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Answers to Questions

NUCLEAR ENERGY

U.S. Department of Energy
Office of Nuclear Energy,
Science, and Technology

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Introduction

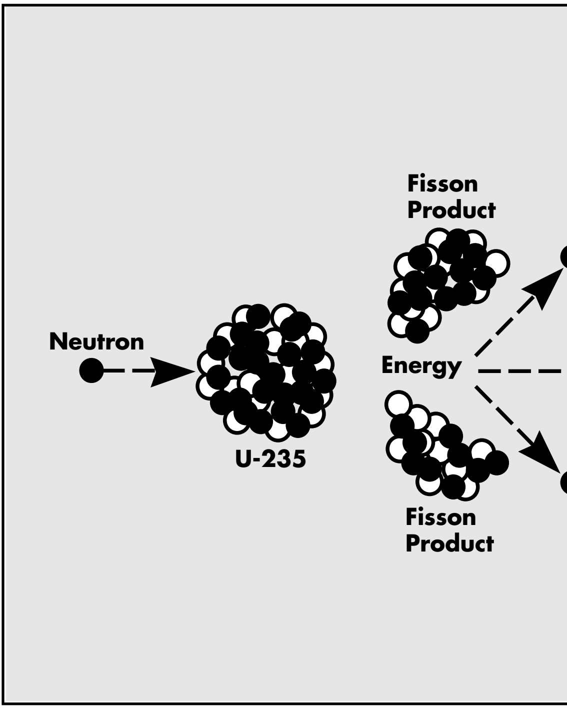
When Thomas Edison and his colleagues perfected the light bulb in 1879, they could not foresee the many ways their invention would improve civilization. But now electricity allows us to heat, cool, and light our homes. It enables us to cook meals, watch television, and listen to music. It powers computers for our homes and businesses and makes modern medical diagnosis and treatment possible. Electricity allows us to explore the vastness of space and to study the tiniest molecules.

Since 1982, nuclear energy has been second only to coal as an energy source for production of electricity in the United States. It surpasses oil, natural gas, and hydroelectric power. Today, over 100 nuclear power plants produce about 21 percent of all the electricity generated in the U.S. Although various new energy technologies hold promise for the future, coal and nuclear energy are the two energy sources most capable of meeting the growing electrical needs of the U.S. in the next few years.

Here are the answers to some frequently asked questions about nuclear energy. The answers may help you to better understand this source of electricity.

What is nuclear energy?

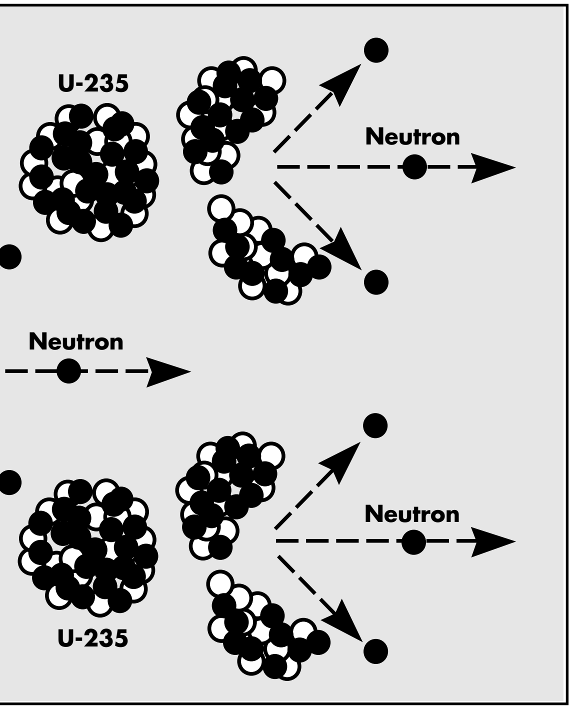
Atoms are the building blocks of matter. They are also the source of nuclear energy. A strong energy bond holds particles together inside the nucleus of an atom. If the nucleus is broken apart, or split, it releases energy in a process called *nuclear fission*. Under precise conditions, we can split an atom's nucleus by striking it with small particles called *neutrons*. Splitting certain very heavy atoms, such as some forms of uranium, into lighter atoms allows additional neutrons and energy to be produced. Under the right circumstances, these neutrons will strike other uranium atoms, causing more atoms to fission. When this takes place as a continuous chain reaction under controlled conditions, it releases heat in useful amounts. It also makes the uranium and some fissioned atoms intensely radioactive.



