

## INTRODUCTION AND BACKGROUND

In the Fiscal Year 2004 Energy and Water Development Conference Report, the U.S. Congress asked the National Academies to provide independent scientific and technical advice on the safety and security<sup>1</sup> of commercial spent nuclear fuel storage in the United States (see Box 1.1). The Nuclear Regulatory Commission and the Department of Homeland Security jointly sponsored this study, as directed by Congress.

Awareness and concerns about the threat of high-impact terrorism have become acute and pervasive since the attacks on September 11, 2001. The information gathered by the committee during this study led the committee to conclude that there were indeed credible concerns about the safety and security of spent nuclear fuel storage in the current threat environment. From the outset the committee believed that safety and security issues must be addressed quickly to determine whether additional measures are needed to prevent or mitigate attacks that could cause grave harm to people and cause widespread fear, disruption, and economic loss. The information gathered during this study reinforced that view. Any concern related to nuclear power plants<sup>2</sup> has added stakes: Many people fear radiation more than they fear exposure to other physical insults. This amplifies the concern over a potential terrorist attack involving radioactive materials beyond the physical injuries it might cause, and beyond the economic costs of the cleanup.

### 1.1 CONTEXT FOR THIS STUDY

The Congressional request for this study was prompted by conflicting public claims about the safety and security of commercial spent nuclear fuel storage at nuclear power plants. Some have argued that the dense packing used for storing spent fuel in cooling pools at nearly every nuclear power plant does not provide a sufficient safety margin in the event of a pool breach and consequent water loss from an accident or terrorist attack.<sup>3</sup> In such cases, the potential exists for the fuel most recently discharged from a reactor to heat up sufficiently for its zirconium cladding to ignite, possibly resulting in the release of large amounts of radioactivity to the environment (Alvarez et al., 2003a). The Nuclear Regulatory Commission's own analyses have suggested that such zirconium cladding fires and releases of radioactivity are possible (e.g., USNRC, 2001a).

To reduce the potential for such an event, Alvarez et al. (2003a) suggested that spent fuel more than five years old be removed from the pool and stored in dry casks, and

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<sup>1</sup> In the context of this study, *safety* refers to measures that protect spent nuclear fuel storage facilities against failure, damage, human error, or other accidents that would disperse radioactivity in the environment. *Security* refers to measures to protect spent fuel storage facilities against sabotage, attacks, or theft.

<sup>2</sup> Safety and security of reactors at nuclear power plants are outside of the committee's statement of task and have been addressed only where they could not be separated from spent fuel storage. The distinctions between spent fuel storage and operating nuclear power reactors are sometimes blurred in public discussions of nuclear and radiological concerns.

<sup>3</sup> The committee refers to such occurrences as *loss-of-pool-coolant events* in this report.

**BOX 1.1 STATEMENT OF TASK**

The issues to be addressed by this study are specified in the Energy and Water Development Conference Report and are as follows:

(1) Potential safety and security risks of spent nuclear fuel presently stored in cooling pools at commercial reactor sites (see Chapter 3).

(2) Safety and security advantages, if any, of dry cask storage versus wet pool storage at these reactor sites (see Chapter 4).

(3) Potential safety and security advantages, if any, of dry cask storage using various single-, dual-, and multi-purpose cask designs (see Chapter 4).

(4) In light of the September 11, 2001, terrorist attacks, this study will explicitly consider the risks of terrorist attacks on these materials and the risk these materials might be used to construct a radiological dispersal device (see Chapter 2).

that the remaining younger fuel be rearranged in the pool to allow more space for cooling (see also Marsh and Stanford, 2001; Thompson, 2003). The Nuclear Regulatory Commission staff, the nuclear industry, and some others have argued that densely-packed pool storage can be carried out both safely and securely (USNRC, 2003a).

Policy actions to improve the safety and security of spent fuel storage could have significant national consequences. Nuclear power plants generate approximately twenty percent of the electricity produced in the United States. The issue of its future availability and use is critical to our nation's present and future energy security. The safety and security of spent fuel storage is an important aspect of the acceptability of nuclear power. Decisions that affect such a large portion of our nation's electricity supply must be considered carefully, wisely, and with a balanced view.

**1.2 STRATEGY TO ADDRESS THE STUDY CHARGES**

Congress directed the National Academies to produce a classified report that addresses the statement of task shown in Box 1.1 within six months and an unclassified summary for unlimited public dissemination within 12 months. This report, which has undergone a security review by the Nuclear Regulatory Commission and found to contain no classified national security or safeguards information, fulfills the second request.<sup>4</sup>

The National Research Council of the National Academies appointed a committee of 15 experts to carry out this study. Biographical sketches of the committee members are provided in Appendix B. The committee met six times from February to June 2004 to gather information and complete its classified report. The committee met again in August, October, and November 2004, and in January 2005 to develop this public report.

