CHARACTERISTICS AND COMMON VULNERABILITIES
INFRASTRUCTURE CATEGORY: NUCLEAR POWER PLANTS

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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 power plants, which are located in 31 states and produce more than 20% of United States electricity requirements.

NUCLEAR POWER PLANT CHARACTERISTICS

A nuclear power plant is an arrangement of components used to generate electric power. Nuclear power plants used in the United States (U.S.) are either boiling water reactors (BWRs) or pressurized water reactors (PWRs). Boiling water reactors (Figure 1) use a direct cycle in which water boils in the reactor core to produce steam, which drives a steam turbine. This turbine spins a generator to produce electric power. Pressurized water reactors (Figure 2) use an indirect cycle in which water is heated under high pressure in the reactor core and passes through a secondary heat exchanger to convert water in another loop to steam, which in turn drives the turbine. In the PWR design, radioactive water/steam never contacts the turbine. Except for the reactor itself, there is very little difference between a nuclear power plant and a coal- or oil-fired power plant.

Nuclear Power Plant Common Components

The following seven major components are common to all nuclear power plants:

1. Nuclear reactor core, reactor vessel, and containment structure;
2. Heat transfer/working fluid loop;
3. Cooling water system;
4. Plant control room and reactor control system;
5. Spent fuel storage;
6. Generation transformers; and
7. Transmission lines and downstream substations.

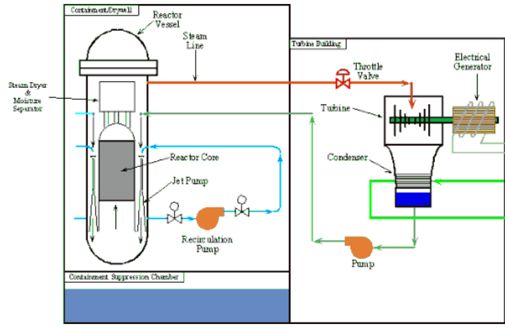


Figure 1 Boiling Water Reactor

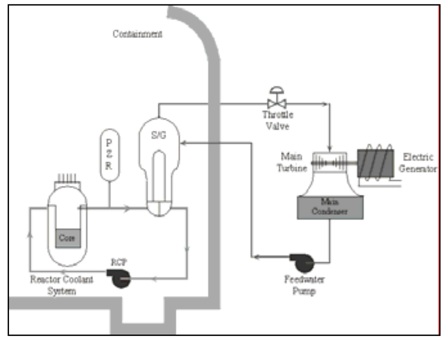


Figure 2 Pressurized Water Reactor

Nuclear Reactor Core and Containment

The most commonly used fuel is uranium enriched in the uranium-235 isotope. Typically, uranium is formed into pellets approximately 0.5 inch in diameter and 1.0 inch long. The pellets are stacked into long rods and assembled into fuel bundles; the bundles are then arranged to form the reactor core inside the reactor vessel. Unirradiated (new) fuel is only slightly radioactive, but after fuel is irradiated in the reactor vessel, it becomes highly radioactive. About 99% of the radioactive isotopes at a nuclear power plant are contained in the fuel rods.

The reactor vessel and the containment structure provide substantial barriers and defense-in-depth protection against the release of radioactive fission products to the environment. The reactor vessel is located inside the containment structure, which is designed to withstand earthquakes and tornados. The containment structure is also designed to minimize leakage of radioactive gases or fluids. At most PWRs and at some BWRs, the containment structure is a large, reinforced-concrete building with a steel liner (Figure 3). At most BWRs, the containment structure is a steel shell, surrounded by a reinforced-concrete building with a sheet metal top.

Figure 3 Nuclear Reactor Containment Building

Heat Transfer/Working Fluid Loop

The heat transfer/working fluid loop removes heat generated by the fission process in the reactor core, creates steam, and transfers it to steam turbine-generators. The heat-removal system includes single- and double-loop heat transfer cycles. The BWR design is an example of a single-loop system in which steam created in the reactor flows directly to the steam turbines. The PWR design is an example of a two-loop system in which water in a primary loop transfers heat from the reactor core to a secondary steam loop that flows to the turbine.

