CHARACTERISTICS AND COMMON VULNERABILITIES INFRASTRUCTURE CATEGORY: NUCLEAR SPENT FUEL STORAGE FACILITIES

Protective Security Division
Department of Homeland Security

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Preventing terrorism and reducing the nation's vulnerability to terrorist acts requires understanding the common vulnerabilities of critical infrastructures, identifying site-specific vulnerabilities, understanding the types of terrorist activities that likely would be successful in exploiting those vulnerabilities, and taking preemptive and protective actions to mitigate vulnerabilities so that terrorists are no longer able to exploit them. This report characterizes and discusses the common vulnerabilities of nuclear spent fuel storage facilities, which are located at operating and decommissioning nuclear reactors and independent spent fuel storage facilities in the United States.

NUCLEAR SPENT FUEL FACILITY CHARACTERISTICS

Introduction

After fuel assemblies have been used in a nuclear reactor for several operating cycles of 18 to 24 months each, the fuel no longer produces energy efficiently. At this point, it is considered "spent." At the end of each operating cycle, the portion of spent fuel assemblies that are spent (typically one-third) are transferred to the spent fuel pool for interim storage. Meanwhile, new fuel assemblies are installed in their place in the reactor. The common characteristics of spent fuel facilities, whether the spent fuel is stored in a pool or dry storage, are that they allow the radioactive material to cool and provide radiation shielding to workers and members of the public.

Spent Fuel Pools

Spent fuel, after it is removed from the reactor core, is safely stored in specially designed pools at individual reactor sites around the country. The spent fuel is first placed into a spent fuel pool (Figure 1), which is like a deep swimming pool with racks to hold the fuel assemblies. It allows the fuel to begin cooling. The spent fuel is moved into the water pools from the reactor along the bottom of water canals, so that the spent fuel is always shielded to protect workers. Fuel assemblies are covered by a minimum of 25 feet of water within the pool, which provides adequate shielding from the radiation for anyone near the pool.

Spent fuel pools are very robust structures that are constructed to withstand earthquakes and other natural phenomena and accidents. They are typically rectangular structures 20 to 40 feet wide, 30 to 60 feet long, and at least 40 feet deep. The outside walls are typically constructed of more than 3 feet of reinforced concrete.

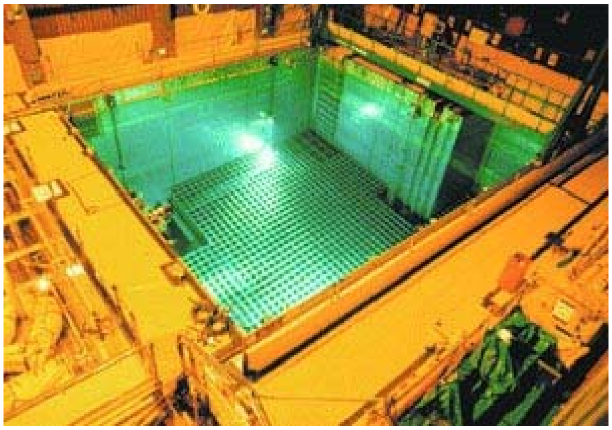

Figure 1 Typical Spent Fuel Storage Pool

Spent fuel pools at pressurized water reactors (PWRs) are commonly located within an auxiliary building near the containment. Many of the PWR pools are located in the building's interior. At boiling water reactors (BWRs), spent fuel pools are typically located at an elevated position within the reactor building, outside the primary containment area.

Some pools at the nation's nuclear plants contain up to 33 years of fuel assemblies, and many are running out of space. Current regulations permit re-racking of the spent fuel pool grid and fuel rod consolidation, subject to U.S. Nuclear Regulatory Commission (NRC) review and approval, to increase the amount of spent fuel that can be stored in the pool. Both re-racking and consolidation are constrained by the size of the pool and the heat removal capacity of the cooling systems. In the United States (U.S.), there are currently five different options for storing spent fuel. Spent fuel can be stored in a pool (wet storage) at either an operating or a decommissioning reactor. Spent fuel can also be stored in dry storage at an operating reactor, decommissioned reactor, or independent spent fuel storage installation (ISFSI) which need not be located at the nuclear power plant site. Regulations 10 CFR 73.51and 10 CFR 73.55, as applicable, describe the physical protection requirements for spent nuclear fuel stored in these various configurations.

The U.S. Department of Energy's permanent storage site in Nevada at Yucca Mountain, projected to open in 2010, is slated to be the single, long-term disposal facility for all spent fuel. Until that happens, additional storage needs can be met by dry cask storage at ISFSIs. There are currently 26 ISFSIs in the U.S. (Figure 2).