Details on the information-gathering sessions and speakers are provided in Appendix A. Most of the information-gathering sessions were not open to the public because they

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<sup>4</sup> The classified report was briefed to the agencies and Congress on July 15, 2004.

involved presentations and discussions of classified information. The committee recognized, however, that important contributions to this study could be made by industry representatives, independent analysts, and the public, so it scheduled open, unclassified sessions at three of its meetings to obtain comments from interested organizations and individuals. Public comments at these meetings were encouraged and considered.

Subgroups of the committee visited several nuclear power plants to learn first-hand how spent fuel is being managed in wet and dry storage: The Dresden and Braidwood Nuclear Generating Stations in Illinois, which are owned and operated by Exelon Nuclear Corp.; the Indian Point Nuclear Generating Station in New York, which is owned and operated by ENTERGY Corp.; and the Palo Verde Nuclear Generating Station in Arizona, which is operated by Arizona Public Service Corp. A subgroup of committee members also traveled to Germany to visit spent fuel storage installations at Ahaus and Lingen and to talk with experts about the safety and security of German spent fuel storage. The German government has been concerned about security for a long time, and the German nuclear industry has made adjustments to spent fuel storage designs and operations that reduce their vulnerability to accidents and terrorist attacks. A summary of the trip to Germany is provided in Appendix C.

The statement of task for this study directed the committee to examine both the safety and security of spent fuel storage. It is important to recognize that these are two sides of the same coin in the sense that any event that results in the breach of a spent fuel pool or a dry cask, whether accidental or intentional, has the potential to release radioactive material to the environment. The committee therefore focused its limited time on understanding two issues: (1) Under what circumstances could pools or casks be breached? And, (2) what would be the radioactive releases from such breaches?

The initiating events that could lead to the accidental breach of a spent fuel pool are well known: A large seismic event or the accidental drop of a cask on the pool wall that could lead to the loss-of-pool coolant. The condition that could lead to an accidental breach of a dry storage cask is similarly well known: An accidental drop of the cask during handling operations. Current Nuclear Regulatory Commission regulations are designed to prevent such accidental conditions by imposing requirements on the design and operation of spent fuel storage facilities. These regulations have been in place for decades and have so far been effective in preventing accidental releases of radioactive materials from these facilities into the environment.

The initiating events that could lead to the intentional breach of a spent fuel pool or dry storage cask are not as well understood. The Nuclear Regulatory Commission has had long-standing requirements in place to deal with radiological sabotage (included in the "design basis threat"; see Chapter 2), but the September 11, 2001 terrorist attacks provided a graphic demonstration of a much broader array of potential threats. As described in the following chapters, the Nuclear Regulatory Commission is currently sponsoring studies to better understand the potential consequences of such terrorist attacks on spent fuel storage facilities.

Early on in this study, the committee made a judgment that it should focus most of its attention concerning such initiating events on the security aspects of its task statement. Many of the phenomena that follow an initiating event (e.g., loss-of-pool coolant or cask breach) would be the same whether it arose from an accident or terrorist attack, as noted previously. While the mitigation strategies for such events might be similar, they would

require different kinds of preparation.

Given the relatively short time frame for this study, the committee focused its efforts on performing a critical review of the security analyses that have been carried out by the Nuclear Regulatory Commission and its contractors, the Department of Homeland Security, industry (i.e., EPRI, formerly named the Electric Power Research Institute, ENTERGY Corp., and dry cask vendors), and other independent experts to determine if they are objective, complete, and credible. The committee could only perform limited independent safety and security analyses based on the information it gathered.

The committee made many requests for information from the Nuclear Regulatory Commission, its Sandia National Laboratories contractor, and other organizations and individuals, often with little advance notice. For the most part, all parties responded well to these requests. The committee was able to access experts who could answer its technical questions and was pleased with the cooperation and information it received during its visits to spent fuel storage facilities. This cooperation was essential in enabling the committee to complete its task within the requested 6-month timeframe.

The committee was forced to circumscribe some aspects of its examinations, however, due to time and/or information constraints. In particular, the committee did not pursue in-depth examinations of the following topics:

- Human factors issues involved in responding to terrorist attacks on spent fuel storage. These include surveillance activities to identify potential threats (both inside and outside the plant); the response of security forces; and the preparation of plant personnel to deploy mitigative measures in the event of an attack.
- The behavior of radioactive material after it enters the environment from a spent fuel pool or dry cask. The committee assumed that any large release of radioactivity from a spent fuel storage facility would be problematic even in the absence of knowledge of how it would disperse in the environment. The committee instead focused its efforts on understanding how much radioactive material would be released, if any, in the case of an attack.
- The economic consequences of potential terrorist attacks, except insofar as noting the possible magnitude of cleanup costs after a catastrophic release of radioactivity.
- The costs of potential measures to mitigate spent fuel storage vulnerabilities. The committee understands that the Nuclear Regulatory Commission would include cost-benefit considerations in decisions to impose any new requirements on industry for such measures.