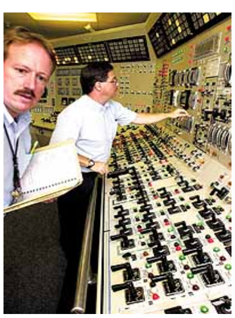
Cooling Water System

The cooling water system removes excess heat from the heat transfer/working fluid loop to the environment. Cooling water systems are composed of three general components: once-through cooling systems, natural-draft cooling towers, and mechanical-draft cooling towers. Once-through cooling systems take a large amount of water from a water supply, such as an ocean, river, or lake, and pump it through an in-plant heat exchanger to remove excess heat from the working fluid loop(s) before the working fluid is returned to the reactor or the steam generators.

In a natural-draft cooling tower, the innate buoyancy of the hot air moves the air upward through the tower, drawing in fresh, cool air through the air inlet at ground level where it cools the cooling water. No fan is required. The tower shell is usually constructed of reinforced concrete and can be as high as 650 ft; it is easily recognizable from the air and from large distances at ground level.

Mechanical-draft cooling towers use a fan to generate the airflow through the tower. Because fans are used, mechanical cooling towers are much smaller than natural-draft cooling towers; however, fan diameters of up to 30 ft are commonly used.

Plant Control Room and Reactor Control System



Modern reactors have numerous control systems. All of these systems are monitored and controlled from a central control room. The function, layout, and configuration of a nuclear power plant’s control room are typical and similar to those of other types of power plants and large industrial operations. In most nuclear power plants, the control room is accessible from inside the large steam turbine-generator building. It is secured by locked doors, but because it is located inside the guarded perimeter, it is not guarded separately.

In addition to all other plant systems, the control room houses the nuclear reactor controls. The system regulates the rate at which nuclear fission occurs and the amount of heat produced within the reactor. The basic method of accomplishing reactor control is to use control rods made of a material that absorbs neutrons. These rods are installed among the fuel assemblies in the reactor core. When an operator wants to produce more heat, the rods are withdrawn. To create less heat, the rods are inserted. The rods can also be inserted completely to shut down the reactor in the event of an accident or fuel change.

Spent Fuel Storage

All nuclear power plants have storage at the site for spent fuel. There are two types of storage: wet storage and dry storage. In wet storage, the spent fuel bundles are stored in a large pool of water, referred to as the spent fuel pool. In dry storage, the spent fuel bundles are stored in concrete and steel casks or modules. All irradiated fuel has continuous heat generation from the decay of fission products (referred to as decay heat). Wet storage includes a heat removal system that uses a pump and heat exchangers. In dry storage, however, the decay heat has reduced over time such that natural conduction and convection to the surrounding air is sufficient to remove the heat.

Generation Transformer

Every nuclear power plant has large electrical transformers located on site just outside the turbine generator building or adjacent to the plant site. These transformers are very large, expensive devices that are difficult and time-consuming to replace. Spares are not generally available.

Transmission Lines and Downstream Substations

Although not technically part of a nuclear power plant site, the transmission lines that connect the plant to the electric power grid are necessary to operate the plant continuously. Any sudden loss of significant transmission capacity, either by a downed tower or line or by destruction or disruption of a downstream substation if large enough and at the right network location, could cause the plant to shut down and interrupt power production. Because these systems extend for miles outside the plant boundary and are not physically guarded, they are vulnerable to terrorist attack.

CONSEQUENCE OF EVENT

Two consequences are of concern. First, malevolent action could possibly damage the nuclear power plant, resulting in a radioactive release that could impact public health and safety. Second, malevolent action could possibly cause the reactor to shut down or damage the electrical generation transformer or the transmission lines, thus interrupting power production or power distribution. All nuclear power plants have emergency generators (typically diesel generators) to supply power to vital equipment at the site in the event of the loss of off-site power.

The U.S. Nuclear Regulatory Commission (NRC) ensures that adequate physical protection measures are in place at nuclear power plants to protect against the design-basis threat (DBT) for radiological sabotage so that malevolent events do not occur that would negatively affect public health and safety. The licensee is responsible for establishing and maintaining an on-site physical protection system and security organization that would ensure that the plant retains the capability to safely shut down the reactor and ensure long-term heat removal in light of a malevolent act by the DBT against the facility. The objective of the licensee's physical protection program is to provide a high degree of assurance that malevolent activities do not constitute an unreasonable risk to public health and safety.