Dry Cask Storage

In the late 1970s and early 1980s, the need for alternative storage began to grow when pools at many nuclear reactors began to fill up with stored spent fuel. Utilities began looking at options such as dry cask storage for increasing spent fuel storage capacity.

Dry cask storage allows spent fuel that has already been cooled in the spent fuel pool for at least one year to be loaded into special casks. The spent fuel is loaded into a cask under water to provide adequate shielding from radiation (Figure 3). A typical cask is designed to hold approximately 2 to 6 dozen spent fuel assemblies, depending on the type of assembly. Water and air are removed. The cask is filled with inert gas, sealed, and rigorously tested for leaks.

The casks are typically steel cylinders that are either welded or bolted closed and provide a leak-tight containment for the spent fuel. Each cylinder is surrounded by additional steel, concrete, or another material to provide radiation shielding to workers and the public. Some of the cask designs, called "dual purpose" casks, have inner canisters that contain the spent fuel and can be inserted in either a storage overpack or a transportation overpack.

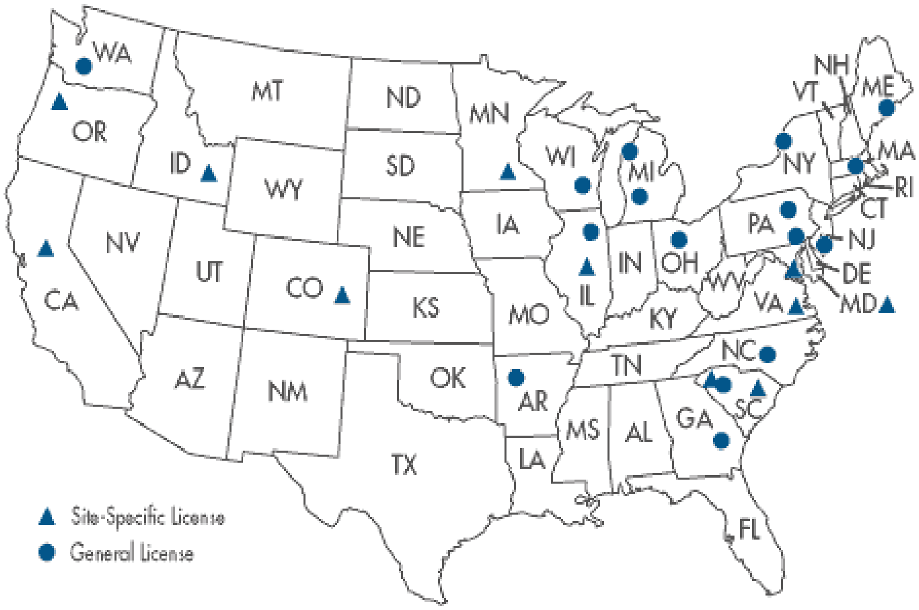

Figure 2 Independent Spent Fuel Storage Locations

There are various dry storage cask system designs. With some designs, the steel cylinders containing the fuel are placed vertically in a concrete or steel overpack (Figure 4); other designs orient the cylinders horizontally (Figure 5). The concrete or steel overpacks provide the radiation shielding. The cask designs are stored on a concrete pad at a dry cask storage site and use both metal and concrete outer cylinders for radiation shielding. An example of such a cask is a vertical stainless steel container (typically 2 inches thick with a 4-inch-thick cover), surrounded by steel-reinforced concrete (26 inches thick) within a steel shell. The structure is 18 feet tall and weighs 270,000 pounds.

