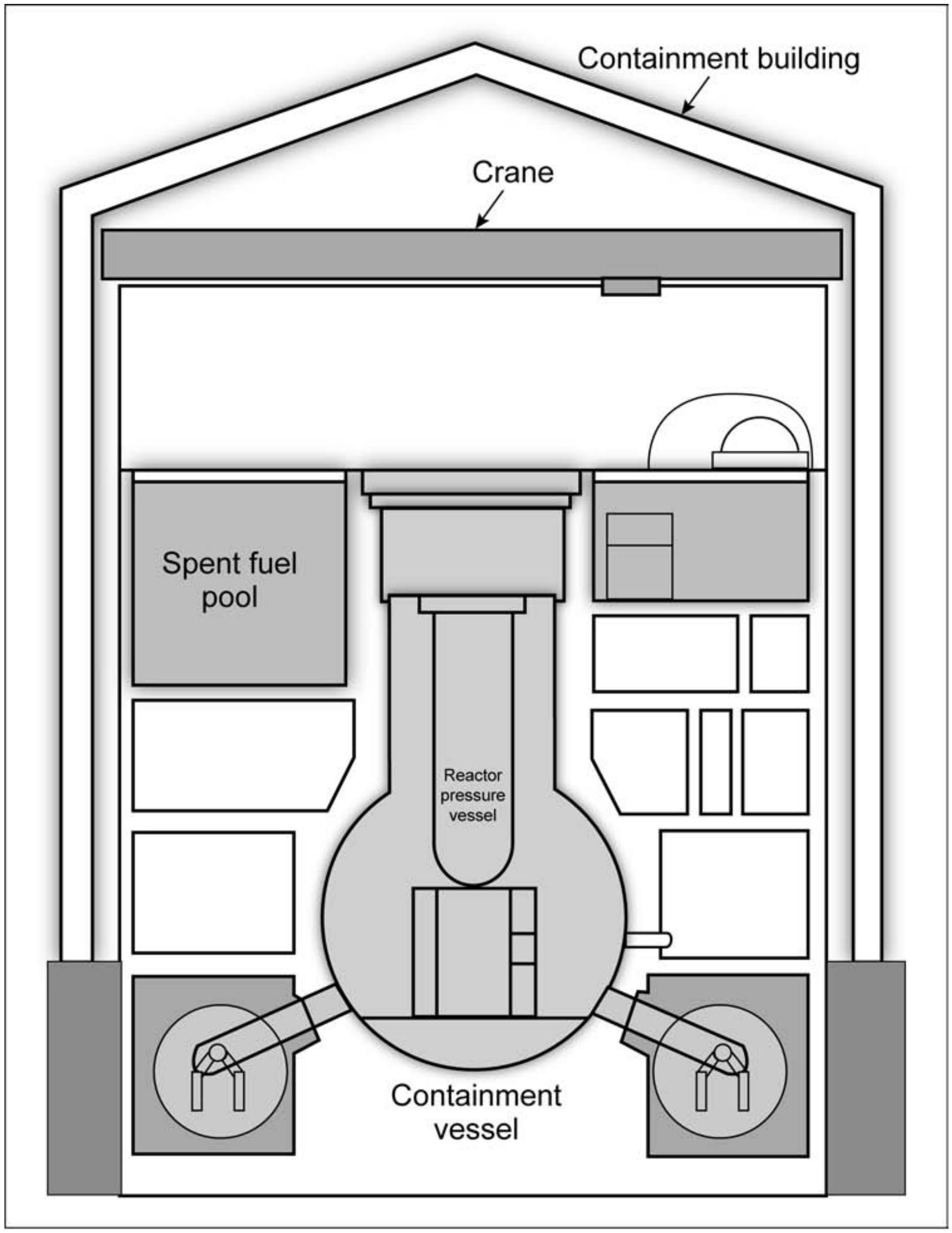
[12]In addition, a pressurized water reactor has two independent loops: one to carry heat to a steam generator and one to carry nonradioactive steam to a turbine to generate electricity. In a boiling water reactor, steam generated by the reactor goes directly to a turbine, and after leaving the turbine, the slightly radioactive steam is condensed into water and recycled back to the reactor.

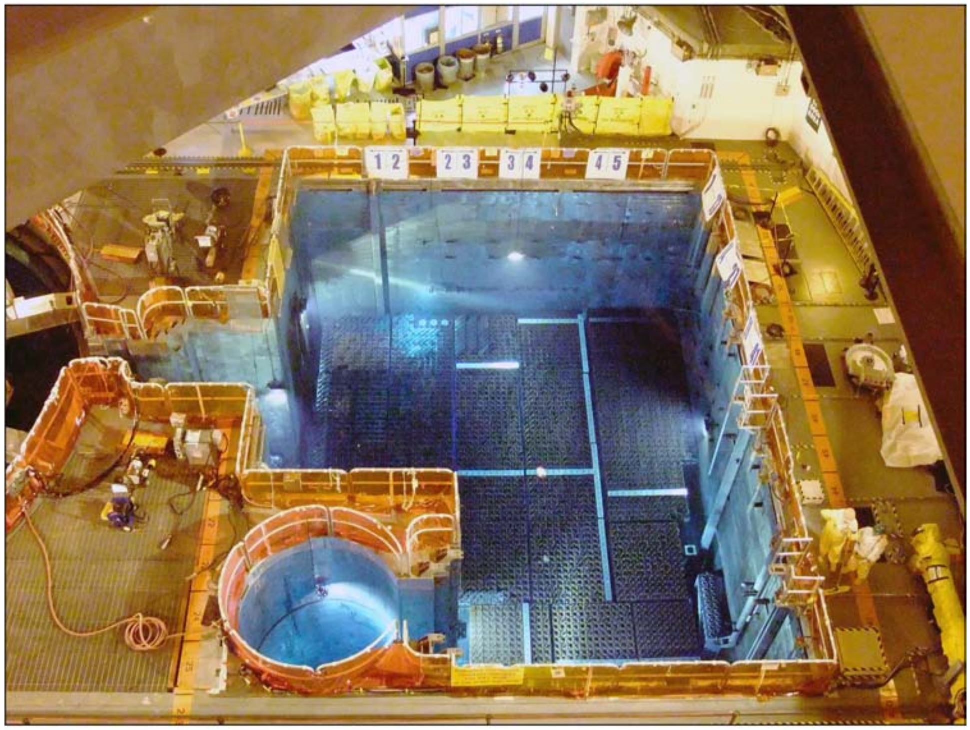
[13]The reactors damaged at the Fukushima Daiichi nuclear power plant complex in Japan were boiling water reactors. The Japanese had difficulty accessing one of the reactor’s spent fuel pools because of its height above ground. According to NRC, all but 4 of the 35 boiling water reactors in the United States have similar designs. The spent fuel pools at these 4 boiling water reactors are situated in a separate fuel storage building at or near ground level.

Figure 3: Location of a Spent Nuclear Fuel Pool in a Boiling Water Reactor



Sources: GAO illustration based on Tokyo Electric Power Company designs.

Figure 4: Spent Nuclear Fuel Pool



Source: Nuclear Energy Institute.

As part of the construction permit and operating license application process for nuclear reactors, NRC requires companies licensed to operate these reactors to assess natural hazards, such as earthquakes, floods, hurricanes, and tidal waves that their reactors might face. Reactor operators must also show that their proposed pool designs would survive the most severe natural hazards, or combinations of less severe hazards, expected for that particular area.[14] Since the Fukushima Daiichi disaster, NRC has required reactor operators to reevaluate their original design criteria against more recent seismic information that has been developed since many of the nuclear power plants were first licensed. According to NRC documents, NRC developed its requirements with a concept of “defense-in-depth,” which is a way of designing and operating nuclear

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

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.[15]

To remove a spent fuel assembly from the reactor, an operator must stop the nuclear chain reaction, then allow the water in the reactor to depressurize and cool before accessing the fuel assemblies, a process that typically takes several days. Once spent fuel is discharged from a reactor and placed in a pool, the spent fuel continues to decay into other substances and continues to generate enormous amounts of heat.[16] For example, plutonium-239—one of the components of spent fuel—decays into various radioactive substances, such as thorium and radium, and eventually decays into a stable, nonradioactive form of lead, although the entire process may take millions of years. As a general rule, the older the spent fuel, the cooler and less hazardous it is, but the spent fuel still has enough long-lived components to make it dangerous to humans and the environment for tens of thousands of years. When in an intact assembly, these components are dangerous only to nearby persons if the assembly is not adequately shielded and is only dangerous to the public and environment if its components are aerosolized and dispersed. Different components of the spent fuel decay at different rates, but many of the more hazardous components decay quickly. For example, iodine-131 has a half-life of 8.04 days and will be virtually gone within 3 months. (Radioactive iodine can congregate in the thyroid and cause thyroid cancer. For this reason, some populations living near nuclear power plants have been given iodine tablets to take if advised to do so during an event to reduce the likelihood of developing cancer in the event of a

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

[16]All radioactive substances—referred to as radioisotopes—are unstable and spontaneously transform themselves into more stable isotopes by capturing or emitting atomic particles or by fission. The time it takes a radioisotope to decay into more stable substances is measured by a half-life. A half-life is the length of time it takes for one-half of a particular radioisotope to decay into a new isotope. After two half-lives, one-quarter of the original radioisotope will be left, but three-quarters will have changed to the new isotope. After 10 half-lives, only 1/1,000 of the original radioisotope is left.

nuclear emergency.[17]) In contrast, cesium-137 has a half-life of 30.2 years and will take over 300 years to decay to negligible amounts. Cesium-137 contributes to the decay heat in a spent fuel pool and is a significant land contaminant if released.

Typically, according to NRC officials, spent fuel must remain in a pool for at least 5 years to decay enough to remain within the heat limits of currently licensed dry cask storage systems. Spent fuel cools very rapidly for the first 5 years, after which the rate of cooling slows significantly. Spent fuel can be sufficiently cool to load into dry casks earlier than 5 years, but doing so is generally not practical. Some casks may not accommodate a full load of spent fuel because of the greater heat load. That is, the total decay heat in these casks needs to be limited to prevent the fuel cladding from becoming brittle and failing, which could affect the alternatives available to manage spent fuel in the future, such as retrieval. In recent years, reactor operators have moved to a slightly more enriched fuel, which can burn longer in the reactor. Referred to as high-burn-up fuel, this spent fuel may be hotter and more radioactive coming out of a reactor than conventional fuel and may have to remain in a pool for as long as 7 years to cool sufficiently.

In the original designs submitted for spent fuel pools, fuel assemblies were packed in relatively low densities, but operators have replaced these low-density racks with higher-density racks to store more spent fuel. According to NRC officials, NRC accepts high-density storage of spent fuel if certain conditions are met, such as adequate cooling, the maintenance of structural integrity, and the prevention of a critical chain reaction. Neutron-absorbing materials can be used to keep closely packed assemblies from starting a chain reaction.[18] As pools began to fill in the 1980s, NRC conducted several safety studies on the impact of increasing the density of spent fuel in pools and determined that the risk of a potential release from overheating or igniting, or even of a critical chain reaction from the dense geometric configuration, was small, particularly if certain steps were taken to reduce the risk. Even with re-

[17]Taking potassium iodine tablets floods the thyroid with nonradioactive iodine so the thyroid cannot absorb radioactive iodine-131. Children are particularly susceptible to cancer from iodine-131.

[18]Neutron-absorbing material typically contains boron, which absorbs neutrons and will help prevent a nuclear chain reaction. NRC has identified some issues with degradation of the boron plates in boiling water and pressurized water reactors and asked operators to monitor their condition.

racking to a dense configuration, however, spent nuclear fuel pools are reaching their capacities and may contain several thousand assemblies each.

As reactor operators have run out of space in their spent fuel pools, more operators have turned to dry cask storage systems. These systems consist of a steel canister protected by an outer cask made of steel or steel and concrete to provide shielding from the heat and radiation of spent fuel. In one typical process of transferring spent fuel to dry storage, reactor operators place a steel canister inside a larger steel transfer cask and lower both into a pool. Spent fuel is loaded into the canister, a lid is placed on the canister, and then both the canister and transfer cask are removed from the pool. The lid is welded onto the canister, and the water drained. Then the canister and transfer cask are aligned with a storage cask and the canister is maneuvered into the storage cask. The storage casks, in either vertical or horizontal designs, are usually situated on a large concrete pad surrounded by safety systems and a security infrastructure, such as radiation detection devices and intrusion detection systems. The transfer process has become routine at some power plants (see fig. 5).

Figure 5: Canister in a Transfer Cask in a Spent Nuclear Fuel Pool

Source: Nuclear Energy Institute.

In addition to regulating the construction and operation of commercial nuclear power plants, NRC also regulates spent fuel in dry storage. NRC requires that spent fuel in dry storage be stored in approved systems that offer protection from significant amounts of radiation. NRC evaluates the design of passively air-cooled dry storage systems for resistance to certain natural disasters, such as floods, earthquakes, tornado missiles, and temperature extremes. NRC may require physical tests of the systems, or it may accept information derived from scaled physical tests and computer modeling. For example, dry storage systems must be able to withstand, among other things, being dropped from the height to which it would be lifted during operations; being tipped over by seismic activity, weather, or other forces or accidents; fires; and floods. NRC has also analyzed the performance of dry storage systems in different terrorist attack scenarios. Once a dry storage system is approved, NRC issues a certificate of compliance for a cask design. Currently, NRC may issue a cask certificate for a term not to exceed 40 years.[19] Similarly, NRC may renew a cask certificate for a term not to exceed 40 years (see fig. 6).[20]

Figure 6: Spent Fuel in Dry Storage

Source: Portland General Electric Co.