What is radiation?

Radiation is a natural energy force that has always existed on earth and throughout the cosmos. It is energy transferred over distance through waves or particles. The term radiation can include such things as light and radio waves, but it usually refers to *ionizing radiation*. We cannot detect ionizing radiation with any of our five senses. It is made up of energized particles or waves of pure energy. Its name refers to its ability to ionize, or electrically charge, stable atoms. Ionizing radiation can cause a change in the chemical composition of many things — including living tissue.

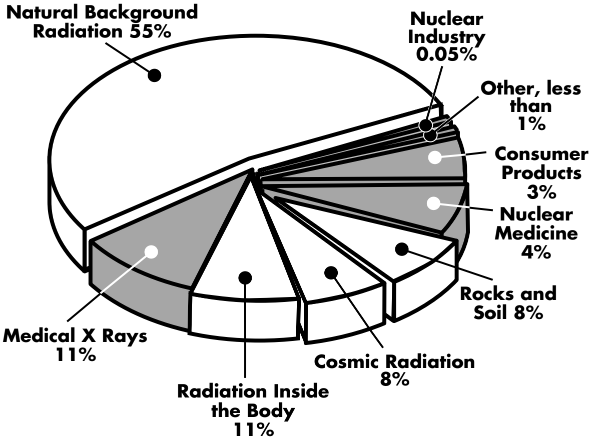
Some naturally occurring elements, such as uranium, radium, and thorium, give off ionizing radiation as they change into more stable forms. Man-made elements like plutonium and curium also have this property. Such elements are said to be *radioactive*.



Where does radiation come from?

We receive radiation from both natural and man-made sources. The primary sources of natural radiation are cosmic rays from outer space and naturally radioactive elements in the earth's crust. These sources are *natural background radiation*. The altitude at which we live and the types of rocks that surround us affect the amount of background radiation we receive. Even brick houses and the ground we walk on are slightly radioactive because of the minerals they contain. Natural sources of radiation are also found in plants, animals, and the human body. For example, bones contain naturally radioactive potassium, and body tissues contain radioactive carbon.

We also receive radiation from man-made sources. In the U.S., most man-made radiation comes from mechanical and dental sources, including X-rays, medical diagnoses, and



Note: Shaded portion indicates man-made radiation.

Source: National Council on Radiation Protection and Measurements, NCRP Report No. 93.

treatment. It also comes from smoke detectors, television sets, nuclear power plants, and emissions from coal-fired power plants.

In nuclear power plants, uranium fuel becomes intensely radioactive as the reactor produces heat. However, the amount of radiation released during the normal operation of nuclear power plants is very small compared to other man-made and natural sources. A National Academy of Sciences study* estimates that a person living in the U.S. receives, on the average, less than 1 percent of his or her total annual radiation exposure from nuclear power industry operations.

Does radiation present a hazard to public health?

People have always lived with small amounts of natural background radiation with no ill effects. Yet, we know that extremely large doses of radiation are hazardous. Too much radiation can cause sickness, increased cancer risk, or death.

We usually measure the biological effects of radiation in a unit called *a millirem* (mrem). Most people receive a total of about 300 mrem of radiation a year from all sources — both natural and man-made. Most of this exposure comes from natural radiation in the environment and medical diagnosis and treatment. Limits for radiation exposure from man-made sources have been established through extensive scientific research. The U.S. Nuclear Regulatory Commission (NRC) continually reviews these limits to be sure they do not represent a significant risk to public health.

Permitted radiation dose levels for radiation workers are higher than for the public. That is

*Source: The Effects on Populations of Exposure to Low Levels of Ionizing Radiation, National Academy of Sciences, 1980.

because these workers voluntarily accept employment where they know they might be exposed to radiation. The NRC prescribes limits for the amount of radiation that workers or members of the public can be exposed to from all pathways — air, water, etc. These regulations apply to operators of nuclear power plants and to industrial and medical facilities licensed to use man-made radioactive materials. The NRC bases its regulations on standard radiation limits recommended by the National Council on Radiation Protection.