Figure 3 Loading a Spent Fuel Cask under Water

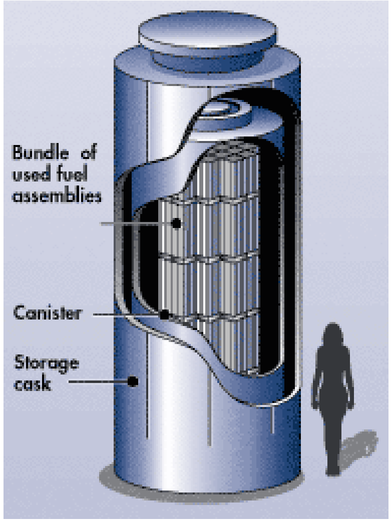

Figure 4 Vertical Canister Design

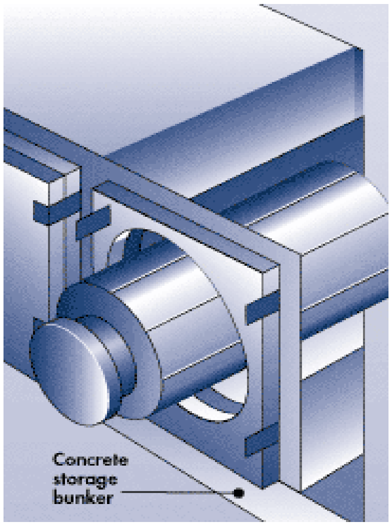

Figure 5 Horizontal Canister Design

CONSEQUENCE OF EVENT

Spent fuel storage facilities and cooling systems at operating power reactors are built to be robust but were not specifically designed to withstand a terrorist attack. Assessing the precise amount of any contamination resulting from a potential release depends on many factors, such as the type and amount of damage to the pool, location of the damage, proximity of the storage facility to populated areas, and meteorological conditions at the time of the event.

The only postulated scenario at a decommissioned power reactor spent fuel pool that could result in a significant off-site radiological release is a beyond-design-basis event commonly referred to as a “zirconium fire.” An event sequence resulting in a zirconium fire begins with a substantial loss of water from the spent fuel pool, subsequently uncovering the spent fuel. Uncovering the spent fuel could result in a heat-up of the spent fuel to the point where the fuel’s zirconium cladding might begin to oxidize in a rapid, exothermic, self-sustaining reaction.

COMMON VULNERABILITIES

Critical infrastructures and key assets vary in many characteristics and practices relevant to specifying vulnerabilities. There is no universal list of vulnerabilities that applies to all assets of a particular type within an infrastructure category. Instead, a list of common vulnerabilities has been prepared, based on experience and observation. These vulnerabilities should be interpreted as possible vulnerabilities and not as applying to each and every individual facility or asset.

The following is a list of common vulnerabilities found at nuclear spent fuel storage facilities.

Exhibit 1 Economic and Institutional Vulnerabilities	
Economic and institutional vulnerabilities are those that would have extensive national, regional, or industry-wide consequences if exploited by a terrorist attack.	
1	A successful attack or diversion of waste materials could cause widespread loss of public confidence.
2	An incident could lead to new nation-wide security procedures.

Exhibit 2 Site-Related Vulnerabilities	
Site-related vulnerabilities are conditions or situations existing at a particular site or facility that could be exploited by a terrorist or terrorist group to do economic, physical, or bodily harm or to disable or disrupt facility operations or other critical infrastructures.	
Site Access and Access Control	
1	Sites may be potentially vulnerable to aircraft attack.
2	Spent fuel pool or on-site dry storage facilities may be potentially vulnerable to a very large vehicle-borne explosive device.
3	Rules of engagement and use of force may be narrowly defined for situations in which a threat to a guard’s life is not imminent.
4	Sites are typically located adjacent to water bodies, and, therefore, potentially vulnerable to water-borne threats.
Operational Security	
5	Detailed information may be publicly available (e.g., Environmental Impact Statements).
6	Critical assets may be easy to identify.
7	Websites may provide information on site locations and other data.
8	Lists of spent fuel storage locations may be available through public sources.

OTHER INFORMATION

Nuclear power plants in the U.S. are commercial facilities that are owned and operated by various entities. For decades, however, these facilities have been licensed and regulated by the NRC. The Atomic Energy Act of 1954, as revised, and the Energy Reorganization Act of 1974 give NRC the responsibility for protecting public health and safety, the environment, and the common defense and security from the effects of radiation from nuclear reactors, materials, and waste facilities. To accomplish this goal at nuclear power plants, the NRC established a regulatory program, described in Title 10, "Energy," Chapter 1, of the *Code of Federal Regulations* (CFR). As a part of this program, 10 CFR Part 73 contains requirements that must be implemented by licensees at nuclear power plants to protect spent fuel against radiological sabotage (Figure 6). To define the threat that must be protected against, NRC established a design-basis threat (DBT) for radiological sabotage (10 CFR 73.1(a)(1)). This DBT describes the approximate size and attributes of the threat. To ensure that the DBT remains a current characterization of the threat, the NRC, in close coordination with the national intelligence and law enforcement community, constantly monitors the actual threat environment, continually examines the assumptions underlying the DBT, and makes changes, as appropriate. The NRC also has a continuing inspection program to review the implemented physical protection program at each nuclear power plant to ensure continued compliance with NRC regulations. To accomplish this goal at independent ISFSIs, the NRC established a regulatory program, described in 10 CFR 73.51, which contains requirements for the physical protection of stored spent nuclear fuel and high-level radioactive waste. At ISFSIs, the licensee must protect against loss of facility control rather than against the DBT for radiological sabotage.