The length of time that spent fuel can safely be stored in dry casks is uncertain. We earlier reported that experts agree that spent fuel can be safely stored for up to about 100 years, assuming regular monitoring and maintenance.[21] In December 2010, NRC issued a determination and associated rule stating that spent fuel can be safely stored for up to 60

[19]Cask certificates issued before May 17, 2011, expire 20 years from the date of issuance and may be renewed for an additional 20 years. In February 2011, NRC amended part 72 to change the 20-year term and renewal period to a term not to exceed 40 years. 76 Fed. Reg. 8872, 8875-76. (Feb. 16, 2011). 10 C.F.R. § 72.238 (2012).

[20]10 C.F.R § 72.240(a) (2012).

[21]GAO-10-48.

years beyond the licensed life of the reactor in a combination of wet and dry storage.[22] Four states, an Indian community, and environmental groups petitioned for review of NRC's rule, however, arguing in part that NRC violated the National Environmental Policy Act by failing to prepare an environmental impact statement in connection with the determination.[23] On June 8, 2012, the U.S. Court of Appeals for the District of Columbia Circuit held that the rulemaking did require either an environmental impact statement or a finding of no significant environmental impact and remanded the determination and rule back to NRC for further analysis. NRC has not yet indicated what actions it will take in response to the court's action. On August 7, 2012, the commissioners voted not to issue final licenses dependent on the determination and rule until it addresses the court's remand, however, the commission is currently preparing an environmental impact statement on the effects of storing spent fuel for 200 years. In addition, NRC, DOE, and industry are conducting a series of studies to evaluate the regulatory actions or additional engineering measures needed for long-term storage of spent fuel to account for possible degradation of the canisters or the spent fuel in the canisters.

Federal Efforts to Identify and Develop a Site for a Spent Fuel Repository

Since the 1950s, even before operation of the first commercially licensed nuclear power reactor in the United States, the federal government recognized the need to manage the back end of the fuel cycle—spent nuclear fuel removed from a reactor. A 1957 National Academy of Sciences report endorsed deep geological formations to isolate high-level radioactive waste, which includes spent nuclear fuel, but during the 1950s and 1960s, nuclear waste management received relatively little attention

[22]NRC first issued the determination and rule in 1984 and updated them in 1990. Because the licensed life of a reactor may include the term of a revised or renewed license, which together may extend to 60 years, NRC's determination extends to 120 years. The determination and rule also state that NRC believes that sufficient mined geologic repository capacity will be available when necessary. 75 Fed. Reg. 81037 (Dec. 23, 2010); 10 C.F.R. § 51.23 (2012). NRC has stated that, as a matter of policy, it will not license reactors if it does not have reasonable confidence that the spent fuel can be disposed of safely and that spent fuel, if properly stored and monitored, can be kept safe and secure on site for decades.

[23]The National Environmental Policy Act requires federal agencies to evaluate the likely environmental effects of a proposed project using an environmental assessment or, if the project is likely to significantly affect the environment, a more detailed environmental impact statement evaluating the proposed project and alternatives. 42 U.S.C. §§ 4321-4347 (2006).

from policymakers. The early regulators and developers of nuclear power viewed waste disposal primarily as a technical problem that could be solved when necessary by applying existing technology. Attempts were made to reprocess the spent nuclear fuel—that is, to reuse some useful elements remaining in a spent fuel assembly after it is discharged from a reactor, such as unfissioned uranium-235—but this process was not pursued because of economic issues and concerns that reprocessed nuclear materials raise proliferation risks.[24]

As noted above, the Nuclear Waste Policy Act of 1982 charged DOE with investigating sites for a federal geologic repository and authorized DOE to contract with reactor operators to take custody of spent fuel for disposal at the repository beginning in 1998. In 1987, Congress amended the Nuclear Waste Policy Act to direct DOE to focus its efforts only on Yucca Mountain for a repository. DOE did not submit a license application for Yucca Mountain until 2008, however—10 years after it was supposed to start taking custody of spent fuel. In 2009, DOE announced that it planned to terminate its work related to the Yucca Mountain repository, and in 2010 it filed a motion to withdraw the license application. NRC's licensing board denied the motion, but DOE continued to take steps to dismantle the repository project. In September 2011, the NRC commissioners considered whether to overturn or uphold the licensing board's decision, but they were evenly divided and unable to take final action on the matter. Instead, the NRC commissioners directed the licensing board to suspend work by September 30, 2011. NRC's failure to consider the application, among other things, is being contested in federal court. Several parties have filed a petition against NRC asking the federal court to, among other things, compel NRC to provide a proposed schedule with milestones and a date for approving or disapproving the license application. Currently, it remains uncertain whether NRC will have to resume its license review efforts and whether a repository at Yucca Mountain will be built. In the interim, in 2010, the administration directed DOE to establish a Blue Ribbon Commission of experts to study an array of nuclear waste management alternatives. DOE established the

[24]Over 95 percent of spent fuel consists of uranium and plutonium that can be reprocessed and reused as fuel in a commercial power reactor. Concerns have been raised, however, that separating plutonium from other components of spent fuel raises proliferation risks, since plutonium can be used to make nuclear weapons. See GAO, *Nuclear Fuel Cycle Options: DOE Needs to Enhance Planning for Technology Assessment and Collaboration with Industry and Other Countries*, GAO-12-70 (Washington, D.C.: Oct. 17, 2011).

commission, which studied alternatives including options for interim storage of spent fuel and permanent disposal. In its January 2012 report, the commission recommended that the nation adopt centralized storage of some spent fuel as an interim measure but, at the same time, develop a process to find and license a site for a permanent repository. With nowhere to send the spent fuel, operators must keep it on-site at decommissioned and operating commercial reactors until some option to move it off-site becomes available.

Countries other than the United States also produce electricity from nuclear power reactors and have programs to manage their spent nuclear fuel. Some countries, such as France, store their spent fuel in pools until it can be reprocessed, and other countries, such as Canada, use both wet and dry storage systems. Following the accident at Fukushima, Japan temporarily shut down its nuclear reactors, but it has restarted one and may restart others. Several countries have programs to develop permanent disposal facilities. See appendix II for more information on other countries' programs.

Large Quantities of Spent Nuclear Fuel Are Expected to Remain at Commercial Reactor Sites for Decades

The amount of spent fuel accumulating at commercial reactor sites is expected to increase by about 2,000 metric tons each year until it can begin to be shipped off-site and, even then, shipping it off-site will be a decades-long process. By then, currently operating reactors will begin to retire, dismantling their spent fuel pools and leaving the spent fuel stranded in dry storage canisters with limited options for repackaging them, should repackaging be required to replace degraded canisters, or to meet transportation or disposal requirements.

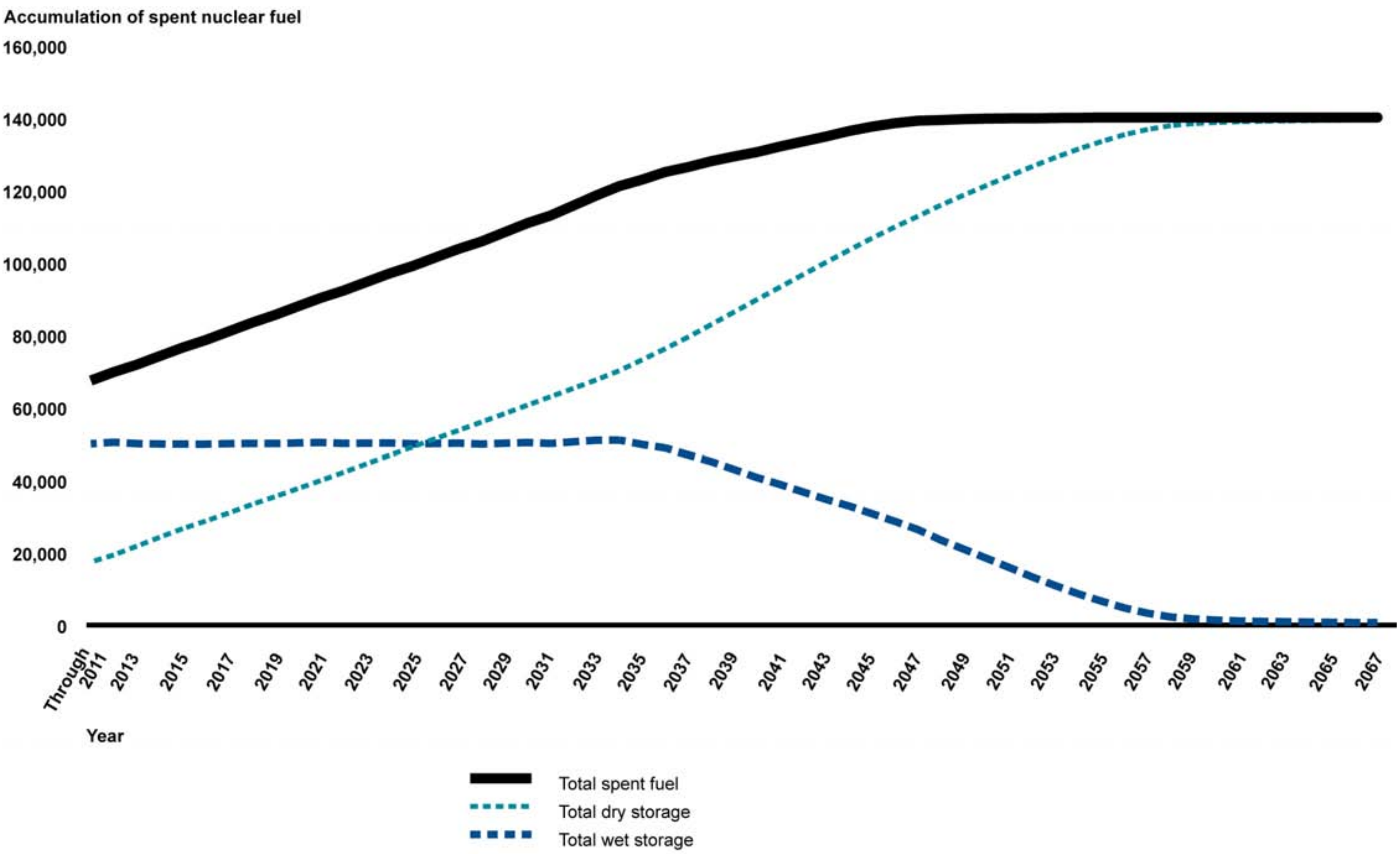
Spent Nuclear Fuel Could Nearly Double before Being Transported to a Storage or Disposal Facility

The amount of spent fuel is expected to more than double to about 140,000 metric tons by 2055, when the last of currently operating reactors is expected to retire, according to the Nuclear Energy Institute, but it may take at least that long to ship the spent fuel off-site. This amount is based on the assumption that the nation's current reactors continue to produce spent nuclear fuel at the same rate—about 2,000 additional metric tons annually; that no new reactors are brought online; and that some decline in the generation of spent fuel takes place as reactors are retired. At the end of 2012, over 69,000 metric tons is expected to accumulate at 75 sites in 33 states, enough to fill a football field about 17 meters deep.[25] Without central storage options or an available permanent disposal facility, spent fuel continues to accumulate at the sites where it was generated.

Current industry practice has been to store the spent fuel in the pools, with an industry expectation that, at some point, DOE would begin to take custody of it. In 2011, about 74 percent of commercial spent fuel was stored in pools, and the remaining 26 percent was in dry storage, but these proportions will slowly change as more pools fill and the spent fuel is transferred to dry storage. According to the Nuclear Energy Institute, by 2025, assuming no new reactors, the proportion of spent fuel in wet storage and dry storage should be roughly equal, about 50,000 metric tons in each. Shortly after 2055, when the last currently operating reactors' licenses are expected to expire, and the reactors are expected to retire, virtually all the spent fuel arising from the current fleet will have been moved to dry storage. Figure 7 shows the trend of accumulated spent fuel and the rate of spent fuel transferred from wet storage to dry storage through 2067, according to our analysis of Nuclear Energy Institute data.

[25]The expected accumulation of about 140,000 metric tons of spent fuel by about 2055 does not include spent fuel from new reactors. By 2016, NRC projects it will have received 23 applications to construct 37 new nuclear power reactors. For example, 2 new reactors are currently under construction in Georgia.

Figure 7: Trends in Accumulation of Spent Nuclear Fuel Overall and in Wet and Dry Storage



Source: GAO analysis of Nuclear Energy Institute data.

When it became evident that DOE was likely decades behind its deadline to pick up spent fuel, nuclear power plant operators began transferring spent fuel to dry storage to retain enough space in their pools to safely discharge fuel from their reactors. The rate of transfer differs by the operating and spent fuel characteristics of the reactor—that is, reactor type and size—as well as the size of the spent fuel pool. In general, reactor operators must transfer an average of three to six canisters each year to keep pace with the discharge of spent fuel from their reactors. Table 1 provides data on reactors and spent fuel and the rate of transfer anticipated to dry storage.

Table 1: Typical Reactor Characteristics and Storage Capacity

Type of reactor	Typical core size	Typical discharge	Typical capacity of dry storage canister	Typical number of canisters to be loaded to keep pace with discharge
Pressurized water reactor	193 assemblies (87 metric tons)	72 to 84 assemblies every 18 months (32 to 38 metric tons)	32 assemblies (14.4 metric tons)	3-6 canisters annually
Boiling water reactor	560 assemblies (101 metric tons)	224 assemblies every 24 months (40 metric tons)	61 assemblies (11 metric tons)	4 canisters biennially

Sources: GAO analysis of data from the Electric Power Research Institute and the Nuclear Energy Institute.