Statistics show that the nuclear industry is by far one of the safest for workers. The standard overall whole body radiation limit for workers in the nuclear industry is 5,000 mrem (5 rem), including the average background radiation of 300 mrem. Workers wear film badges which are monitored at regular intervals by health physicists who specialize in radiation detection. For some parts of the body, the standard radiation limits set by the NRC are higher. For instance, exposures of 18,750 mrem are allowed for hands and feet.

In practice, however, occupational exposures in the U.S. nuclear industry average less than 10 percent of the limit because of employers' adherence to the principle that all radiation exposures should be kept "as low as reasonably achievable." The average exposure for each worker in the U.S. nuclear energy industry is 290 mrem, which is only one-third of the 900 mrem per year occupational exposure of airline pilots and cabin crews who regularly fly the high-altitude New York - Tokyo route.

Some people favor more stringent limits if allowable radiation limits pose any human health and safety risk at all. But any risks from nuclear energy must be weighed against the benefits made possible by its careful use.

What is a nuclear reactor?

A nuclear reactor is the heat source of a nuclear power plant. The reactor is the part of the plant that makes it different from other electric power plants. Most electric power plants heat water and convert it into steam. This process drives a turbine generator to produce electricity. Fossil-fueled power plants produce heat by burning coal, oil, or natural gas. Nuclear power plants produce heat by the continuous fissioning of uranium atoms in the reactor. Electricity produced at a nuclear power plant is the same as the electricity produced at other power plants.

We use several commercial reactor designs in the U.S. The most widely used design consists of an 8- to 10-inch-thick steel vessel surrounding a reactor core. This vessel is about 40 feet tall and 16 feet in diameter. The reactor core contains the uranium fuel. The fuel is formed into cylindrical ceramic pellets about one-half inch in diameter and sealed in long metal tubes called *fuel pins.* *Fuel assemblies* are groups of fuel pins. A group of fuel assemblies, in turn, forms the *core* of the reactor.

How does a reactor work?

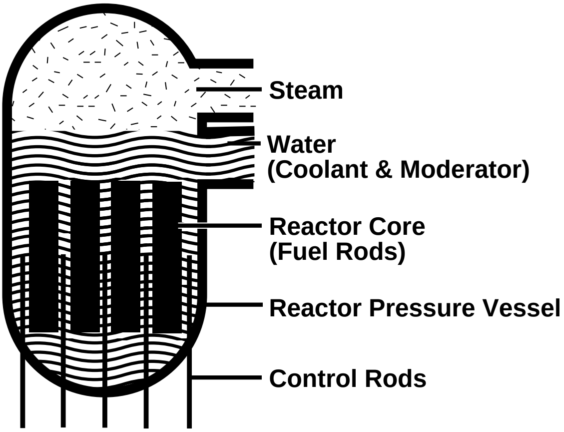
Neutrons striking uranium atoms produce heat in a chain reaction in a nuclear reactor. Control rods made of material that absorbs neutrons are placed among the fuel assemblies.

Pulling the control rods out of the core makes more neutrons available. This causes the chain reaction to speed up, producing more heat.

Inserting control rods into the core allows more neutrons to be absorbed. Then, the chain reaction slows or stops, reducing the heat.

Most commercial nuclear reactors use water to remove the heat created by the fission process. We call these *light water reactors.* Although the control rods are the main way to control the nuclear reaction, the water helps too. The greater the nuclear reaction, the more heat is produced. The increasing heat turns more water to steam, which slows down the nuclear reaction. So the water works like a brake. It prevents the nuclear reaction from running out of control. If the water is cut off, the fission process stops.

Water flowing in a closed, pressurized loop removes heat in a *pressurized water reactor*. The heat passes to a second water loop through a heat exchanger. The second loop stays at a lower pressure, allowing the water to boil and create steam. The steam turns the turbine generator and produces electricity. Afterward, the steam is condensed into water and returned to the heat exchanger.



In a *boiling water reactor*, water boils inside the reactor itself. Steam from the water goes directly to the turbine generator to produce electricity. Here, too, steam is condensed and reused.