The committee also did not examine the potential vulnerability of commercial spent fuel while being transported. That topic is not only outside of the committee's task, but there is another National Academies study currently underway to examine transportation issues.<sup>5</sup>

Because most of the studies on spent fuel storage vulnerabilities undertaken for the Nuclear Regulatory Commission are still in progress, the committee was not able to review

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<sup>5</sup> Committee on Transportation of Radioactive Waste. See <http://national-academies.org/transportofradwaste>. This committee's final report is now planned for completion in the late summer of 2005.

completed technical documents. Instead, the committee had to rely on presentations by and discussions with technical experts. The committee does not believe that these difficulties prevented it from developing sound findings and recommendations from the information it did receive. The committee was able to draw upon other information sources both domestic and foreign,<sup>6</sup> including the experience and expertise of its members, to fill some of the information gaps.

### 1.3 REPORT ROADMAP

The sections that follow in this chapter provide background on storage of spent nuclear fuel, which may be helpful to non-experts in understanding the issues discussed in the following chapters. The other chapters are organized to explicitly address the four charges of the committee's statement of task:

- Chapter 2 addresses the last charge to the committee to "explicitly consider the risks of terrorist attacks on these materials and the risk these materials might be used to construct a radiological dispersal device."
- Chapter 3 addresses the first charge to the committee to examine the "potential safety and security risks of spent nuclear fuel presently stored in cooling pools at commercial reactor sites."
- Chapter 4 addresses the second and third charges to examine the "safety and security advantages, if any, of dry cask storage versus wet pool storage at these reactor sites" and the "potential safety and security advantages, if any, of dry cask storage using various single-, dual-, and multi-purpose cask designs."
- Chapter 5 concerns implementation of the recommendations in this report, specifically concerning timing and communication issues.

The appendixes provide supporting information, including a glossary and acronym list, descriptions of the committee's meetings, and biographical sketches of the committee members.

### 1.4 BACKGROUND ON SPENT NUCLEAR FUEL AND ITS STORAGE

This section is provided for readers who are not familiar with the technical features of spent nuclear fuel and its storage. Other readers should skip directly to Chapter 2.

Spent nuclear fuel is fuel that has been irradiated or "burned" in the core of a nuclear reactor. In power reactors, the energy released from fission reactions in the nuclear fuel heats water<sup>7</sup> to produce steam that drives turbines to generate electricity. Spent nuclear fuel from non-commercial reactors (such as research reactors, naval propulsion reactors, and plutonium production reactors) is not considered in this study.

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<sup>6</sup> For example, the aforementioned visits to Lingen and Ahaus, in Germany.

<sup>7</sup> A different coolant can be used, but all power reactors now operating in the United States are water cooled.

### 1.4.1 Nuclear Fuel

Almost all commercial reactor fuel in the United States is in the form of solid, cylindrical pellets of uranium dioxide. The pellets are about 0.4 to 0.65 inches (1.0 to 1.65 centimeters) in length and about 0.3 to 0.5 inches (0.8 to 1.25 centimeters) in diameter. The pellets are loaded into tubes, called *fuel cladding*, made of a zirconium metal alloy, called zircaloy. A loaded tube, which is typically 11.5 to 14.75 feet (3.5 to 4.5 meters) in length, is called a *fuel rod* (also referred to as a *fuel pin* or *fuel element*). Fuel rods are bundled together, with a 0.12 to 0.18 inch (0.3 to 0.45 centimeter) space left between each for coolant to flow, to form a square fuel assembly (see FIGURE 1.1) measuring about 6 to 9 inches (15 to 23 centimeters) on a side.

Typical fuel assemblies for boiling water nuclear reactors (BWRs) hold 49 to 63 fuel rods, and fuel assemblies for pressurized water nuclear reactors (PWRs) hold 164 to 264 fuel rods.<sup>8</sup> Depending on reactor design, typically between 190 and 750 assemblies, each weighing from 275 to 685 kg (600 to 1500 pounds), make up a power reactor core. New fuel assemblies (i.e., those that have not been irradiated in a reactor) do not require special cooling or radiation shielding; they can be moved with a crane in open air. Once in the reactor, however, the fuel undergoes nuclear fission and begins to generate the radioactive fission products and activation products that require shielding and cooling.

The uranium oxide fuel essentially is composed of two isotopes of uranium: Initially, about 3-5 percent<sup>9</sup> by weight is fissile uranium (uranium-235), which is the component that sustains the fission chain reaction; and about 95-97 percent is uranium-238, which can capture a neutron to produce fissile plutonium and other radioactive heavy isotopes (actinides). Each fission event, whether in uranium or plutonium, releases energy and neutrons as the fissioning nucleus splits into two (and infrequently three) radioactive fragments, called fission products.