Note: Estimates were developed by the Electric Power Research Institute and the Nuclear Energy Institute to represent typical systems.

Reactor operators continue to fill their spent fuel pools until capacity is reached, in part because the transfer of spent fuel to dry storage is costly and time-consuming. Specifically, operators must take extensive steps to ensure that safety precautions to protect workers and the public are met. Before an operator can transfer a single fuel assembly to dry storage, the operator must train personnel and practice the procedure. According to industry representatives, these efforts involve several weeks of mobilization and demobilization of equipment before and after the transfer. The transfer of spent fuel to a single canister typically takes at least 1 week.

The amount of spent fuel that accumulates and is stored on-site will also be affected by the timing of an off-site central storage or permanent disposal facility, if and when one becomes available. To estimate the amount of accumulation at commercial nuclear power plants before an off-site facility becomes available, we considered three scenarios: (1) Yucca Mountain as a permanent disposal facility, (2) two federally funded centralized storage facilities, and (3) an alternative permanent disposal facility. For purposes of our analysis, we assumed that each storage facility would be licensed by NRC and funded by Congress. Furthermore, for each scenario, we recognized that multiple factors could affect the projected time frame. These factors include the siting, licensing, and construction, and the start of operations of the storage or disposal facility, as well as the time needed to ship spent fuel to the off-site facility and reduce the backlog of already-accumulated spent fuel. For each scenario, we made certain assumptions and incorporated them into our analyses. We estimated the earliest likely dates that Yucca Mountain, two federal centralized storage facilities, or a permanent repository could be opened. Our analysis was based on information from our prior work in analyzing alternatives to a repository at Yucca Mountain, including expert input to develop assumptions to model the time frames for different scenarios for spent fuel management.[26] See appendix I for more details on our methodology for this analysis.

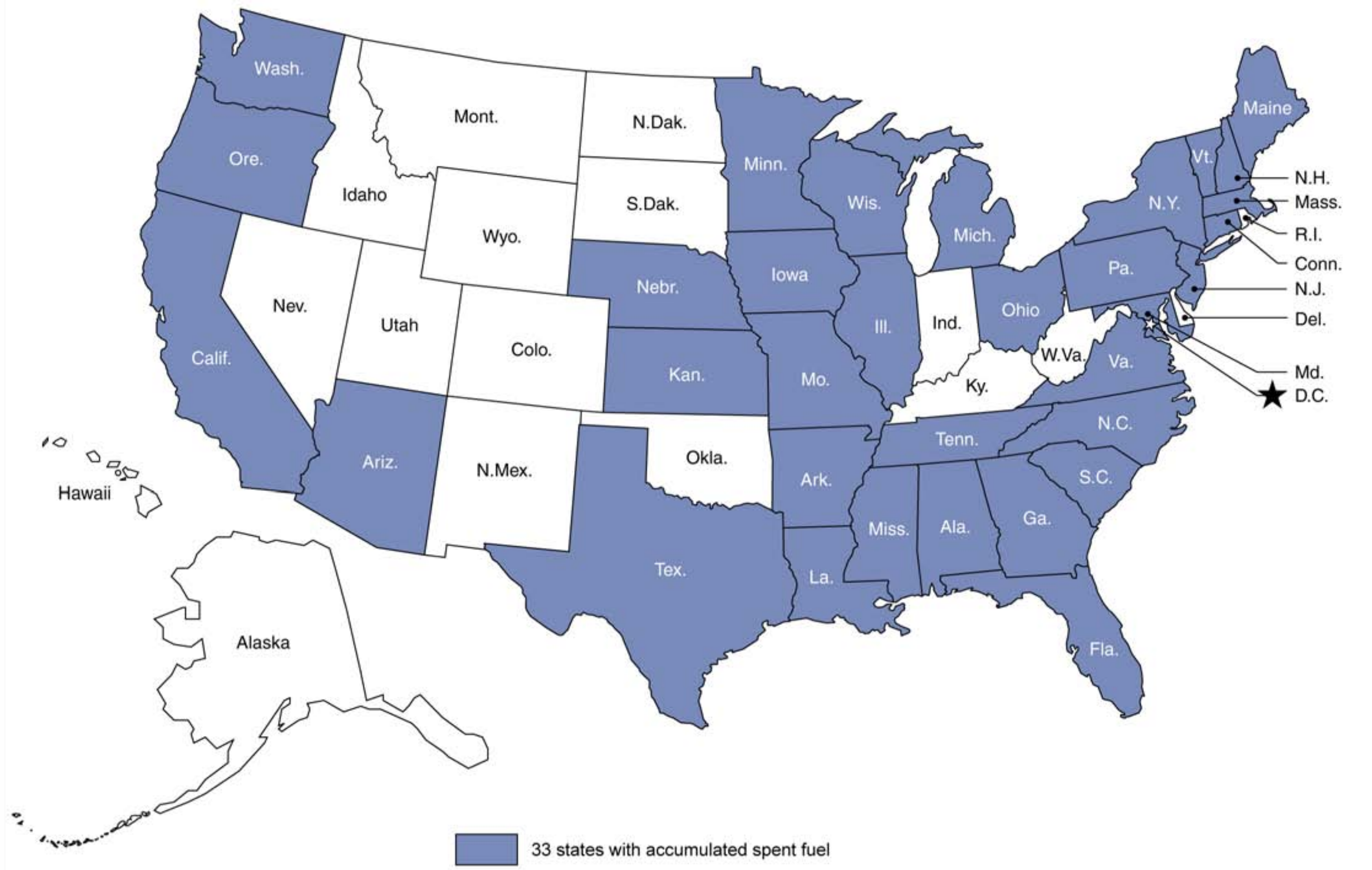
Our analysis showed that regardless of which storage or disposal scenario was considered, it would take at least 15 years to open an off-site location and decades to ship the spent fuel once the central storage or disposal facility became available. The time needed for shipment depends on the amount of fuel accumulated and assumes a shipment rate of 3,000 metric tons per year—the rate that DOE developed as part of its plans for Yucca Mountain. Experts we consulted in our prior work agreed this rate was reasonable. A faster or slower shipping rate could affect the rate of continued accumulation or drawdown of the backlog. When we conducted our analysis in 2009, we reported that Yucca Mountain—the first scenario—was likely to offer the earliest option for off-site disposal, in 2020. Since then, the process for licensing Yucca Mountain has stopped, and it is unclear whether the licensing process will be resumed; in addition, many key workers who worked on Yucca Mountain have left DOE for other employment or retirement. If the licensing process for Yucca Mountain were resumed in 2012, we estimate that DOE would require roughly at least 15 more years to open the site as a repository, or sometime around 2027. We estimate that the second scenario—for the federal government to site, license, construct, and open two centralized storage facilities—might take about 20 years, with completion in 2032, because of the complexities in siting, licensing, and constructing such facilities. We estimate that the third scenario—for a potential permanent disposal facility as an alternative to the Yucca Mountain repository—would take the longest to be realized, about 40 years, or 2052, because of the additional scientific analysis required to ascertain the safety of a permanent disposal facility. Figure 8 shows the amount of spent fuel that is expected to accumulate in each state for the years 2012; 2027 (the earliest likely opening date if the Yucca Mountain repository were to be licensed and constructed); 2032 (the earliest a centralized storage facility could be expected to open); 2052 (the earliest a permanent disposal facility other than Yucca Mountain could be expected to open); and 2067, when all currently operating commercial nuclear power reactors are expected to have retired and transferred their spent fuel to dry storage.

[26] GAO-10-48.

Interactive Graphic

Figure 8: Accumulation of Commercial Spent Fuel by State Over Time

Instructions: **Online, hover over the state names in the graphic for more information.**
For print version, see appendix III, page 57.



Sources: GAO analysis of Nuclear Energy Institute data; Map Resources (map).

Note: When viewing online, place your cursor over a state to see the amount of spent fuel for the years specified. The data for this figure can also be found in a table in appendix III.

Resolving the issue of what to do with commercial spent nuclear fuel will likely be a decades-long, costly, and complex endeavor. Planning ahead to allow reactor operators and local communities to make better-informed and forward-looking decisions is important in such a complex undertaking. For example, DOE had earlier created designs for a specific type of canister for disposal at the Yucca Mountain repository, and had informed reactor operators that all spent fuel destined for Yucca Mountain needed to be packaged in this specific canister, called a transportation, aging, and disposal canister. Although the canister had not gone into commercial production, its design specifications had at least informed reactor operators. Now that both DOE and NRC have suspended their licensing efforts for the Yucca Mountain repository, a great deal of uncertainty exists about future spent fuel management. Given this uncertainty, it may be difficult for reactor operators to make decisions about issues such as the rate of transferring spent fuel to dry storage and the type of canister to be used for disposal.

As Many Nuclear Reactors Begin Closing in 2040, Growing Quantities of Spent Fuel May Be Stranded in Place

During the decades it will take to open a storage or disposal facility, many reactors will be retiring from service, "stranding" their accumulated spent fuel in a variety of different dry storage systems, with no easy way of repackaging them should repackaging be required to meet storage or disposal requirements. Most U.S. reactors were built during the 1960s and 1970s and, after a 40-year licensing period with a possible 20-year extension, will begin retiring in large numbers by about 2030 and emptying their pools by about 2040. NRC regulations require radioactive contamination to be reduced at a reactor to a level that allows NRC to terminate the reactor license and release the property for other use after a reactor shuts down permanently. This cleanup process—known as decommissioning—costs hundreds of millions of dollars per reactor, and NRC is responsible for ensuring that operators provide reasonable assurance that they will have adequate funds to decommission their reactors.[27] Once a spent fuel pool is removed, reactor operators will have limited options for managing spent fuel. For example, if reactor operators need to repackage their spent fuel because a canister has degraded or because other transportation or disposal requirements must be met, they will have to build a new spent fuel pool or some other dry transfer facility, or they will need to ship their spent fuel to another site with a wet or dry transfer facility.

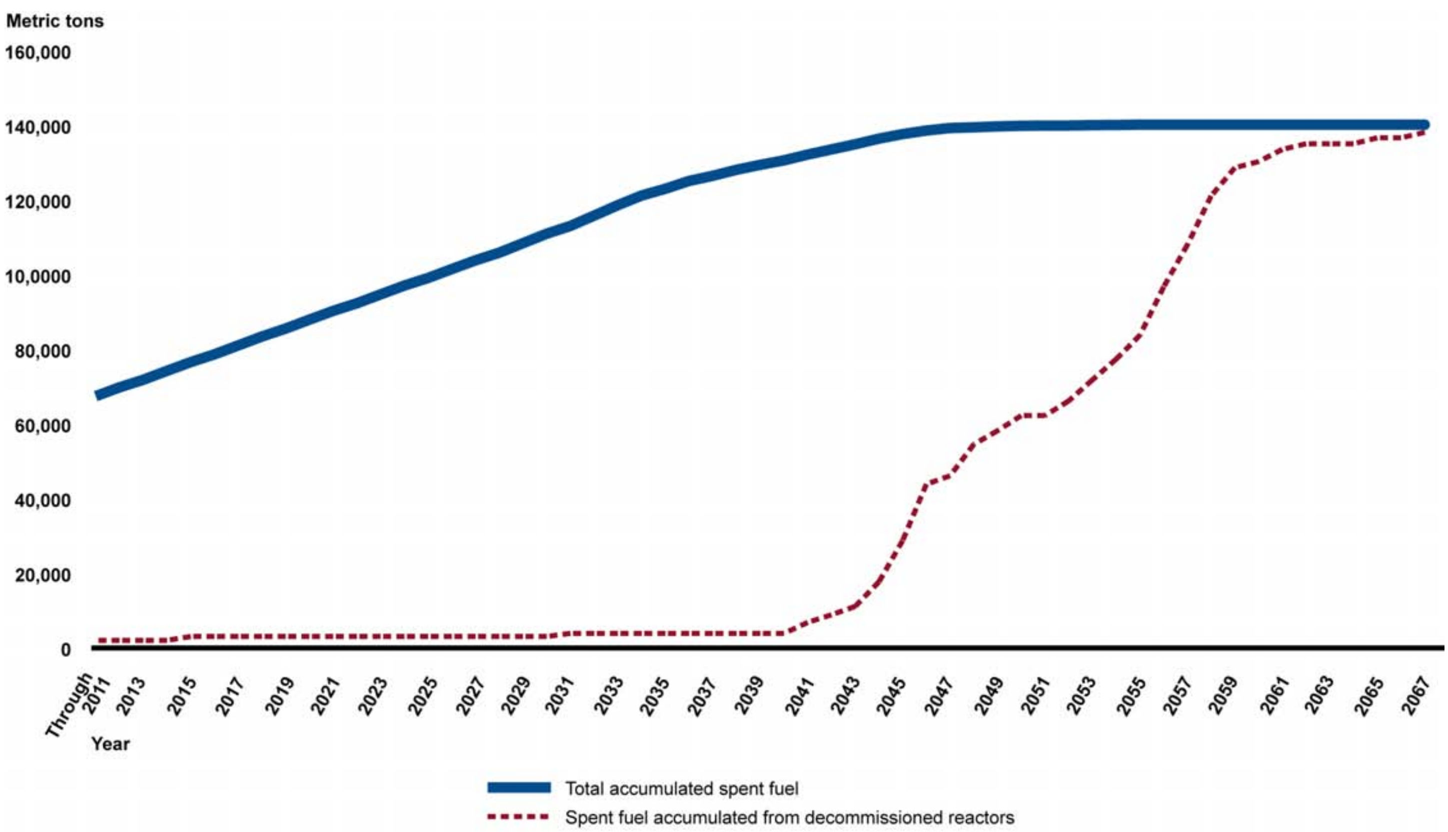
[27]See GAO, *Nuclear Regulation: NRC's Oversight of Nuclear Power Reactors' Decommissioning Funds Could Be Further Strengthened,* GAO-12-258 (Washington, D.C.: Apr. 5, 2012). Decommissioning must generally be completed within 60 years of cessation of reactor operations. Reactor operators may either immediately decontaminate and dismantle their reactor sites or monitor and maintain them as the spent fuel cools and decays over a longer period. In these scenarios, we assumed that operators will immediately decommission their reactors, placing their spent fuel in dry storage and disposing of the rest of their radioactive waste, including the reactor and the spent fuel pool, as either low-level waste or as slightly more radioactive waste called greater-than-class-C waste.