COMMON VULNERABILITIES

Nuclear power plants are likely the most hardened publicly owned infrastructure in the U.S. Like other critical infrastructures and key assets they 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 power plants and associated transmission lines.

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	Loss or reduction of nuclear generation capacity could have significant economic and financial impacts.
2	A successful attack or diversion of waste materials could cause widespread loss of public confidence.
3	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	Public roads may be in close proximity to critical transformer or transmission line assets.
2	Critical assets such as transmission substations and switchyards may be set close to the perimeter fence.
3	Plants with once-through cooling may have access points at cooling water intake/outlet, which may potentially be vulnerable.
4	Plants may be potentially vulnerable to an aircraft attack.
	Continued on next page.

5	Rules of engagement and use of force may be narrowly defined for situations where a threat to the guard's life is not imminent. Guards may be subject to individual state criminal prosecution for actions taken during the performance of their official duties.
Operational Security	
6	Detailed information may be publicly available (e.g., Environmental Impact Statements).
7	Critical assets not located inside buildings may be easily identifiable.
8	Web sites may provide detailed information on plant locations, critical assets, and other data.
9	Lists of nuclear power plant locations are readily available through public sources.
Reactor and Process Control	
10	The potential may exist for an intruder to hack into peripheral plant systems.
Emergency Planning and Preparedness	
11	Spare parts that are large and/or expensive may be in short supply. Some parts, like generation transformers, may have long lead times to obtain replacements.
Plant Interfaces (Inputs and Outputs)	
12	Loss or destruction of major transmission lines from a plant or major substations could result in plant shutdown.
13	Key assets in electric substations and switchyards may be vulnerability to explosive attacks, although the charges would have to be placed in direct contact.
14	Utility communications may be unencrypted and frequencies may be able to be scanned by adversaries to determine operating conditions, location of employees, ongoing activities, etc.

OTHER INFORMATION

Role and Activities of the Nuclear Regulatory Commission

Nuclear power plants in the U.S. are commercial facilities 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 the 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, the NRC established a regulatory program, described in Title 10, "Energy," Chapter 1, of the *Code of Federal Regulations* (CFR). As part of this program, 10 CFR Part 73 contains requirements that must be implemented by licensees at nuclear power plants to protect against radiological sabotage. To define the threat that must be protected against, the NRC established a 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 the NRC regulations. Additional requirements that must be implemented by licensees at nuclear power plants to protect against radiological sabotage are contained in 10 CFR Part 26.

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 the NRC regulations, making them among the most robust and well-protected civilian facilities in the country. Nevertheless, the events of September 11 have resulted in many enhancements to ensure that these facilities remain secure.

Following those 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. Details of 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.

In addition to physical protection measures, the NRC requires expanded, expedited, and more thorough background checks for nuclear power plant employees to ensure that they are reliable and trustworthy. Every employee who has unescorted access is required to pass background checks, which includes, verification of identity, an examination of past employment and a suitable inquiry with past employers, references, credit history, verification of education and military service history, and a Federal Bureau of Investigation (FBI) criminal record check, as well as pre-access psychological, drug, and alcohol testing. While on the job, each employee is also under a behavior observation program and subject to random drug and alcohol testing.

The adequacy of these protective measures is subject to detailed review and inspection by the NRC, including periodic commando-type exercises designed to probe for weaknesses so that any corrections can be made promptly. The NRC has conducted force-on-force security exercises at nuclear power plants since 1991. These are tough, simulated commando-style raids designed to identify shortcomings in security personnel performance or strategy. An important component of these reviews includes enhanced “tabletop” exercises (facilitated discussion using credible scenarios) that now involve a wide array of federal, state, and local law enforcement and emergency planning officials. In addition to the NRC-evaluated exercises, many licensees conduct frequent force-on-force exercises as part of their guard force training programs. Identification of a significant weakness during an exercise leads to immediate corrective or compensatory measures. Furthermore, the NRC is taking steps to augment training and qualifications requirements for security personnel at nuclear power plants, especially in the area of tactical response. This includes more frequent firing of weapons, more realistic training under different conditions, and firing against moving as well as fixed targets. To minimize security personnel fatigue, the agency is establishing detailed requirements for a 48-hour workweek, except for special circumstances, and limits on the amount of overtime guards can work.