When the fissile material has been consumed to a level where it is no longer economically viable (typically 4.5 to 6 years of operation for current fuel designs), the fuel is considered *spent* and is removed from the reactor core. Spent fuel assemblies are highly radioactive. The decay of radioactive fission products and other constituents generates heat (called *decay heat*) and penetrating (gamma and neutron) radiation. Therefore cooling, shielding, and remote handling are required for spent nuclear fuel.

The amount of heat and radiation generated by a spent fuel assembly after its removal from a reactor depends on the number of fissions that have occurred in the fuel, called the *burn-up*, and the time that has elapsed since the fuel was removed from the reactor. The rate of decay-heat generation by spent reactor fuel and how it will change with time after the fuel is removed from the reactor can be calculated. The results of an example calculation are shown in FIGURE 1.2.

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<sup>8</sup> Technical specifications for the fuel assemblies are taken from the American National Standard document for pool storage of spent nuclear fuel (American Nuclear Society, 1988).

<sup>9</sup> With only a few exceptions, commercial nuclear power reactors in the United States have been fueled with low-enriched uranium, that is, less than 20 percent of the uranium is uranium-235. Uranium found in nature has about 0.71 percent uranium-235 by weight.

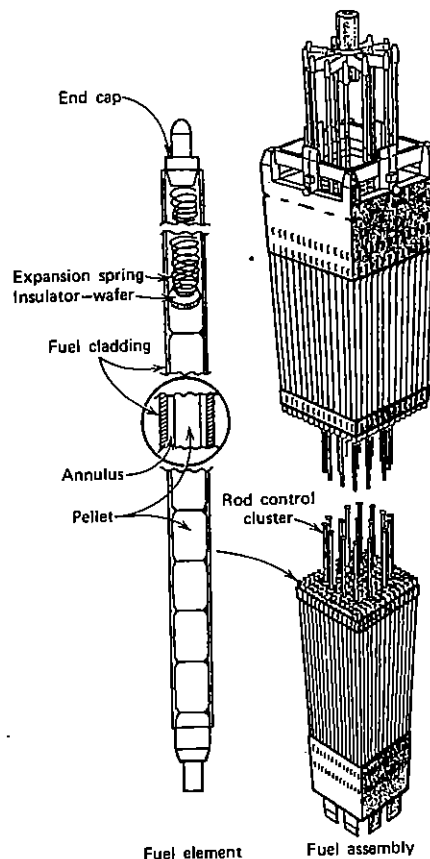


FIGURE 1.1 Fuel rods, also called fuel pins or elements, are bundled together into fuel assemblies as shown here. This fuel assembly is for a PWR reactor. SOURCE: Duderstadt and Hamilton (1976; Figure 3-7).

At discharge from the reactor, a spent fuel assembly generates on the order of tens of kilowatts of heat. Decay-heat production diminishes as very short-lived radionuclides decay away, dropping heat generation by a factor of 100 during the first year; dropping by another factor of 5 between year one and year five; and dropping about 40 percent between year five and year ten (see FIGURE 1.2). Within a year of discharge from the reactor, decay-heat production in spent nuclear fuel is dominated by four radionuclides: Ruthenium-106 (with a 372.6-day half-life), cerium-144 (284.4-day half-life), cesium-137 (30.2-year half-life), and cesium-134 (2.1-year half-life) and their short-lived decay products contribute nearly 90 percent of the decay heat from a spent fuel assembly.

Longer-lived radionuclides persist in the spent fuel even as the decay-heat drops further. Cesium-137 decays to barium-137, emitting a beta particle and a high-energy gamma ray. The cesium-137 half-life of 30.2 years is sufficiently long to ensure that this radionuclide will persist during storage. It and other materials present in the fuel will form small particles, called *aerosols*, in a zirconium cladding fire.