As of January 2012, the United States had nine decommissioned commercial nuclear power plant sites. Seven of these plants have completely removed spent fuel from their pools—a total of 1,748 metric tons—as well as all infrastructure except that needed to safeguard the spent fuel.[28] The other two sites, which have a total of 5,103 metric tons of spent fuel in both wet and dry storage, are in the process of emptying their pools and transferring all their spent fuel to dry storage.

Assuming that no centralized storage or permanent disposal facility becomes available, our analysis indicates that by 2040, the amount of stranded spent fuel in closed commercial nuclear power plants will total an estimated 3,894 metric tons; by 2045, that amount could increase to 28,751 metric tons; and by 2050, the amount could be 62,237 metric tons. By 2067, nearly all of the 140,000 metric tons of spent fuel could be stranded in dry storage. Figure 9 shows the expected pattern of growth for total accumulated spent fuel compared with that of spent fuel from decommissioned reactors, or stranded spent fuel.

[28]These sites include Big Rock Point in Michigan, Haddam Neck in Connecticut, Humboldt Bay and Rancho Seco in California, Maine Yankee in Maine, Trojan in Oregon, and Yankee Rowe in Massachusetts. In addition to these decommissioned sites, an additional spent fuel pool is located in Morris, Illinois. This pool was built and filled with spent fuel in anticipation of reprocessing into usable nuclear fuel, but when reprocessing was suspended, the spent fuel remained in the pool, essentially stranded.

Figure 9: Growth Trend of Total Spent Fuel Compared with Spent Fuel from Decommissioned Reactors



Source: GAO analysis of Nuclear Energy Institute data.

Note: The data assume that additional spent fuel will not be generated by new reactors or extension of reactor licenses beyond 60 years.

The Key Risk of Stored Spent Fuel Is Difficult to Quantify, but Some Mitigating Actions Have Been Taken

According to several studies on spent fuel storage, the key risk of storing spent fuel at reactor sites is radiation exposure from spent fuel that has caught fire when it is stored in a pool, but it is difficult to quantify the probability of such an event. Nuclear reactor operators have put into place several efforts to mitigate the effects of such a fire, although disagreement exists on the mitigation needed. In contrast to pool storage, spent fuel in dry storage is less susceptible to severe radiological releases. Furthermore, NRC has no centralized database to help identify, locate, and access classified studies on spent fuel.

Radiological Release from a Pool Fire Is the Key Risk Posed by Spent Fuel Storage, but Quantifying This Probability Is Difficult

Radiation exposure—from a minor dose resulting from a work-related accident to a severe, widespread release of radiation from a spent fuel fire—is the key concern about the hazard of storing spent nuclear fuel. According to studies we reviewed and NRC officials and representatives of other groups we spoke with, the worst-case scenario for spent fuel at reactor sites is the possibility of a self-sustaining fire in a spent fuel pool, which could engulf all assemblies in the pool, with significant consequences. According to the analysis in a February 2001 NRC study, assuming a high release of radiation, the release of spent fuel fission products resulting from a pool fire could result in nearly 200 early fatalities, thousands of subsequent cancer fatalities, and widespread land contamination. These early fatalities could be reduced or eliminated, according to the study, if the radiation release was less severe and if there were an early evacuation of the affected population. NRC officials told us that the assumptions used in that study were very conservative and that they believed that a lower release of radiation and an early evacuation are more representative of potential scenarios involving operating nuclear power reactors. A 2006 National Academy of Sciences study also found that a spent fuel fire could release large quantities of radioactive materials into the environment and cause widespread contamination.

NRC officials, as well as studies by Sandia National Laboratories (commissioned by NRC) and the National Academy of Sciences (2006), informed us about the conditions that could lead to a fire. Such a fire could occur only if enough water in the spent fuel pool were lost, such as through drainage or boiling away, exposing roughly the top half of the fuel assemblies.[29] Without sufficient water to keep spent fuel covered and cool, it is possible that some of the hotter assemblies—those most recently discharged from a reactor—could ignite. Furthermore, once started, a fire in a spent fuel pool would be very difficult to extinguish because, in such a case, the zirconium alloy making up the metal cladding surrounding the assemblies would react with oxygen and, when

[29]As reported by the Institute of Nuclear Power Operations (*Special Report on the Nuclear Accident at the Fukushima Daiichi Nuclear Power Station*, Atlanta, GA, November 2011), Tokyo Electric Power Company personnel determined that water levels in the spent fuel pool at Fukushima Daiichi did not drop below the top of the fuel. An NRC order noted that during the Fukushima event, there was concern that the spent fuel was overheating, and the concern persisted primarily because of a lack of readily available and reliable information on water levels in spent fuel pools. Nevertheless, the water level at Fukushima did not drop to levels at which a fire could start.

a certain temperature was reached, would begin a chemical reaction that releases energy and raises the temperature. Essentially, the fire becomes hotter and self-sustaining and, depending upon the density of spent fuel in the pool, could spread to other assemblies. On the basis of studies cited by NRC officials and a Sandia National Laboratories study, a fire in a fully drained pool can start at about 1,830 degrees Fahrenheit (about 1,000 degrees Celsius). A zirconium fire does not involve flames; rather, it burns like a welding torch.

A zirconium fire can start only if a complex series of conditions occurs. NRC and other studies indicate that such a fire is not likely. Furthermore, the physical protection features and mitigation measures at nuclear power reactors make the probability of a fire in a spent fuel pool very low. First, there must be an initiating event,[30] such as an earthquake more severe than the pool was designed to withstand, an accidental drop of a cask during dry cask loading operations, or a terrorist attack. Second, the initiating event must result in a critical loss of water, such as through a breach in the pool wall or floor that would allow water to drain out. Third, the reactor operator must be unable to respond adequately to a water loss, such as being unable to replenish lost pool water sufficiently to cool the assemblies.

Whether a self-sustaining fire starts and spreads depends on additional variables, according to Sandia National Laboratories studies commissioned by NRC from 2003 through 2006 to assess the effects of some of these variables for pool fires. Two important variables are:

- *The age and the heat of the spent fuel*. Spent fuel is hottest when first discharged from a reactor but cools relatively quickly. The risk of a zirconium fire is much greater with recently discharged fuel than with older fuel.

- *The size of a hole in the pool and subsequent rate of water drainage*. A Sandia National Laboratories study analyzed the effects of differently sized holes for various fuel assembly configurations, fuel ages, ventilation assumptions, and replacement water scenarios, and this analysis showed that larger holes and drainage rates, all other

[30]In this report, we use the term “event” to generally describe a situation involving an accident or attack on a spent fuel pool. We also use the term “*initiating* event” to specifically describe the first action that takes place to trigger severe damage to a spent fuel pool.

factors being equal, resulted in higher temperatures of the fuel assemblies.

NRC officials told us that, from a regulatory perspective, the risks of an event causing a large release of radiation that endangers public safety from spent fuel in either wet or dry storage are low enough to be within acceptable limits of risk. NRC officials also said the agency considers risk to be the probability of an event occurring multiplied by the consequences of that event and has determined that a spent fuel fire is a low-probability, high-consequence event. In 2001, an NRC study estimated the frequency of having spent fuel pool assemblies uncovered and exposed to the air to be, on average, an event that occurs once every 420,000 years.[31] NRC officials told us the agency did not update its quantitative likelihood estimates after the September 11, 2001, terrorist attacks. Since Fukushima Daiichi, NRC has been engaged in ongoing initiatives related to items such as addressing a loss of off-site electricity and seismic hazard reevaluation. It has been conducting a study on the consequences of accident scenarios affecting spent fuel pools and is undertaking a probabilistic risk assessment to quantify spent fuel risk for a selected reactor site of interest.

Independent studies we reviewed indicate the difficulty of quantifying the level of risk of stored spent fuel. Examples of these studies follow:

- The Institute for Resource and Security Studies, a Massachusetts-based technical and policy research group, reported in 2009 that the methodology needed to estimate the probability of nuclear accidents is complex, requiring consideration of internal and external initiating events, analyses involving uncertainty, peer review, and estimates of radiological consequences.

- The National Academy of Sciences stated in a 2006 study that the probability of a terrorist attack on spent fuel storage cannot be assessed quantitatively or comparatively and that it is not possible to predict the behavior and motivations of terrorists. This study noted, and a National Academy of Sciences official expressed concern, that in the NRC-sponsored studies available when the National Academy

[31]Nuclear Regulatory Commission, *Technical Study of Spent Fuel Pool Accident Risk at Decommissioning Nuclear Power Plants*, NUREG-1738 (Washington, D.C.: February 2001).

of Sciences was performing its work, NRC did not examine some low-probability scenarios that could result in severe consequences and that, although unlikely, should be protected against.

Mitigation Efforts Could Reduce the Likelihood of Severe Consequences, but Disagreement Exists on the Mitigation Needed

Efforts to mitigate safety and security risks could reduce the effects of key factors in the dynamics of a potential fire in a spent fuel pool, according to our analysis of Sandia National Laboratories studies on pool fire scenarios. Still, disagreement exists—largely between community action groups and NRC—as to the appropriate density of assemblies in a spent fuel pool.

Fuel Assembly Configurations and Density in Pools

Storage configurations that disperse the hottest spent fuel assemblies are among the most important mitigation efforts that Sandia National Laboratories has identified. NRC and community action groups differ, however, on the extent to which these efforts should be employed. In 2011, Sandia National Laboratories reported on its study of the safety and security benefits presented by five different fuel configurations in a storage pool. According to this study, it is preferable to employ configurations that place the more recently discharged, hotter assemblies away from each other—the farther the better—and intersperse them with older, cooler assemblies or, preferably, with empty adjacent cells. NRC has provided regulatory guidance to reactor sites to take advantage of these safer configurations.

Representatives from community action groups we interviewed said that even with NRC's mitigation efforts, spent fuel pools remain too densely packed and that the total amount of spent fuel in the pools should be reduced by accelerating the transfer of spent fuel into dry storage. In addition, a 2003 study led by a scholar at a community action group proposed open rack storage for spent fuel pools. Under this proposal, 20 percent of the pool assemblies would be transferred to dry storage, which would then allow an open channel on each side of the pool. This configuration would help promote air convection between the assemblies and, in turn, reduce the probability of an ignition and subsequent spread to other assemblies. The fewer assemblies that catch fire, the smaller the amount of potential radiation that could be released into the atmosphere.[32] Furthermore, in 2006, over 150 community action and environmental groups collaborated to develop a set of principles for safeguarding spent fuel. They advocated spent fuel storage policies, including an open-frame, low-density layout for spent fuel pools and transfer of this fuel to dry storage within 5 years after its removal from a reactor. According to NRC, a state regional organization, and representatives from industry and community action groups, there are trade-offs between the benefits versus the costs and risks of moving spent fuel. Nonetheless, no clear agreement exists—according to Sandia National Laboratories' analysis and input from community action groups—on the extent to which the density of spent fuel in pools should be reduced.

Replacement Water and Sprays

NRC requires nuclear reactor sites to develop and implement strategies to maintain or restore cooling of reactor cores, containment, and cooling capabilities for spent fuel pools under circumstances due to explosions or fire—a requirement that includes providing sufficient, portable, and on-site cooling equipment. A Sandia National Laboratories study determined that when holes in pool structure cause significant water drainage, reactor operators would generally have from a few hours to a few days to replace lost water or cool spent fuel with sprays in an effort to prevent a fire. If no water drained, such as in a loss-of-power event that caused a loss of cooling and allowed the pool water to boil, reactor operators might have days or weeks. NRC officials said that as spent fuel is uncovered, sprays are efficient and effective in cooling fuel assemblies. They also told us that trade-offs exist between installed and portable spray systems. Installed spray systems can be operated remotely but are susceptible to damage during an event. Portable systems provide adequate spray and are stored at least 100 yards away from the pool in secure places, but in case of an event, reactor operators may not always have access to the pool area to use them because of radiation hazard or physical obstruction. According to a member of a community action group we interviewed, replacement water and sprays may be effective in cooling spent fuel, but replacement water may not contain boron, which is needed to absorb neutrons and prevent a critical chain reaction. This member told us that there is no requirement for reactor operators to keep a supply of

[32] NRC issued a 2002 order that, according to NRC officials, accomplished a functionally similar action to the open rack proposal. The order, which took several years to implement, required the reactor operator to establish contiguous open areas in the pool for natural air circulation and active heat removal using sprays, if water were lost.

boron to add to replacement water. According to NRC officials, only operators of pressurized water reactors have the option of adding boron to the water to prevent a critical chain reaction, but operators of these reactors must also show that the assemblies will remain sub-critical without the boron. The NRC officials stated that all reactors are required to have a 5-percent margin of safety to prevent a critical chain reaction. In addition to boron in the water, prevention of a critical chain reaction can also be achieved by boron in plates in the racks, spacing among the assemblies, and other storage configurations.