The NRC requires licensees to have detailed emergency preparedness procedures for responding to events, making timely notifications to appropriate authorities, and providing accurate radiological information. These licensees are required to exercise their programs on a periodic basis and to coordinate their planned actions with federal, state, and local officials. Since September 11, the NRC has issued orders to its licensees requiring that emergency plans be reviewed and revised as necessary to ensure that they are compatible with the heightened security posture that currently exists at each plant.

The NRC is also coordinating with the Bureau of Citizenship and Immigration Services (BCIS) (formerly the Immigration and Naturalization Service) in an effort to facilitate the ability of licensees to validate the employment eligibility of employees at nuclear power plants. This effort seeks to ensure that only persons authorized to work in the U.S. are employed in nuclear power plants. However, there are limitations on the NRC’s and its licensees’ ability to obtain and use information available in BCIS and other federal data bases for this purpose. For example, current law (8 U.S.C.§1342b) prohibits discrimination on the basis of alienage in the context of employment. This section has been interpreted to preclude asking noncitizens for more proof of identity than citizens. In addition, in the process of dealing with access authorization, the Constitutional rights of both citizens and noncitizens must be protected.

In addition to requiring licensees to implement additional protective measures, the NRC is responding to the terrorist threat in a comprehensive fashion. The NRC has undertaken a comprehensive re-evaluation of the agency’s safeguards and security program, regulations, and procedures that has resulted in numerous security improvements. As part of this program review, the NRC has revised its DBT for radiological sabotage. It should be noted, however, that it will take some time to implement all associated changes in physical protection measures.

The NRC has studies under way to further investigate potential vulnerabilities of nuclear power plants. Although nuclear power plants were not designed to withstand an intentional attack from a large commercial airliner, reactor containments are massive structures, typically constructed with 2 to 5 feet of steel-reinforced concrete. The containments have an interior steel lining and redundant safety equipment to add further protection. Notwithstanding this, the NRC has completed a preliminary vulnerability assessment for deliberate aircraft crashes on power reactors. While these studies are being conducted, certain interim compensatory measures have been put in place at reactor sites. For example, improved capabilities to respond to an event that results in damage to large areas of a nuclear power plant from explosions or fires, to protect against land attacks, including the use of a larger vehicle bomb, and to protect against water-borne attacks have been implemented.

The NRC is also working with appropriate federal agencies to deal with a potential airborne threat. For example, the NRC has worked with the Federal Aviation Administration and the U.S. Department of Defense to put in place a Notice to Airmen advising pilots to not circle or loiter above nuclear power plants and other nuclear facilities, or they can expect to be interviewed by law enforcement personnel.

The NRC developed a new Threat Advisory and Protective Measures System that corresponds to the color-coded Homeland Security Advisory System that allows government officials to communicate the nature and degree of terrorist threats consistently nationwide. The NRC's system identifies specific actions to be considered by NRC licensees for each threat level to counter projected terrorist threats. If a credible threat emerges against a specific nuclear facility, additional protective measures may be implemented even without a change in the overall threat level.

Finally, the NRC has provided legislative proposals to Congress detailing specific initiatives that would further enhance security of NRC-licensed activities. These proposals address a spectrum of activities. One provision would authorize guards at NRC-regulated facilities to use deadly force to protect property significant to the common defense and security. This would give guards protection from state criminal prosecution for actions taken during the performance of their official duties. Another provision would allow the NRC, in consultation with the Attorney General, to confer upon guards at NRC-designated facilities the authority to possess or use weapons that are comparable to those used by the DOE's guard forces. Some state laws currently preclude private guard forces at NRC-regulated facilities from utilizing a wide range of weapons. Another provision would make it a federal crime to bring unauthorized weapons and explosives into NRC-licensed facilities. The NRC would also make federal prohibitions on sabotage applicable to the operation and construction of certain nuclear facilities.

USEFUL REFERENCE MATERIAL

1. *Code of Federal Regulations*, 10 CFR Part 73.

2. *Code of Federal Regulations*, 10 CFR Part 26.

3. U.S. Nuclear Regulatory Commission Website [http://www.nrc.gov/].

4. *Nuclear Regulatory Commission Fundamentals Course Manual – Boiling Water Reactors*.

5. *Nuclear Regulatory Commission Fundamentals Course Manual – Pressurized Water Reactors*.

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

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

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

9. Nuclear Control Institute Website [http://www.nci.org/].

10. American Nuclear Society Website [http://www.ans.org/].