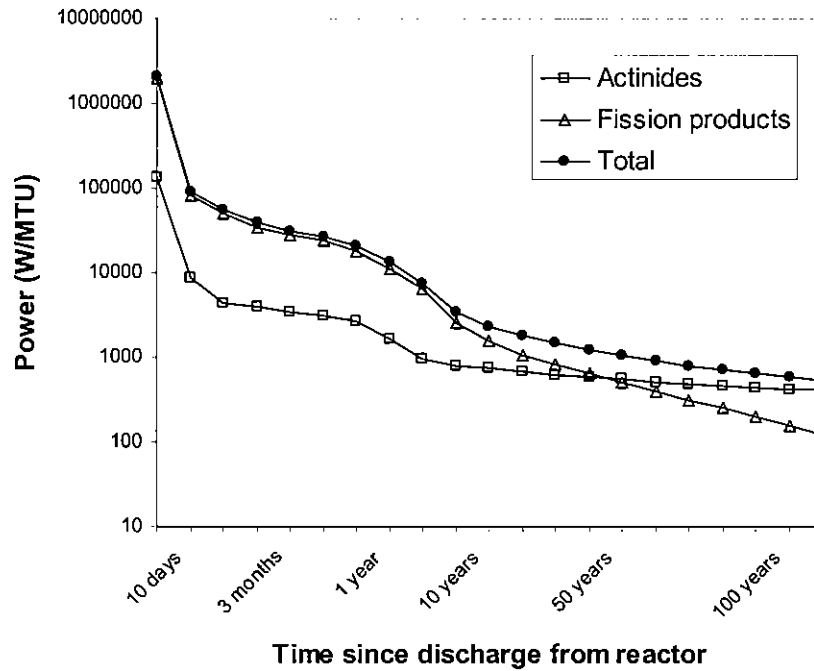


FIGURE 1.2 Decay heat power for spent fuel (measured in watts per metric ton of uranium) plotted on a logarithmic scale as a function of time after reactor discharge. Note that the horizontal axis is a data series, not a scale. SOURCE: Based on data from USNRC (1984).

Shorter-lived radionuclides decay away rapidly after removal of the spent fuel from the reactor. One of these is iodine-131, which is of particular concern in reactor core accidents because it can be taken up in large quantities by the human thyroid. This radionuclide has a half-life of about 8 days and typically persists in significant quantities in spent fuel only on the order of a few months.

#### 1.4.2 Storage of Spent Nuclear Fuel

Storage technologies for spent nuclear fuel have three primary objectives:

- Cool the fuel to prevent heat-up to high temperatures from radioactive decay.
- Shield workers and the public from the radiation emitted by radioactive decay in the spent fuel and provide a barrier for any releases of radioactivity.
- Prevent criticality accidents (uncontrolled fission chain reactions).

After the fuel assemblies are unloaded from the reactor they are stored in water pools, called *spent fuel pools*. The water in the pools provides radiation shielding and cooling and captures all but noble gas radionuclides in case of fuel rod leaks.<sup>10</sup> The geometry of the fuel and neutron absorbers (like boron, hafnium, and cadmium) within the

<sup>10</sup> If the cladding in the fuel rods is breached some radioactive materials will be released into the pool.



racks that hold the spent fuel or in the cooling water help prevent criticality events.<sup>11</sup> The water in the pool is circulated through heat exchangers for cooling and ion exchange filters to capture any radionuclides and other contaminants that get into the water. Makeup water is also added to the pool to replace pool water lost to evaporation. The operation of the pumps and heat exchangers is especially important during and immediately after reactor refueling operations, because this is when larger quantities of higher heat-generating spent fuel are placed into the pool.

Current U.S. regulations require that spent fuel be stored in the power plant's fuel pool for at least one year after its discharge from the reactor before being moved to dry storage. After that time the spent fuel can be moved, but only with active cooling. Active cooling is generally necessary for about three years after the spent fuel is removed from the reactor core (USNRC, 2003b).

When a spent fuel pool is filled to capacity, older fuel, which has lower decay-heat, is moved to other pools or placed into dry casks. Heat generated in the loaded dry casks is removed by air convection and thermal radiation. The cask provides shielding of penetrating radiation and confinement of the radionuclides in the spent fuel. As with pool storage, criticality control is accomplished by placing the fuel in a fixed geometry and separating individual fuel assemblies with neutron absorbers. Standard industry practice is to place in dry storage only spent fuel that has cooled for five years or more after discharge from the reactor.<sup>12</sup> Most spent fuel in wet or dry storage is located at nuclear power plant sites (i.e., on-site storage).

There are significant differences in the design and construction of wet and dry storage installations at commercial nuclear power plants. The characteristics depend on the type of the nuclear power plant, the age of the spent fuel storage installation, or the type of dry casks used. The design and features of spent fuel pools and dry storage facilities are discussed in Chapters 3 and 4, respectively.

### 1.4.3 Spent Fuel Inventories

As of 2003, approximately 50,000 MTU (metric tons of uranium) of spent fuel have been generated over the past four decades in the United States. A typical nuclear power plant generates about 20 MTU per year. The entire U.S. nuclear industry generates about 2,000 MTU per year.

Of the approximately 50,000 MTU of commercial spent fuel in the United States, 43,600 MTU are currently stored in pools and 6,200 MTU are in dry storage. Pool storage exists at all 65 sites with operating commercial nuclear power reactors<sup>13</sup> and at eight sites where commercial power reactors are no longer operating (i.e., they have been shutdown or decommissioned) (FIGURE 1.3). Additionally, there is an away-from-reactor spent fuel pool operating at the G.E. Morris Facility in Illinois (see Appendix D).

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<sup>11</sup> See the Glossary for a definition of criticality. Most of the fuel's capacity for sustaining criticality is expended in the reactor as the uranium and plutonium are fissioned.

<sup>12</sup> Fuel aged as little as three years could be stored in passively cooled casks, but fewer assemblies could be accommodated in each cask because of the higher heat load.

<sup>13</sup> There are 103 operating commercial nuclear power reactors in the United States. Many sites have more than one operating reactor.