After the Fukushima Daiichi nuclear power reactor accident, NRC in March 2012 supplemented existing requirements by issuing an order instructing nuclear power operators to install monitoring equipment to remotely measure a wider range of water levels in spent fuel pools. NRC issued a second order, also in March 2012, that required reactor operators to ensure the effectiveness of water mitigation measures. It is more difficult to provide sprays and replacement water to boiling water reactor pools because they are typically several stories above ground and located close to the reactor,[33] whereas spent fuel pools for pressurized water reactors are at ground level or partially embedded in the ground. At Fukushima Daiichi, cooling flow to the spent fuel pool was lost during the loss of off-site power and was not immediately restored with the use of emergency diesel generators. Emergency operators did not have remote monitoring equipment to determine whether pool water levels had dropped enough to expose the spent fuel. Subsequent inspections, however, determined that water levels did not drop below the top of the fuel assemblies in the pool.

Ventilation

As we stated in our 2003 report, air ventilation can mitigate the likelihood of a pool fire in the event of water drainage. Logically, this mitigation potential depends upon where the ventilation occurs and how much ventilation can be created. A Sandia National Laboratories study found that space between assemblies and the pool wall can help promote ventilation, as can doors and vents in the room where the pool is located. Space under the assemblies can be created at the foot of racks supporting fuel assemblies, which allows circulating air to flow up between the assemblies and carry heat away with it in the event of

[33] Mark I and Mark II boiling water reactors are elevated, but Mark III reactors are not, because of a different design.

complete drainage of water from the pool. However, according to a study led by a scholar at a community action group, with assemblies packed in dense configurations in racks at most nuclear reactor pools and boron plates lining the racks of assemblies, ventilation may be reduced.

Spent Fuel in Dry Storage Is Less Susceptible to a Significant Radiological Release Than Is Spent Fuel Stored in Pools

Spent nuclear fuel in dry storage is less susceptible to a radiological release of the magnitude of a zirconium fire in a spent fuel pool, according to documents we reviewed and interviews we conducted with officials from NRC, the National Academy of Sciences, and the Nuclear Waste Technical Review Board; officials from industry; and representatives of community action groups. Such a release is less likely for the following reasons:

- Spent fuel cools rapidly, and spent fuel in dry storage—typically at least 5 years old—has cooled sufficiently so that ignition is less likely. In addition, passive air cooling in dry cask storage systems is not affected by the loss of off-site power, and active monitoring—other than ensuring that air vents are not clogged—is not necessary to prevent overheating and possible ignition.

- The amount of radioactive material in a dry storage canister is a fraction of the amount of radiation in a spent fuel pool. According to the National Academy of Sciences' 2006 study, each dry storage canister contains 32 to 68 fuel assemblies—whereas thousands of assemblies are typically stored in pools—and therefore each canister has less radioactive material that can be released than the radiation from a pool. Logically, breaching dozens of spent fuel canisters simultaneously could result in more severe consequences than a single breached canister, but breaching dozens of canisters simultaneously is difficult.

- To trigger any severe off-site radiological release from spent fuel stored in a canister, the fuel would have to undergo aerosolization, which would entail breaching the outer and inner shielding units. Furthermore, any holes would have to be sufficiently large enough to allow release of the aerosolized spent fuel. It would be difficult to aerosolize radioactive material in dry storage and difficult to have some mechanism to transport the radioactive material away from the reactor site. Such mechanisms would require energy, such as a fire.

- Dry storage is not as susceptible to the buildup of hydrogen as are spent fuel pools. If an accident or attack involving a spent fuel pool causes a loss of water, the fuel assemblies can heat up and produce steam. This steam can react with the hot zirconium cladding surrounding the fuel assemblies, producing hydrogen that, when mixed with oxygen, could cause an explosion and structural damage to the reactor building.

As we reported in our 2003 study, NRC had concluded before September 11, 2001, that spent fuel in dry cask storage systems was considered safe and secure.[34] A Sandia National Laboratories study conducted from 2003 through 2005, supplemented by NRC analyses, evaluated several representative types of dry cask storage designs against airplane and ground attacks to determine if any other security measures were needed, in addition to those already issued by order. This work did not find that any further mitigating or security procedures were needed for nearly all the scenarios, but it did identify some potential scenarios in which some radiation could be released.

This study helped inform NRC's technical evaluation—first discussed internally at NRC in 2007, according to NRC officials, and published for solicitation of public comments in 2009.[35] This evaluation included a proposal to establish a security-based dose limit that would require owners of spent fuel in dry storage systems to develop site security strategies to protect against a potential radiological release that exceeds NRC's acceptable dose limits at a site boundary. NRC issued this evaluation for public comment for a proposed rule to revise security requirements for storing spent fuel away from a reactor. During the public comment period, NRC received general comments showing a preference for guarding against a specific threat rather than the dose-based approach proposed in the technical evaluation. For example, under the dose-based approach, some owners told NRC that they might have to increase their security forces to prevent potential radiological releases, and they raised concerns about the cost of such efforts compared with the benefit. As a result, according to NRC officials, the agency has delayed the proposed rule in order to gather more information regarding the public comments. NRC officials told us the agency plans to

[34]GAO, *Spent Nuclear Fuel: Options Exist to Further Enhance Security*, GAO-03-426 (Washington, D.C.: Jul. 15, 2003).

[35]*See* Draft Technical Basis for Rulemaking Revising Security Requirements for Facilities Storing SNF and HLW; Notice of Availability and Solicitation of Public Comments, 74 Fed. Reg. 66589 (Dec. 16, 2009).

commission additional studies to help assess the situation and determine the appropriate security strategy.

NRC Has No Centralized Mechanism to Help Identify, Locate, and Access Classified Studies on Spent Fuel

In conducting our work, we found that NRC does not have a mechanism to ensure that it can easily identify and locate all classified studies conducted over the years. When we requested classified and other studies from NRC officials, it was difficult for them to provide us with the information we requested in a timely manner. Specifically, nearly 5 months elapsed from our initial request for classified studies of wet storage until NRC provided these documents. A National Academy of Sciences official told us that the academy had also experienced difficulty in obtaining some of NRC's classified studies while performing its 2004 study.[36] To identify studies, we interviewed numerous NRC and other officials and identified studies through references in other studies we reviewed. NRC officials said the classified studies are stored in the safes of NRC officials. We also contacted officials from Sandia National Laboratories and requested a list of all their studies on spent fuel safety and security. NRC officials told us that developing and maintaining a classified database covering the most important topics involving spent fuel, as designated by agency management, would not be burdensome.

Managing spent fuel until permanently disposed of may take many decades, and NRC and DOE managers and staff and operators with appropriate clearances may need to review an extensive number of classified studies conducted for NRC on the safety and security of spent fuel. Several studies conducted after September 11, 2001, by NRC and other groups referred to NRC studies conducted before that date—some conducted as early as 1979. We also found decades-old NRC studies to still be useful in our review. The nature and characteristics of spent fuel discharged from a reactor likely will not change, and therefore the underlying principles and knowledge of spent fuel safety and security are likely to remain applicable and informative to future scientists and others. Although preserving key scientific and technical studies is important, preservation of information alone is not enough if others may not be aware of a study's existence or location. Scientists and others rely on mechanisms that allow them to easily identify, locate, and access

[36] The 2004 National Academy of Sciences study is the classified version of its 2006 study, which is unclassified.

pertinent information, as well as to prevent unnecessary duplication of research.

Transfer of Spent Fuel from Wet Storage Offers Benefits but Also Presents Challenges

Transferring spent fuel from wet to dry storage is generally safe and offers several key benefits, but any movement of spent fuel entails some level of risk. Accelerating the transfer of spent fuel from wet to dry storage to reduce the inventory of spent fuel in a pool could increase those risks. Additional operational and other challenges to accelerating the transfer of spent fuel to dry storage may limit the degree of acceleration that may ultimately be achieved. Once spent fuel is in dry storage, additional challenges may arise, such as costs for repackaging should it be needed.

Transferring Spent Fuel from Wet to Dry Storage Offers Benefits

The transfer of spent fuel from wet to dry storage and long-term storage at reactor sites, although not originally part of the plan for managing spent fuel, has offered some benefits, according to our analysis of documents and interviews with NRC officials, representatives from industry, and community action and environmental groups. For example, without a permanent means of disposing of spent nuclear fuel for at least several decades, the transfer of spent fuel from pools to dry storage has provided the nation with time to develop a more permanent solution. We previously reported—on the basis of input from experts—that dry storage is considered safe for at least 100 years and is easily retrievable.[37] Moreover, because most spent fuel pools are nearly at capacity, reactor operators must transfer as much spent fuel to dry storage as is discharged from the reactor. According to our analysis of input from these officials and representatives, accelerating the transfer of spent fuel from wet to dry storage may offer the following additional benefits:

- *Reducing the potential consequences of pool fires*. An accelerated transfer of spent fuel to dry storage may return the pools to a low-density, open-frame configuration that could reduce potential consequences should an unintended release of radiation occur from a pool fire. Accelerated transfer has been advocated by more than 150 community action and environmental groups.

[37] GAO-10-48.

- *Potentially increasing the volume of transportation-ready spent fuel.* Accelerating the transfer of spent fuel to dry storage could increase the volume of readily transportable spent fuel for ease of removal to an off-site facility for storage, reprocessing, or disposal, with the caveat that reactor operators take steps to ensure that canisters and their contents meet transportation requirements.

In addition, we note that once a reactor is decommissioned, spent fuel is less expensive to safeguard in dry storage than in wet storage. Specifically, we previously reported that the cost of operating a spent fuel pool at a decommissioned reactor could range from about $8 million to nearly $13 million a year but that the cost of operating a dry storage facility might amount to about $3 million to nearly $7 million per year.[38] Nine reactor sites nationwide are currently shut down and partly decommissioned and have already transferred all their spent fuel to dry storage or are in the process of doing so, with plans to remove their spent fuel pools. A tenth site never had an operating reactor but was built as an interim storage pool in anticipation of reprocessing.[39] The operators of this site have not announced any plans to transfer spent fuel to dry storage.

Accelerating Transfer of Spent Fuel from Wet to Dry Storage Presents Challenges and Some Risk

Accelerating the transfer of spent fuel from wet to dry storage entails some operational challenges, and some industry representatives told us that they have questioned whether the cost of overcoming these challenges is worth the benefit, particularly considering the low probability of a catastrophic release of radiation. Furthermore, in a 2003 response to a recommendation by the Institute of Policy Analysis to accelerate the transfer of spent fuel from wet to dry storage to reduce the likelihood and potential consequences of a pool fire, NRC reported that accelerating the transfer of spent fuel is not justified, particularly given the billions of dollars it will cost, with no appreciable increase in safety. In commenting on a draft of this report, NRC reiterated this position, stating that it does not require the accelerated transfer of spent fuel to dry storage, particularly considering the small increase in safety that could be

[38]In constant 2012 dollars. GAO-10-48.

[39]General Electric originally built the pool to store spent fuel intended for reprocessing, but when reprocessing was suspended in the United States—and never resumed—the spent fuel became stranded. In 2007, General Electric transferred ownership of the spent fuel pool to GE-Hitachi Nuclear Energy Americas LLC.

achieved, because it considers both wet and dry storage to be safe under current regulations.

The studies that NRC provided to us on the safety and security of spent fuel did not include any comprehensive analysis of the advantages and disadvantages of accelerating the transfer of spent fuel from wet to dry storage. However, NRC officials stated that the commission is currently evaluating accelerated transfer of spent fuel to dry storage as part of a larger review of lessons learned from the Fukushima event. The officials stated that the evaluation will allow NRC to determine whether regulatory action is needed to require accelerated transfer of spent fuel. NRC officials have stated that they believe they can complete their planned evaluation within about 5 years. Some of the challenges from accelerating the transfer of spent fuel include the following:

- *Increasing the need for skilled workers and potential radiation doses to those workers*. Workers at reactors face radiation exposure during routine transfer of spent fuel from wet to dry storage, particularly during loading operations, but this risk could increase if transfer were accelerated, according to a 2010 analysis by EPRI. The institute estimated worker exposure rates, assuming transfer of spent fuel in generic reactors both at the rate of current practice and at an accelerated rate. At the rate of current practice, EPRI reported, workers would collectively receive a dose of 15,836 rem over a nearly 90-year period associated with transferring the expected inventory of about 140,000 metric tons from wet to dry storage,[40] performing annual maintenance and inspection of the dry storage systems, and constructing additional dry storage systems if additional dry storage capacity is needed. Assuming an accelerated rate of transfer after 5 years of cooling, EPRI calculated that worker dose would increase by 507 rem, or 3 percent, as a result of the transfer, maintenance and inspection, and construction duties performed over the same 90-year period. Assuming worker exposure rates would remain roughly the

[40]The rem (roentgen equivalent man) is a unit that measures absorbed dose of radiation to a human and helps estimate the effects of a given absorbed dose on a human body. To determine this radiation dosage, an equation is used that multiplies the absorbed dose by a qualifying factor, which is based on factors such as the rate of exposure and the type of radiation. For instance, the annual effective dose to the general population in the United States is about 620 millirem, about half of which comes from natural sources, such as radon, a naturally occurring radioactive gas produced from the natural radioactive decay of uranium, that is found in rocks and soil. The remainder comes from medical, commercial, and industrial activities, such as dental X-rays.

same, the additional 507 rem under an accelerated transfer scenario would represent the equivalent of an estimated 1,500 workers.[41] Furthermore, EPRI has reported that industry is moving to high-burn-up fuel for greater efficiency. But this high-burn-up fuel is hotter and more radioactive than conventional fuel and requires cooling for about 7 years before it can be safely transferred to dry storage. If transfer is accelerated, this high-burn-up fuel could potentially increase worker dose.