Another type of reactor is the *high-temperature gas cooled reactor*. It relies on helium gas instead of water to remove heat produced by fission. The reactor fuel heats the helium gas. Heat from the high-temperature helium then goes through a heat exchanger to boil water and produce steam. As in other power plants, the steam drives a turbine generator to produce electric power.

From 64 to 256 fuel pins are arranged together to form a fuel assembly.

How is uranium prepared for use in a nuclear reactor?

Like other fuels, uranium ore is processed before it is used in power plants to produce electricity. Uranium ore goes to a mill after mining. At the mill, the uranium ore is crushed and ground into a fine sand. Then it is dumped into acid tanks. The acid dissolves the uranium mineral, leaving behind the sand-like crushed rock. The crushed rock is called *tailings*, and this process is called *leaching*. The acid solution is drained and treated to remove the uranium.

The next step is to refine and purify the material into a uranium compound called *yellowcake* and convert it into gaseous uranium hexafluoride.

Enriching the uranium hexafluoride increases the uranium atoms that fission easily and makes the fuel more efficient. The enriched uranium is taken to a fuel fabrication plant and converted from a gas to uranium dioxide powder. The powder is pressed into small cylindrical ceramic pellets. They are then ground to a specific size. These pellets later become fuel in a nuclear reactor.

How is a nuclear power plant licensed and regulated?

A utility must follow a lengthy series of licensing procedures before it can build and operate a nuclear power plant in the U.S. These include extensive technical reviews and public hearings. This open and detailed process protects public health and safety and the environment.

The NRC enforces comprehensive nuclear power plant licensing regulations. The existing NRC licensing process has two steps: A utility must first get a permit to build the plant, and then another permit to operate it. The NRC will not grant either permit unless it is satisfied that the plant can operate safely.

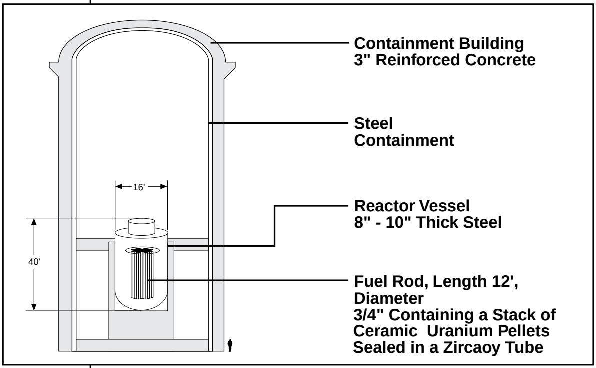
A utility must submit a formal application to the NRC to receive a construction permit to build a power plant at a particular site. The application must describe the design and location of the proposed plant and all safety systems. Both the NRC and the Advisory Committee on Reactor Safeguards (ACRS), an independent, technical advisory group, review the application. The ACRS recommends to the NRC whether or not to issue a permit. At the same time, the NRC performs an environmental review and issues a draft Environmental Impact Statement for public comment. Public hearings are required to give private citizens, community groups, and state and local officials an opportunity to express their views on the plant.

The NRC may authorize limited amounts of work before granting a construction permit. However, it grants this *Limited Work Authorization* only after reviewing the environmental findings and determining that they satisfy the safety conditions. After receiving the proper permit, work on a facility can proceed. When construction reaches the point where design and operating information is available, the utility can apply for an operating license. This application goes through essentially the same rigorous examination as the construction permit application.

The regulatory process does not end when an operating license is issued. Throughout the construction and operation of a plant, the NRC conducts inspections to ensure strict compliance with licensing regulations. It also receives annual reports from the utility about plant operations and special reports on unusual occurrences. All of these reports are available to the public upon request. If there are any violations, the NRC can fine the utility or revoke its license.

How safe are nuclear power plants?

Nuclear energy to produce electricity commercially began in the U.S. in 1957. Since then, it has proven itself as one of our safest energy technologies. Safety is a major consideration throughout the design, construction, and operation of a nuclear power plant. Hundreds of systems monitor, control, and support the safe operation of the reactor at each power plant. These systems provide maximum safety and reliability and reduce the chance of an accidental release of radioactivity into the environment.