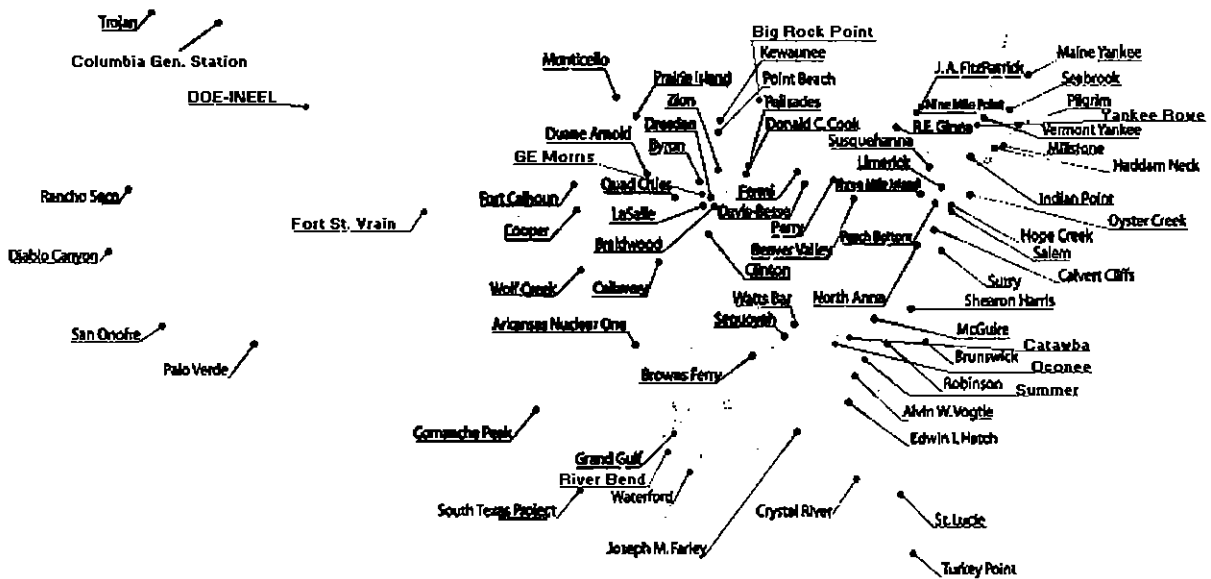


FIGURE 1.3 Locations of spent fuel storage facilities in the United States.

Of the spent fuel in dry storage, 4,500 MTU are in storage at 22 sites with operating commercial nuclear power reactors, and 1,700 MTU are in storage at six sites where the commercial reactors are no longer operating. An additional dry-storage facility is operated by the federal government at the Idaho National Engineering and Environmental Laboratory. It stores most of the damaged fuel from the Three Mile Island Unit 2 reactor accident.

TABLE 1.1 provides a listing of the 30 operating Independent Spent Fuel Storage Installations (ISFSIs<sup>14</sup>) in the United States. These ISFSIs include the dry-storage facilities at operating and shutdown commercial power reactor sites as well as the storage facilities at the Morris and Idaho sites, as described above. The committee did not examine the Morris and Idaho facilities as part of this study. At-reactor pool storage is not considered to be an ISFSI because it operates under the power reactor license.

#### 1.4.4 History of Spent Fuel Storage

Spent fuel pools at commercial nuclear power plants were not designed to accommodate all the fuel used during the operating lifetime of the reactors they service. Most commercial power plants were designed with small pools under the assumption that fuel would be cooled for a short period of time after discharge from the reactor and then be

<sup>14</sup> An ISFSI is a facility for storing spent fuel in wet pools or dry casks and is defined in Title 10, Part 72 of the Code of Federal Regulations.

Table 1.1: Operating ISFSIs in the United States as of July, 2004

Name	Location
Palo Verde	Arizona
Arkansas Nuclear One	Arkansas
Rancho Seco	California
San Onofre	California
Diablo Canyon	California
Fort St. Vrain (1)	Colorado
Edwin L. Hatch	Georgia
DOE-INEEL (2)	Idaho
G.E. Morris (3)	Illinois
Dresden	Illinois
Duane Arnold	Iowa
Maine Yankee	Maine
Calvert Cliffs	Maryland
Big Rock Point	Michigan
Palisades	Michigan
Prairie Island	Minnesota
Yankee Rowe	Massachusetts
Oyster Creek	New Jersey
J.A. FitzPatrick	New York
McGuire	North Carolina
Davis-Besse	Ohio
Trojan	Oregon
Susquehanna	Pennsylvania
Peach Bottom	Pennsylvania
Robinson	South Carolina
Oconee	South Carolina
North Anna	Virginia
Surry	Virginia
Columbia Gen. Station	Washington
Point Beach	Wisconsin

## NOTES:

- (1) The Fort St. Vrain ISFSI stores fuel from a commercial gas-cooled reactor. The facility is operated by the Department of Energy.
- (2) The DOE-INEEL facility stores fuel from the Three-Mile Island Unit 2 reactor. The facility is operated by the Department of Energy.
- (3) The G.E. Morris ISFSI is a wet storage facility.