- *Increasing the potential for accidents*. Accelerating the transfer process would result in more movements of equipment and, therefore, potentially more accidents. Additionally, an industry representative said that workers might have to be rotated to reduce worker exposure to radiation, increasing the number of workers moving spent fuel, including those with less experience. Under normal conditions, operators risk accidents every time spent fuel is moved. NRC has not reported any accidents with severe consequences during efforts to transfer spent nuclear fuel from wet to dry storage, but human and mechanical errors sometimes occur. For example, from 1969 to 2002, NRC reported 57 events involving load drops at reactor sites.[42] According to the Nuclear Energy Institute, none of these events involved a spent fuel cask or canister, but in 25 instances, one or more fuel assemblies were dropped. Accidents are of concern because, for example, if a cask is dropped, it can damage other

[41]GAO performed this analysis using EPRI's data to provide a basis for comparing current worker exposure rates with future exposure rates, assuming an accelerated transfer rate. Actual worker exposure rates can be higher or lower depending on work performed. For example, EPRI assumes a worker dose of 400 millirem during a typical loading campaign, but it is possible that as high-burn-up spent fuel is transferred to dry storage, worker dose may be higher. Specifically, EPRI estimated that worker dose would rise by 284 rem for transferring spent fuel to dry storage, a 7.5 percent increase representing an estimated increase of 710 workers; a 102 rem increase for performing annual maintenance and inspection duties, a 1 percent increase representing an estimated increase of 63 workers; and a 121 rem increase for duties associated with constructing additional dry storage systems and moving additional loaded dry storage casks to the storage pad, a 7.6 percent increase representing an estimated increase of 712 workers. In addition, NRC limits annual radiation exposure for workers. The limits vary depending on the affected part of the body, but the total annual effective dose equivalent is 5 rem. 10 C.F.R. § 20.1201(a)(1) (2012).

[42]NRC, *A Survey of Crane Operating Experience at U.S. Nuclear Power Plants from 1968 through 2002*, NUREG-1774 (Washington, D.C.: July 2003).

assemblies or the pool liner, potentially leading to water drainage.[43] A single fuel assembly from a boiling water reactor weighs about 700 pounds, and a single fuel assembly from a pressurized water reactor weighs about 1,500 pounds; dry storage casks, once fully loaded, can weigh from 100 to 180 tons or more. NRC has provided guidance to industry to take steps to minimize damage from such a drop, such as using overhead cranes with special added safety features so that a single failure will not result in dropping a damaging load or developing handling routes designed to avoid lifting heavy loads over vulnerable equipment.[44,45]

- *Working within time constraints*. Timing preferences and operational limitations could constrain how much spent fuel is transferred in a given year and may present an obstacle to accelerated transfer from wet to dry storage. Industry representatives told us that under current practice, reactor operators prefer to transfer spent fuel to dry storage during periods of time that do not interfere with refueling, receiving new fuel, required inspections, and maintenance or other activities vital to plant operations. These activities typically consume about 8 to 9 months of each year's calendar. A routine dry storage loading operation may take 2 months or more, according to industry representatives. For example, one industry representative told us that it can take about 2 weeks to mobilize workers and equipment before the operation and about 2 more weeks to demobilize after the operation. Additionally, according to industry representatives at one operating reactor site we visited, each canister takes about 1 week to load, dry, seal, and move to a storage pad, which limits the number of canisters that can be loaded in a given year. In addition, spatial limitations—such as space for drying or welding lids onto multiple canisters, limited heavy lifting capabilities, and lack of free space in spent fuel pools to accommodate more than one cask at a time—may make simultaneous loading of canisters difficult. Some industry representatives we spoke with told us that there are limits on how much acceleration can be achieved in a single year.

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[43]NRC, *Technical Study of Spent Fuel Pool Accident Risk at Decommissioning Nuclear Power Plants*, NUREG-1738 (Washington, D.C: February 2001).

[44]NRC, *Single-Failure-Proof Cranes for Nuclear Power Plants,* NUREG-0554 (Washington, D.C.: May 1979).

[45]NRC, *Control of Heavy Loads at Nuclear Power Plants: Resolution of Generic Technical Activity A-36,* NUREG-0612 (Washington, D.C.: July 1980).

- *Increasing costs.* The transfer of spent fuel from wet to dry storage is costly in several ways. We estimated in a November 2009 report that the transfer cost for about five canisters is about $5.1 million to $8.8 million.[46] One industry representative told us that if the transfer of spent fuel to dry storage were accelerated, the associated high up-front costs could strain some nuclear power plants' budgets. These up-front costs, which would be incurred over a longer period without acceleration, include the construction of a storage pad with accompanying safety and security features, which, we reported, could cost about $19 million to $44 million.[47] These costs are initially borne by ratepayers or plant owners but may be passed on to taxpayers as a result of industry lawsuits against DOE for failure to take custody of the spent fuel. Moreover, EPRI reported that as older, cooler spent fuel is loaded into canisters, reactor operators eventually will be left with younger, hotter spent fuel to transfer from wet to dry storage. Spent fuel stored in canisters generally should not exceed about 752 degrees Fahrenheit (400 degrees Celsius), and, as we reported earlier, spent fuel being discharged from reactors today may have to cool at least 7 years before it can be placed in dry storage. Given the heat load requirements for storing spent fuel, EPRI noted that it may not be possible to fill some canisters to capacity. Specifically, a canister with a capacity for 60 boiling water reactor assemblies that would store 60 older, cooler assemblies may be able to contain only 38 younger, hotter assemblies.

Managing Spent Fuel after Transfer from Wet to Dry Storage at Reactor Sites Presents Additional Challenges

Reactor operators had never intended to leave spent fuel on their sites for extended periods, but even if the United States began to develop an off-site centralized storage or disposal facility today, spent fuel—which has already been stored on-site for several decades—would be stored on-site for several decades more. As a result, the following challenges could affect decisions on managing spent fuel.

Repackaging stranded spent fuel. Once reactors are decommissioned, reactor operators have limited options for managing the stored spent fuel.

[46] In constant 2012 dollars. GAO-10-48.

[47] In constant 2012 dollars. These costs are not intended to be all-inclusive and represent a generic case for comparative purposes. A storage pad could be used to store multiple vertical or horizontal dry storage systems. For example, at Haddam Neck in Connecticut, 43 vertical casks are stored on a single pad. GAO-10-48.

Specifically, once they package the spent fuel in canisters and dry casks, they are unlikely to have any means of repackaging if the canisters degrade over the long term, or if the operators have to meet different storage or disposal requirements. As we previously reported, experts told us that canisters are likely safe for at least 100 years, but by then the spent fuel may have to be repackaged because of degradation.[48] By the time such repackaging might be needed, reactor operators may no longer have pools or the necessary infrastructure to undertake the repackaging, as was the case at the Haddam Neck site we visited. Specifically, the Haddam Neck site had already decommissioned the reactor, transferred all its spent fuel from wet to dry storage, and dismantled its spent fuel pool. If the spent fuel at the site needed to be repackaged, a special transfer facility would need to be built, or the spent fuel would need to be shipped to a site that had a transfer facility. In addition, to reduce costs, reactor operators are selecting a variety of dry storage systems that maximize storage capacity. These varied systems do not raise safety issues, but they may complicate a transfer to a centralized storage facility or a permanent disposal facility because different systems require different handling requirements, such as the type of grappling hook and the size of the transport cask required. These differences may present more complex engineering challenges and cost issues as time passes, and the volume of spent fuel in various systems increases. In addition, over time, it is possible that handling equipment would not be maintained and personnel would not continue to be trained. Maximizing storage capacity may raise additional engineering challenges and cost issues, particularly since larger canisters may meet storage requirements but not transportation requirements. The Nuclear Energy Institute has reported that of all the spent fuel currently in dry storage, only about 30 percent is directly transportable. It also reported that the remaining spent fuel could need as much as 10 more years of cooling to meet NRC's transportation heat-load requirements to ensure that assemblies can withstand the force of a potential accident.

Reducing community opposition. As reactors begin to be closed down and decommissioned, reactor operators will leave spent fuel on sites that will serve no other purpose than storing that fuel. Continued on-site storage would likely face increasing community opposition, which could make it difficult for operators to obtain NRC recertification for storage

[48] GAO-10-48.

sites at reactors, approval for licenses to extend the operating life of other reactors, or licenses for new reactors. According to officials from a state regional organization we spoke with, the longer the federal government defers a permanent disposition pathway for spent fuel, the less likely the public would be to accept interim solutions, for fear such solutions would become de facto permanent solutions. Also, in our prior work, experts noted that many commercial reactor sites are not suitable for long-term storage and that none have had an environmental review to assess the impacts of storing spent fuel beyond the period for which the sites are currently licensed.[49] As discussed above, in June 2012, a federal appellate court remanded NRC's waste confidence determination and rule for the preparation of an environmental impact statement or finding of no significant environmental impact.

Managing costs. Continued storage of spent fuel may be costly. Because owners of spent fuel would have to safeguard it beyond the life of currently operating reactors, decommissioned reactor sites would not be available to local communities and states for alternative development. The Blue Ribbon Commission recommended that the nation open one or more centralized storage facilities and put a high priority on transferring the so-called stranded spent fuel to free decommissioned reactor sites for other uses. We previously reported the cost of developing two federal centralized storage facilities to be about $16 billion to $30 billion, although this estimate does not include final disposal costs, which could cost tens of billions of dollars more.[50] In addition, we also previously reported that if spent fuel needs to be repackaged because of degradation, repackaging could cost from $180 million to nearly $500 million,[51] with costs

[49]GAO-10-48.

[50]In constant 2012 dollars. Centralized storage poses additional challenges as well. Provisions in the Nuclear Waste Policy Act of 1982, as amended, that allowed DOE to arrange for centralized storage have either expired or are unusable because they were tied to milestones in repository development that have not been met. DOE acknowledged that it might have authority to arrange for centralized storage of spent fuel through the Atomic Energy Act of 1954, as amended, but only under certain circumstances, such as emergencies involving spent fuel that threaten public health. Transportation risks, too, are associated with centralized storage, since the spent fuel would have to be transported twice, once to the interim storage site and once to a disposal site.

[51]In constant 2012 dollars.

depending on the number of canisters to be repackaged and whether a site has a transfer facility, such as a storage pool.[52]

Planning transportation to an off-site facility. The transportation of large amounts of spent fuel is inherently complex and may take decades to accomplish, depending on a number of variables including distance, quantity of material, mode of transport, rate of shipment, level of security, and coordination with state and local authorities. For example, according to officials from a state regional organization we talked to and the Blue Ribbon Commission report, transportation planning could take about 10 years, in part because routes have to be agreed upon, first responders have to be trained, and critical elements of infrastructure and equipment need to be designed and deployed. In addition, according to the Nuclear Energy Institute, some spent fuel in canisters that serve a dual purpose—both storage and transportation—might not be readily transportable because NRC's transportation requirements for heat and radioactivity may require additional time for cooling and decay. To transport spent fuel before it is sufficiently cooled, reactor operators might have to repackage it or place it in more robust transportation casks. Uncertainties also surround the transportation of high-burn-up fuel. The Blue Ribbon Commission noted that NRC has not yet certified a shipping cask for the transport of high-burn-up fuels,[53] which are now commonly being discharged from reactors. Spent fuel that has been stored for extended periods may become degraded and require additional handling before it can be transported. NRC has reported that the zirconium cladding of high-burn-up fuel is known to become more brittle after long cooling periods. Once sealed in a canister, the spent fuel cannot easily be inspected for degradation. If the cladding degrades, there is no assurance the spent fuel would remain in a safe configuration, potentially leading to a nuclear reaction if conditions were right. NRC officials told us that if they determined that a safe geometry could not be maintained during transportation because of cladding degradation, they would require the owner of the spent fuel to demonstrate that an uncontrolled critical chain reaction would not occur and would not issue an approval for transportation until they could assure a safe geometric configuration. In addition, NRC expressed concerns about the safe handling of spent fuel

[52]GAO-11-229.

[53]A license is required for delivery of licensed material to a carrier for transport or for the transport of licensed material. 10 C.F.R. § 71.3 (2012).

after transportation because of uncertainties over the condition of large amounts of high-burn-up fuel that might have to be repackaged for disposal. As a result, NRC stated that until further guidance is developed, the transportation of high-burn-up fuel will be handled on a case-by-case basis using the criteria given in current regulations.[54] Without a standardized cask design for storage, transportation, and disposal, it may be difficult to design the type of large-scale transportation program needed to transfer high-burn-up fuel away from reactor sites.

Maintaining security over the long term. Future security requirements for the extended storage of spent fuel are uncertain and could pose additional challenges. Specifically, before the September 11, 2001, terrorist attacks, spent nuclear fuel was largely considered to be self-protecting for several decades because its very high radiation would prevent a person from handling the material without incurring health or life-threatening injury in a very short time, although incapacitating health impacts may sometimes not occur for up to 16 hours.[55] In addition, as spent fuel decays over time, it produces less decay heat. A spent fuel assembly can lose nearly 80 percent of its heat 5 years after it has been removed from a reactor and 95 percent of its heat after 100 years. Given the willingness of terrorists in recent years to sacrifice their lives as part of an attack, the national and international communities have begun to rethink just how long spent fuel really might be self-protecting. As spent fuel ages and becomes less self-protecting, additional security precautions may be required.