Figure 6 Protection of Spent Fuel Casks

The NRC took security seriously well before the September 11, 2001, terrorist attacks and has redoubled its efforts since then in light of the increased threat. As discussed above, nuclear power plants already had security measures in place in accordance with NRC regulations, making them among the most robust and well-protected civilian facilities in the country. ISFSIs had protection in place commensurate with their lower associated risk. Nevertheless, the events of September 11 have resulted in many enhancements to ensure that these facilities remain secure.

Following these attacks, the NRC immediately advised nuclear facilities to go to the highest level of security in accordance with the system in place at the time. A series of advisories, orders, and guidance documents have since been issued to further strengthen security at nuclear power plants and ISFSIs. Details on the specific actions taken are sensitive, but for facilities such as power reactors, they generally include increased security patrols, augmented security forces, additional security posts, installation of additional physical barriers, vehicle checks at greater stand-off distances, enhanced coordination with law enforcement and intelligence communities, and more restrictive site access controls for all personnel, as well as expanded, expedited, and more thorough employee background checks.

In NUREG-1738, the NRC concluded that the risk from a spent fuel pool zirconium fire at decommissioning plants is very low and well below its safety goals for operating reactors. The study found that the event sequences most important to the zirconium fire risk at decommissioning plants are large (catastrophic) earthquakes and spent fuel cask drop events.

It must be noted that current analyses are underway. The analyses use updated methods and build upon results from thermal hydraulic and severe accident research and experience from probabilistic risk assessments. Preliminary insights from current analyses indicate that even if water was lost and fuel was not cooled, the consequences of the accident would be less severe than previously listed in NUREG-1738.

NUREG-1738 analyses were based on more conservative assumptions and analytic models than those used for the current analyses. The current analyses use more sophisticated models and techniques that allow more realistic calculations and reductions in unnecessary conservatism. Even if water was lost and fuel was not cooled, the current analyses suggest the radioactive release would be smaller and would begin later. There would thus be more time to implement effective protective measures to reduce health effects and land contamination.

If a serious accident were to occur, the NRC would activate incident response at its Headquarters Operations Center and one of its four Regional Incident Response Centers (Region I in King of Prussia, Pennsylvania; Region II in Atlanta, Georgia; Region III in Lisle, Illinois; and Region IV in Arlington, Texas). The NRC's highest priority is to provide expert consultation, support, and assistance to state and local public safety officials responding to the event. Once the NRC incident response program was activated, teams of specialists would be assembled at the Headquarters Operations Center and appropriate Regional Incident Response Center to obtain and evaluate event information and assess the potential impact of the event on public health and safety and the environment.

Scientists and engineers would analyze the event and evaluate possible recovery strategies. Meanwhile, other experts would evaluate the effectiveness of protective actions recommended by the licensee and implemented by state and local officials to minimize the impact on public health and safety and the environment. Communications with the news media, state, other federal agencies, Congress, and the White House would be coordinated through the Headquarters Operations Center.

If event conditions warranted, the NRC would immediately dispatch a team of experts from the Regional Office to the site. An Executive Team would be assembled in the Headquarters Operations Center to lead the response. (The Executive Team is typically headed by the Chairman of the NRC or a Commissioner acting as Chairman.) Once the Site Team was in place, authority to manage event-related activities would be turned over to that team. The Site Team would serve as the NRC's eyes and ears on site, allowing a firsthand assessment of the situation and face-to-face communications with all participants. The Headquarters Operations Center would provide round-the-clock logistical and technical support throughout the response.

USEFUL REFERENCE MATERIAL

1. *Code of Federal Regulations*, 10 CFR 73.51.

2. *Code of Federal Regulations*, 10 CFR 73.55.

3. NUREG-1571, "Information Handbook on Independent Spent Fuel Storage Installations," (December 1996).

4. Nuclear Regulatory Commission Website [http://www.nrc.gov/].

5. How Stuff Works Website [http://www.howstuffworks.com/].

6. Nuclear Tourist Website [http://www.nucleartourist.com/].

7. Nuclear Energy Institute Website [http://www.nei.org/].

8. Nuclear Control Institute Website (http://www.nci.org/).

9. Nuclear Regulatory Commission, *GE Morris Order, Modifying License, Docket Number 72-01*, May 23, 2002.

10. *Nuclear Regulatory Commission News*, No. 02-063, May 24, 2002.

11. Nuclear Regulatory Commission, *(Chairman Merserve's) Report to the Senate*, June 5, 2002.

12. Nuclear Regulatory Commission, *Regulatory Issue Summary 2002-12c*, August 19, 2002.