SOURCES: Data from the Nuclear Regulatory Commission.

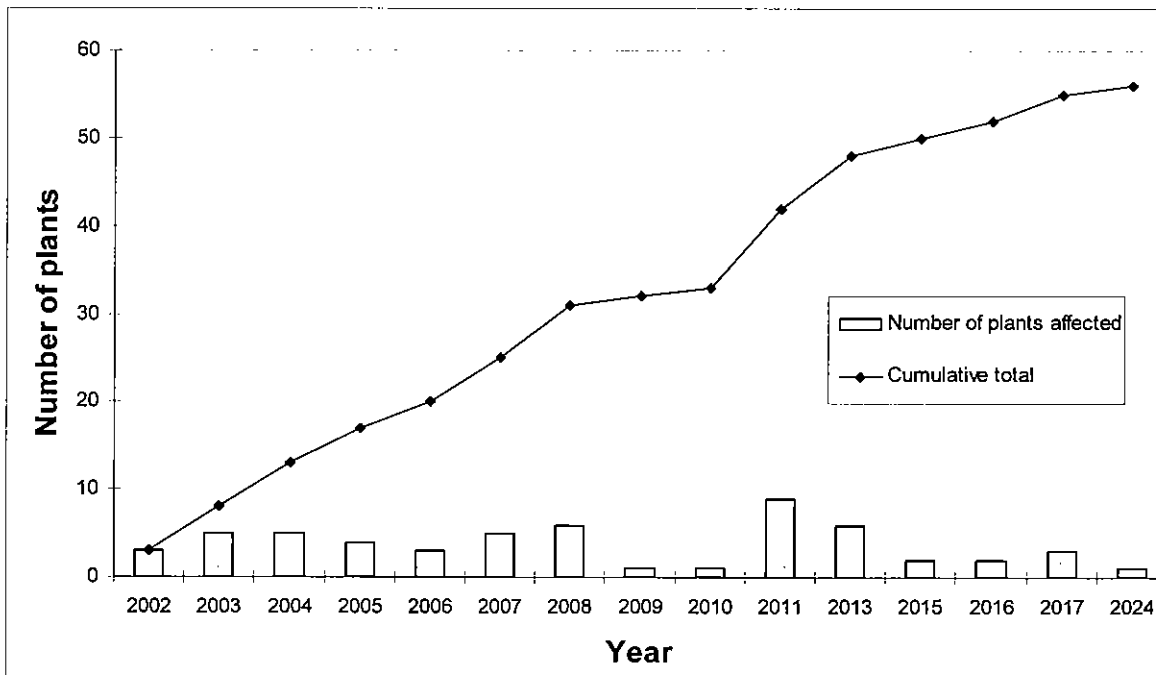


FIGURE 1.4 Projection of the number of commercial nuclear power plants that will run out of needed space in their spent fuel pools in coming years if they do not add interim storage. These data, looking only at plants that did not already use dry cask storage, were provided to the Nuclear Regulatory Commission in 2000. SOURCE: USNRC (2001b).

sent offsite for recycling (i.e., reprocessing).<sup>15</sup> A commercial reprocessing industry never developed, however, for the reasons discussed in Appendix D. Newer power plants were designed with larger pool storage capacities. Even plants with larger-capacity pools will run out of pool space if they operate beyond their initial 40-year licenses. In 2000, the nuclear power industry projected that roughly three or four plants per year would run out of needed storage space in their pools without additional interim storage capacity (see FIGURE 1.4).

Another development that logically could reduce the demand for storage of spent nuclear fuel at the sites of power plants is the availability of a geologic repository for disposal of spent nuclear fuel. But a nuclear waste repository is not expected to be in operation until at least 2010, and even then it will take several decades for all of the spent fuel to be shipped for disposal. Thus, onsite storage of spent fuel is likely to continue for at least several decades.

Power plant operators have made two changes in spent fuel storage procedures to increase the capacity of onsite storage. First, starting in the late 1970s, plant operators began to install high-density racks that enable more spent fuel to be stored in the pools. This has increased storage capacities in some pools by up to about a factor of five (USNRC, 2003b). Second, as noted above, many plant operators have moved older spent fuel from the pools into dry-cask storage systems (see Chapter 4) or into other pools when available

<sup>15</sup> Residual uranium-235 and plutonium in the spent fuel would be recovered for the manufacture of new fuel. The waste products in the fuel, principally the fission products, would be immobilized in solid matrices and stored for eventual disposal.

to make room for freshly discharged spent fuel and to maintain the capacity for a full-core offload.<sup>16</sup>

The original spent fuel racks, sometimes called “open racks,” were designed to store spent fuel in an open array, with open vertical and lateral channels between the fuel assemblies to promote water circulation. The high-density storage racks eliminated many of the channels so that the fuel assemblies could be packed closer together (FIGURE 1.5). This configuration does not allow as much water (or air circulation in loss-of-pool-coolant events) through the spent fuel assemblies as the original open-rack design.