Continuing taxpayer liabilities. The continued on-site storage of spent fuel will not alleviate industry's lawsuits against DOE for failure to take custody of the spent fuel in 1998 as required by contracts authorized under the Nuclear Waste Policy Act of 1982, as amended. DOE estimates that the federal government's liabilities resulting from the lawsuits will be about $21 billion through 2020 and about $500 million each year after that. These costs are paid for by the taxpayer through the Department of the Treasury's Judgment Fund.

[54]These regulations include 10 C.F.R. §§ 71.55, .43(f), and .51.

[55]The International Atomic Energy Agency, DOE, and NRC have considered spent fuel to be self-protecting with a radiation level exceeding 100 rad—or, radiation absorbed dose, a unit of measurement—per hour at 1 meter unshielded. After short-term exposure to 250 to 500 rad, about 50 percent of the people coming in contact with the spent fuel would be expected to die within 60 days.

Conclusions

The decades-old problem of where to permanently store commercial spent nuclear fuel remains unsolved even as the quantities of spent fuel—in either wet or dry storage—continue to accumulate at reactor sites across the country. It is not yet clear where a repository will be sited, but it is clear that it may take decades more to site, license, construct, and ultimately open a disposal site. In the interim, some scientists, environmentalists, community groups, and others have expressed growing concerns about the spent nuclear fuel that is densely packed in spent fuel pools, especially after the water in the pools at the Fukushima Daiichi nuclear power plant complex in Japan were at risk of being depleted, increasing the risk of widespread radioactive contamination. The chances of a radiation release are extremely low in either wet or dry storage, but the event with the most serious consequences—a self-sustaining fire in a spent fuel pool—could result in widespread radioactive contamination. NRC has studied the likelihood of such an event and has taken a number of steps to prevent a fire, including a number of mitigating measures, though some community action groups have raised questions if those steps are enough, given the severity of consequences.

Moreover, because storage or disposal facilities may take decades to develop, in managing spent fuel, NRC and DOE officials and others with appropriate clearances and a need to know may need to review classified studies conducted by and for NRC on the safety and security of spent fuel. These studies are likely to be relevant for decades and, therefore, continue to contribute to institutional knowledge and the ultimate decisions made concerning the handling and storage of spent nuclear fuel. Nevertheless, NRC does not have a mechanism that allows for easy identification and location of classified studies conducted over the years. Without such a mechanism, it may be difficult and time-consuming to access the necessary studies.

Recommendation for Executive Action

To help facilitate decisions on storing and disposing of spent nuclear fuel over the coming decades, we recommend that the Chairman of the Nuclear Regulatory Commission direct agency staff to develop a mechanism that allows individuals with appropriate clearances and the need to know to easily identify and access classified studies so as to help ensure that institutional knowledge is not lost.

Agency Comments

We provided NRC with a draft of this report for review and comment. In written comments, which are reproduced in appendix IV, NRC generally agreed with the findings and the recommendation in our report. NRC did note, however, that our characterization of NRC's position to not require accelerated transfer of spent fuel to dry storage was factually incorrect. Specifically, NRC stated that we characterized its position on accelerated transfer as being solely a cost-benefit decision. NRC stated that it does not require accelerated transfer because it considers both wet and dry storage to provide a safe means of storing spent fuel that is in full conformance with agency regulations. We clarified the report language to more clearly state NRC's position. Regarding the recommendation, NRC stated that it planned to review its internal procedures to determine if any measures need to be taken to ensure the classified information is readily available to future decision makers. NRC also provided technical comments, which we have incorporated as appropriate.

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 Nuclear Regulatory Commission, the Secretary of Energy, appropriate congressional committees, and other interested parties. In addition, the report will be available at no charge on the GAO website at http://www.gao.gov.

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

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Appendix I: Scope and Methodology

To determine the amount of spent fuel projected to accumulate before it can be moved from individual reactor sites, we obtained data from the Nuclear Energy Institute, an industry advocacy organization, on current inventories of commercial spent nuclear fuel in wet and dry storage and a database on year-to-year projections of on-site spent fuel accumulation in wet and dry storage. We developed the projections of this amount on the basis of several assumptions, including that all 104 reactors would renew their licenses for 20 years, with the early shutdown of Oyster Creek, in New Jersey, 10 years before its license expires; that no new reactors are brought online; that the nation's current reactors continue to produce spent fuel at the same rate; and that all spent fuel remaining in wet storage would be moved to dry storage 12 years after a reactor's final shutdown. As part of our analysis, we obtained information in reports and from interviews from the Nuclear Regulatory Commission (NRC); the Department of Energy (DOE); the Electric Power Research Institute, a nonprofit research entity; and representatives from industry, academia, and community action and environmental groups. To assess the reliability of existing data, we reviewed available documentation and conducted interviews with individuals knowledgeable about the data. On the basis of this information, we found these data to be sufficiently reliable for the purposes of our report.

To determine the most likely options for moving spent fuel off-site, we used prior work that had analyzed the Yucca Mountain program and its most likely alternatives to help us assess three scenarios: (1) Yucca Mountain, (2) two federally funded central storage facilities, and (3) a new permanent disposal facility.[1] We used assumptions from our prior work, including updating dates from our assumptions, and we supplemented these assumptions by reviewing documents and interviewing officials from federal and state regional organizations and representatives from industry, independent groups, and community action and environmental groups. Specifically, for the Yucca Mountain option, we asked DOE how long it would take for a repository at Yucca Mountain to open if licensing were to resume in 2012, assuming the license and funding were both approved. DOE told us that the best way to develop a new estimate would be to take the estimates that existed before the program was shut down and add the time elapsed between when DOE stopped work on licensing and when it may resume licensing, which is 10 years. We previously reported, however,

[1] GAO-10-48.

that DOE's original estimate for licensing was likely too optimistic. Furthermore, because all of DOE's former Yucca Mountain program staff have been assigned to other offices, left the agency, or retired, some delays are likely in reassembling a licensing team—as much as 2 years, according to one former DOE official familiar with the Yucca Mountain program.[2] Given these challenges, we added 5 additional years to DOE's original 10-year estimate of completing Yucca Mountain. If licensing for the Yucca Mountain program were to resume in 2012, the earliest possible opening date is roughly 2027. For the two federal centralized storage facilities, we updated dates we developed for a prior report, in which we projected when the centralized storage facilities might be built, which was 19 years.[3] Since these are rough estimates, we rounded the time frame to 20 years, meaning that if the process were started in 2012, the earliest that two federal centralized storage sites could open would be 2032. For a new repository, we analyzed DOE's actual and projected time frames for licensing and opening the Yucca Mountain repository and DOE's report to Congress on the time frames necessary to open a second repository. We also analyzed the time frames necessary to open the nation's only high-level radioactive disposal facility, the Waste Isolation Pilot Plant in New Mexico. On the basis of our analysis, we determined that if a process were started in 2012 to open a new repository, it could open in about 40 years, or 2052.

To determine key safety and security risks of spent fuel, as well as potential mitigation actions, we reviewed NRC-commissioned studies performed by Sandia National Laboratories and studies by NRC, the National Academy of Sciences, community action groups, and industry. Our primary period of focus was post-September 11, 2001, which included studies from 2002 to 2009, but we also reviewed pre-September 11, 2001, studies dating back to 1979. We identified relevant studies for review by asking officials from NRC, DOE, and Sandia National Laboratories, as well as knowledgeable persons whom we interviewed, and by reviewing the citations in these studies to identify still other relevant studies. We reviewed studies of spent fuel pools and dry casks at the classified, NRC safeguards, official use only, and unclassified levels. In addition, we toured the Haddam Neck decommissioned reactor site and the Millstone reactor in Connecticut, the Hope Creek and Salem

[2] GAO-10-48 and GAO-11-229.

[3] GAO-10-48.

reactors in New Jersey, and the Susquehanna reactor in Pennsylvania, and we spoke with NRC officials and industry representatives about wet and dry spent fuel storage issues, including potential mitigation actions, at these sites. Our site visits included decommissioned and operating reactor sites, sites with both pressurized water reactors and boiling water reactors, sites having both wet and dry storage, and sites using both vertical and horizontal dry storage systems. We also reviewed NRC requirements addressing the safety and security of spent fuel, as well as directives from the nuclear power industry.

To determine the benefits and challenges of transferring spent fuel from wet to dry storage, including transferring this fuel at an accelerated rate, we reviewed prior GAO reports and documents from NRC, DOE, the Nuclear Waste Technical Review Board, the National Academy of Sciences, the Blue Ribbon Commission on America's Nuclear Future, academia, industry, and community action and environmental groups. We also interviewed officials from NRC, DOE, and state regional organizations, and representatives of industry, academia, the Blue Ribbon Commission on America's Nuclear Future, and community action and environmental groups. We spoke with industry representatives and NRC inspectors at the decommissioned and operating reactor sites we visited. In our interviews, we asked for their views on the benefits and challenges of transferring spent fuel from wet to dry storage and the benefits and challenges of accelerating that transfer. To further determine the cost considerations for transferring spent fuel from wet to dry storage, we updated cost component estimates developed for our 2009 report to constant 2012 dollars. In that report, we obtained information from a small group of experts to develop initial assumptions, which we then provided to a larger set of nearly 150 experts for comment.[4]

We conducted this performance audit from June 2011 to August 2012, in accordance with generally accepted government auditing standards. These 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.

[4]For further information on the scope and methodology used, please see appendixes I, II, and III in GAO-10-48.

Appendix II: Selected Other Countries' Spent Fuel Management Programs

Like the United States, other countries produce electricity from nuclear power reactors and have programs to manage their spent nuclear fuel. Table 2 provides a brief description of the programs in selected countries.

Table2: Summary of Commercial Nuclear Programs and Spent Fuel Management Programs for Selected Countries

Country	Began commercial nuclear operations	Number of operating reactors	Spent fuel Inventory at end of 2007 (tons of heavy metal)	Spent fuel management program
Canada	1968	18	38,400	• Does not reprocess spent nuclear fuel. • Stores spent nuclear fuel at nuclear power reactor sites in both wet and dry storage. • Does not have an independent centralized interim storage facility. • Plans to develop an independent centralized interim storage facility in rock formations suitable for shallow underground storage. • A group that includes Canadian utilities and the Canadian government has recommended a geological repository, but no specific site has been selected.
Japan	1966	50[a]	19,000	• Reprocesses spent nuclear fuel. Historically, Japan has shipped its spent nuclear fuel to France and the United Kingdom. • Stores spent nuclear fuel in pools at reactor sites with two reactor sites that also store spent fuel in dry storage. • Constructed its own reprocessing plant at Rokkasho, Japan. (Uncertainty surrounds the future of Rokkasho as the Japanese government reviews its nuclear policy after the disaster at the Fukushima Daiichi nuclear power plant. No date for operation has been set.) • Rokkasho contains an interim wet storage pool for spent nuclear fuel. The pool is currently full, awaiting start of reprocessing operations. • An interim dry storage facility is under construction at Mutsu near the Rokkasho reprocessing plant. The plan is to store spent fuel there until transfer for reprocessing. (Construction at Mutsu has been put on hold following the Fukushima disaster in March 2011.) • Plans to construct a geological repository but has not selected any sites.
Russia	1963	33	17,895	• Reprocesses some spent nuclear fuel as well as spent fuel from other countries. • Pools are used to store spent nuclear fuel at reactor sites. • In 2011, construction was completed on the world's largest dry storage facility at Zheleznogorsk, Siberia. Zheleznogorsk also houses wet storage pools as part of Russia's centralized interim storage facilities. • No formalized plans for a geological repository.

Country	Began commercial nuclear operations	Number of operating reactors	Spent fuel Inventory at end of 2007 (tons of heavy metal)	Spent fuel management program
France	1964	58	13,500	• Reprocesses its own spent nuclear fuel as well spent fuel from other countries; virtually all of the spent fuel reprocessed today is domestic. • Uses only wet storage for spent nuclear fuel. • Spent nuclear fuel from French reactors is cooled in pools for several years at reactor sites and then transported to the reprocessing plant at La Hague, France. The spent fuel is then stored for several more years in massive pools before reprocessing. • No independent centralized storage facility. La Hague serves as a quasi-centralized storage facility while spent fuel awaits reprocessing. • Plans to develop a geological repository. A tentative site has been selected at Bure, France, but no final plan has been approved.
South Korea	1978	23	10,900	• Does not reprocess spent nuclear fuel. • Stores spent nuclear fuel at nuclear power reactor sites in both wet and dry storage systems. • A centralized storage facility for spent nuclear fuel is pending construction by 2016. • Envisions a geological repository but has not selected a site.
Germany	1969	9	5,850	• Shipped most of its spent nuclear fuel to France and the United Kingdom for reprocessing, until 2005. • Stores the majority of spent nuclear fuel in interim dry storage facilities at reactor sites. • Stores some spent nuclear fuel at sites away from reactors in interim dry storage. • Plans to develop a geological repository for spent nuclear fuel. A site that was tentatively selected has become controversial, and no final decision on a site has been made.
United Kingdom	1956	18	5,850	• Reprocesses its own spent nuclear fuel as well spent fuel from other countries. • Uses only wet storage for spent nuclear fuel. • Does not have an independent centralized interim storage facility. • Plans to develop a geological repository for spent nuclear fuel but has not selected a site.
Sweden	1972	10	5,400	• Does not reprocess spent nuclear fuel. • Stores spent nuclear fuel at reactor sites in pools before transfer to a central interim underground wet storage facility at the Oskarshamn nuclear power plant. • Finalized plans for a geological repository for spent nuclear fuel at the Forsmark nuclear power plant in Sweden. Full construction at the site is scheduled to begin in 2015 and operation in approximately 2023.

Country	Began commercial nuclear operations	Number of operating reactors	Spent fuel Inventory at end of 2007 (tons of heavy metal)	Spent fuel management program
Finland	1977	4	1,600	• Does not reprocess spent nuclear fuel. After collapse of Soviet Union, discontinued sending some of its nuclear fuel to the Soviet Union for reprocessing. • Stores spent nuclear fuel in pools at nuclear power plants until transfer to a deep geological repository. • Finalized plans for a geological repository sited next to its Olkiluoto nuclear power plant. Acceptance of spent nuclear fuel is scheduled to start in approximately 2020.

Sources: For the spent nuclear fuel inventory amounts at the end of 2007, International Panel on Fissile Materials, *Managing Spent Fuel from Nuclear Power Reactors: Experience and Lessons from Around the World* (Princeton, NJ: September 2011). The amounts reflect fuel stored in cooling pools and dry storage. In addition, we used the following sources for the countries listed:

For Canada: International Panel on Fissile Materials, *Managing Spent Fuel from Nuclear Power Reactors*; World Nuclear Association, "Country Briefings: Nuclear Power in Canada," accessed May 2012, http://www.world-nuclear.org; Nuclear Energy Institute, "Global Nuclear Power Development: Major Expansion Continues" (Washington, D.C.: May 2012); U.S. Nuclear Waste Technical Review Board, *Survey of National Programs for Managing High-Level Radioactive Waste and Spent Nuclear Fuel: A Report to Congress and the Secretary of Energy* (Arlington, VA: October 2009), and *Experience Gained from Programs to Manage High-Level Radioactive Waste and Spent Nuclear Fuel in the United States and Other Countries: A Report to Congress and the Secretary of Energy* (Arlington, VA: April 2011).

For Japan: World Nuclear Association, "Country Briefings: Nuclear Power in Japan," accessed May 2012, http://www.world-nuclear.org; Japan Atomic Industrial Forum, "Moves Afoot to Restart Nuclear Power Plant Operation and Its Related Issues in Japan," (Tokyo: May 31,2012), accessed May 31, 2012, http://www.jaif.or.jp/english/activities_new.html#purpose; International Panel on Fissile Materials, *Managing Spent Fuel from Nuclear Power Reactors*.

For Russia: World Nuclear Association, "Country Briefings: Nuclear Power in Russia," accessed May 2012, http://www.world-nuclear.org; International Panel on Fissile Materials, *Managing Spent Fuel from Nuclear Power Reactors*; World Nuclear Association, "Radioactive Waste Management," *Nuclear Fuel Cycle: Nuclear Wastes,* accessed April 2012, http://www.world-nuclear.org; International Panel on Fissile Materials, "Spent Fuel from Nuclear Power Reactors: Overview of a New Study." Presentation by Frank von Hippel, hosted by the American Association for the Advancement of Science, Washington, D.C., June 3, 2011; World Nuclear Association, "Country Briefings: Russia's Nuclear Fuel Cycle," accessed March 2012, http://www.world-nuclear.org.

For France: Embassy of France in Washington, D.C. "Nuclear Energy in France," accessed March 2008, http://ambafrance-us.org/spip.php?article637; World Nuclear Association, "Country Briefings: Nuclear Power in France," accessed February 2012, http://www.world-nuclear.org; International Panel on Fissile Materials, *Managing Spent Fuel from Nuclear Power Reactor*s and "Spent Fuel from Nuclear Power Reactors"; World Nuclear Association, "Radioactive Waste Management," accessed April 2012, http://www.world-nuclear.org.

For South Korea: World Nuclear Association, "Country Briefings: Nuclear Power in South Korea," accessed April 2012, http://www.world-nuclear.org; International Panel on Fissile Materials, *Managing Spent Fuel from Nuclear Power Reactors* and "Spent Fuel from Nuclear Power Reactors."

For Germany: International Panel on Fissile Materials, *Managing Spent Fuel from Nuclear Power Reactors*; EnBW, *Uranium Is Energy: The Nuclear Power Plants of EnBW* (Karlsruhe: Energy Baden-Wurttemberg, June 2007); International Panel on Fissile Materials, "Spent Fuel from Nuclear Power Reactors,"; World Nuclear Association, "Country Briefings: Nuclear Power in Germany," accessed April 2012, http://www.world-nuclear.org; U.S. Nuclear Waste Technical Review Board, *Survey of National Programs for Managing High-Level Radioactive Waste*.

For the United Kingdom: World Nuclear Association, "Country Briefings: Nuclear Development in the United Kingdom," accessed March 2012, http://www.world-nuclear.org; Nuclear Energy Institute "Global Nuclear Power Development"; International Panel on Fissile Materials, *Managing Spent Fuel from Nuclear Power Reactors* and "Spent Fuel from Nuclear Power Reactors";World Nuclear Association, "Radioactive Waste Management"; U.S. Nuclear Waste Technical Review Board, *Survey of National Programs for Managing High-Level Radioactive Waste*; World Nuclear Association, "Country Briefings: Nuclear Power in the United Kingdom", accessed May 2012, http://www.world-nuclear.org.

For Sweden: World Nuclear Association, "Country Briefings: Nuclear Power in Sweden," accessed April 2012, http://www.world-nuclear.org; International Panel on Fissile Materials, *Managing Spent Fuel from Nuclear Power Reactors* and "Spent Fuel from Nuclear Power Reactors"; World Nuclear Association, "Radioactive Waste Management," app. 3, "National Policies," accessed April 2012, http://www.world-nuclear.org.

For Finland: World Nuclear Association, "Country Briefings: Nuclear Power in Finland," accessed April 2012, http://www.world-nuclear.org; International Panel on Fissile Materials, *Managing Spent Fuel from Nuclear Power Reactors* and "Spent Fuel from Nuclear Power Reactors"; U.S. Nuclear Waste Technical Review Board, *Experience Gained from Programs to Manage High-Level Radioactive Waste and Spent Nuclear Fuel in the United States and Other Countries*.

[a]On May 5, 2012, Japan's lone operating nuclear power plant ceased operation. All of Japan's nuclear power plants were to remain shut down pending the Japanese government's safety inspections and support of local Japanese governments to restart nuclear operations. Since May 5, 2012, Japan has restarted one nuclear power plant to full power and may determine restart dates for other reactors. The disaster at the Tokyo Electric Power Company's Fukushima Daiichi nuclear power plant, triggered by the earthquake and tsunami of March 11, 2011, had a debilitating effect on the operation of Japan's nuclear power plants. On June 16, 2012, the Japanese government announced plans to restart two reactors at the Ohi nuclear power plant in July 2012, but the future of the Japanese nuclear energy program is uncertain, and not all of the 50 reactors listed are expected to restart.

Appendix III: Accumulation of Commercial Spent Fuel by State over Time

Our report identified three scenarios in which spent fuel could be moved to an off-site location. Briefly, the earliest likely opening date if the Yucca Mountain repository were to be licensed and constructed is about 2027, the earliest a centralized storage facility could be expected to open is about 2032, and the earliest a permanent disposal facility that was an alternative to Yucca Mountain could be expected to open is about 2052. Table 3 summarizes the amount of spent fuel that is expected to accumulate in each state for these dates, as well as 2012—the current spent fuel accumulation—and 2067, when all currently operating commercial nuclear power reactors are expected to have retired and transferred their spent fuel to dry storage. The table also shows the rank for each state in terms of the amount of its accumulated spent fuel in comparison with the other states.

Table 3: Cumulative Quantities of Spent Fuel, by State, for 2012, 2027, 2032, 2052, and 2067

Metric tons

	2012		2027		2032		2052		2067	
State	Total volume	Rank	Total volume	Rank	Total volume	Rank	Total volume	Rank	Total volume	Rank
Alabama	3,341	5	5,300	5	6,004	5	6,899	4	6,899	4
Arizona	2,041	15	3,331	14	3,761	14	5,108	13	5,108	13
Arkansas	1,377	18	2,117	17	2,369	17	2,659	19	2,659	19
California	3,059	6	4,565	6	5,039	6	6,351	6	6,351	6
Connecticut	2,079	14	2,729	16	2,962	16	3,477	16	3,477	16
Florida	3,035	7	4,319	7	4,847	7	5,467	9	5,467	9
Georgia	2,691	10	4,101	9	4,584	9	5,815	8	5,815	8
Illinois	8,995	1	12,978	1	14,639	1	17,354	1	17,354	1
Iowa	476	32	692	31	746	31	838	31	838	31
Kansas	685	25	1,075	25	1,192	26	1,593	25	1,593	25
Louisiana	1,288	20	2,062	18	2,275	18	3,035	17	3,035	17
Maine	542	31	542	32	542	32	542	32	542	32
Maryland	1,379	17	1,979	19	2,179	19	2,451	20	2,451	20
Massachusetts	664	27	888	29	1,046	29	1,046	29	1,046	29
Michigan	2,692	9	4,012	11	4,468	10	5,193	12	5,193	12
Minnesota	1,235	21	1,767	22	1,973	22	2,077	22	2,077	22
Mississippi	805	24	1,215	24	1,379	24	1,805	23	1,805	23
Missouri	679	26	1,059	26	1,211	25	1,553	26	1,553	26
Nebraska	904	23	1,309	23	1,462	23	1,608	24	1,608	24

	2012		2027		2032		2052		2067	
State	Total volume	Rank	Total volume	Rank	Total volume	Rank	Total volume	Rank	Total volume	Rank
New Hampshire	586	30	966	28	1,080	28	1,517	27	1,517	27
New Jersey	2,667	11	4,031	10	4,419	11	5,390	10	5,390	10
New York	3,726	4	5,423	4	6,045	4	6,771	5	6,771	5
North Carolina	4,984	3	7,484	3	8,294	3	10,384	3	10,384	3
Ohio	1,154	22	1,829	21	2,044	20	2,699	18	2,699	18
Oregon	345	33	345	33	345	33	345	33	345	33
Pennsylvania	6,272	2	9,408	2	10,410	2	13,082	2	13,082	2
South Carolina	2,898	8	4,308	8	4,807	8	5,324	11	5,324	11
Tennessee	1,672	16	2,742	15	3,063	15	4,056	15	4,215	15
Texas	2,199	13	3,759	12	4,305	12	6,264	7	6,343	7
Vermont	624	29	854	30	989	30	989	30	989	30
Virginia	2,527	12	3,607	13	4,031	13	4,471	14	4,471	14
Washington	656	28	1,032	27	1,126	27	1,500	28	1,500	28
Wisconsin	1,367	19	1,847	20	2,024	21	2,119	21	2,119	21

Source: GAO analysis of Nuclear Energy Institute data.

Note: The data from this table constitute the underlying data in figure 8.

Appendix IV: Comments from the Nuclear Regulatory Commission

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

July 20, 2012

Janet Frisch, Assistant Director
Natural Resources and Environment
U.S. Government Accountability Office
701 Fifth Ave., Suite 2700
Seattle, WA 98104

Dear Ms. Frisch:

I would like to thank you for the opportunity to review and submit comments on the draft of the report GAO-12-797, "Spent Nuclear Fuel: Accumulating Quantities at Commercial Reactors Present Storage and Other Challenges," which the U.S. Nuclear Regulatory Commission (NRC) received on July 2, 2012. The NRC appreciates your review of this important topic.

The draft report concludes that while spent fuel continues to accumulate at reactor sites across the country, a repository has not been sited and will take decades to site, license, construct, and ultimately open, and that the chances of a radiation release from either wet or dry storage of spent fuel is extremely low.

The draft report recommends that the NRC Chairman direct the agency staff to develop a mechanism that allows individuals with appropriate clearances and the need-to-know to easily identify and access classified studies and help ensure that institutional knowledge is not lost. We believe that making sure this information is readily available to future NRC decision-makers is important. In response, NRC will review its current internal practices for maintaining and assuring access to classified documents to determine whether additional document management measures should be implemented. In addition, we will verify that the classified studies and related documents are appropriately captured in the Agency's knowledge management plans.

In several places, the GAO characterizes the NRC's position on expedited transfer of spent fuel to dry cask storage as being solely a cost-benefit decision. This is not factually correct. The NRC does not require expedited transfer of spent nuclear fuel because both wet and dry storage provide a safe means of storing spent fuel that is in full conformance with agency regulations, which ensures adequate protection of public health and safety, protects the environment, and promotes the common defense and security. Over the years, the staff has conducted numerous technical studies on the safety of spent fuel pools and the storage of spent fuel in dry cask storage systems. These studies have concluded that the current approaches to storage of spent fuel maintain safety. Nevertheless, the NRC has initiated a long-term evaluation of expedited spent fuel transfer as part of the Fukushima Lessons Learned Project that will include review of other studies.

J. Frisch -2-

As new information or circumstances warrant, the NRC reviews and evaluates storage of spent fuel to ensure that both wet and dry storage operations are safe and secure.

The enclosure provides more comprehensive perspective about spent fuel storage and additional comments on the draft GAO report. Should you have any questions about these comments, please contact Jesse Arildsen, of my staff, at 301-415-1785.

Sincerely,

Michael F. Weber
Deputy Executive Director for Materials, Waste,
Research, State, Tribal, and Compliance Programs
Office of the Executive Director for Operations

Enclosure: As stated

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Appendix V: GAO Contact and Staff Acknowledgments

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Staff Acknowledgments

In addition to the individual named above, Janet E. Frisch (Assistant Director), Antoinette Capaccio, Virginia Chanley, Ellen W. Chu, Randall Cole, R. Scott Fletcher, Cristian Ion, Mehrzad Nadji, Kevin Remondini, Robert Sánchez, Carol Shulman, Kiki Theodoropoulos, and Franklyn Yao made key contributions to this report.

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