Several nuclear utilities have already submitted license applications to the Nuclear Regulatory Commission to build 16 new ISFSIs. Among the potential new ISFSIs, a consortium of utilities has submitted a license for a private fuel storage facility (PFS) in Utah for interim dry storage of up to 40,000 metric tons of spent fuel.

Most or all pools store some spent fuel that has aged more than five years after discharge from the reactor, and so could be transferred to dry-cask storage. The amount that could be transferred depends on plant-specific information such as pool size and configuration, operating history of the reactor, the enrichment and burn-up level in the fuel, and availability of an ISFSI.

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<sup>16</sup> Although not required by regulation, it is standard practice in the nuclear industry to maintain enough open space in the spent fuel pool to hold the entire core of the nuclear reactor. This provides an additional margin of safety should the fuel need to be removed from the reactor core in an emergency or for maintenance purposes.

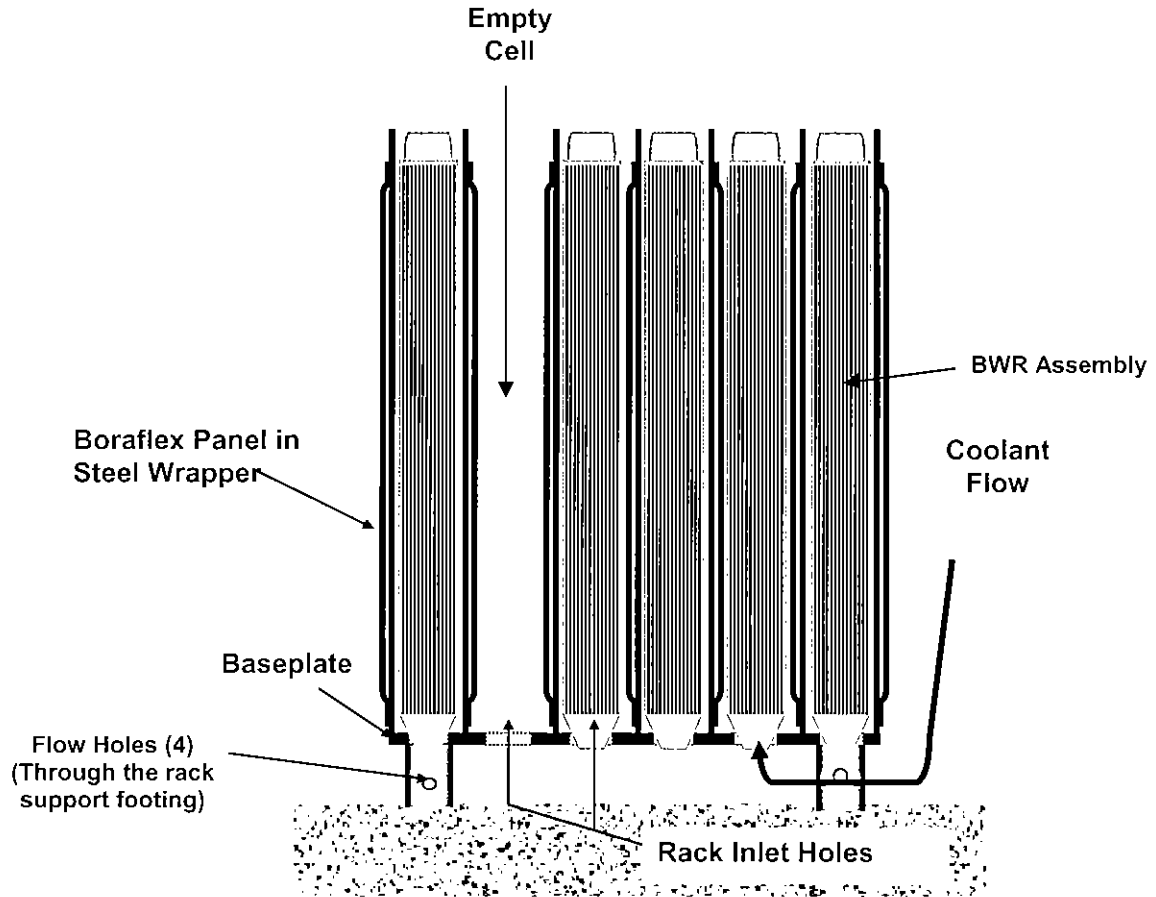


FIGURE 1.5 Dense spent fuel pool storage racks for BWR fuel. This cross-sectional illustration shows the principal elements of the spent fuel rack, which sits on the bottom of the pool. SOURCE: Nuclear Regulatory Commission.