The fuel used in nuclear power plants becomes intensely radioactive and thermally hot. For this reason, nuclear power plants have many physical barriers to guard against the accidental release of this radioactive material. These barriers include the ceramic form of the fuel pellets; the metal encasing the fuel pins; the reactor vessel with 8- to 10-inch-thick walls of steel; and a *containment building* with a lining of 3/4-inch steel and walls of reinforced concrete 3 or more feet thick. This containment building is strong enough to withstand earthquakes, violent storms, and even the direct impact of a large aircraft. The design prevents radioactive material from escaping into the environment even if there are serious mechanical failures or operator errors at the plant.

Engineered safety systems help prevent reactor accidents and lessen the effects if accidents occur. All crucial safety systems have backup systems that duplicate their jobs. For example, huge stainless steel pipes about 2 feet in diameter carry water to the reactor core, where it cools the fuel. Any of several independent emergency cooling systems included in the design of the plant can cool the reactor adequately if the others fail.

Another vital part of nuclear power plant safety is the intensive training and preparedness of the people who operate the power plant. Reactor operators are trained and tested on the procedures of power plant operation. To train operators, utilities use sophisticated power plant *simulators* — replicas of the control room of a real power plant. The simulators are computer controlled, allowing the operators to gain practical experience in managing all types of normal and unusual occurrences without any danger to the public or the environment.

The nuclear industry has rigid safety standards, which the NRC sets and regulates. Utilities operating nuclear power plants must prove to the NRC that each plant can meet these stringent safety standards. Periodic inspections also ensure that each facility operates safely. Utilities face severe financial penalties if NRC inspections show that the plant is not operating in full compliance with federal regulations.

Some people think a nuclear reactor can explode like an atomic bomb. This cannot happen. A nuclear explosion requires a very high concentration of fissionable uranium. That is the form that splits to release energy. Fuel in nuclear power plants has a very low concentration of fissionable uranium — only about 3 percent. It releases energy at a very low rate. An atomic bomb releases tremendous amounts of energy instantaneously.

Since 1957, utilities in the U.S. have operated commercial nuclear power plants. During this time, no one in the U.S. has died or

Simulated control rooms are used to train nuclear power plant operators to be prepared for emergencies.

been injured as a result of operations at a commercial nuclear power plant. Efforts to ensure that nuclear power plants maintain this safety record are constantly emphasized, and the record compares favorably with all other ways of making electricity.

What does the term *meltdown* mean?

A reactor core meltdown is one of the most thoroughly studied nuclear accident scenarios. During normal operation, water circulating through the reactor vessel cools the reactor core. This keeps the reactor's temperature well below the 5,000 degrees Fahrenheit melting point of the fuel. For a meltdown to occur, the cooling water would have to be lost from around the fuel for an extended period, allowing fuel pins and pellets to overheat. To prevent this, nuclear power plants have many independent cooling systems that come on automatically if there is a loss of coolant.

Even if reactor fuel melts, the molten fuel cannot melt through the reactor vessel and the reinforced concrete containment building. Extensive studies made of this accident scenario show that if all emergency cooling systems failed, the fuel would cool before it could pass through the containment building into the environment. There has never been a meltdown at a nuclear power plant in the U.S., although some melting of fuel assemblies did occur during the accident at Three Mile Island in 1979.

What happened in the accident at Three Mile Island?

On March 28, 1979, the Three Mile Island (TMI) Nuclear Power Station near Harrisburg, Pennsylvania, experienced this country's most serious accident in a commercial nuclear power plant. TMI's Unit #2 suffered a loss-of-coolant accident in which the reactor's primary cooling system failed. Operators made a relatively minor incident more serious by cutting off backup systems. This error caused the water level to drop low enough to uncover all but about 2 feet of the reactor's 12-foot-long fuel assemblies. Without cooling water surrounding the fuel, its temperature exceeded 5,000 degrees Fahrenheit. This caused melting and damage to a large part of the reactor core. As a result of this damage, radioactive material normally confined to the fuel escaped into the reactor's cooling water system. It was several hours before the operators understood the size of the problem. By then, the core was damaged.

The Three Mile Island Nuclear Power Station near Harrisburg, Pennsylvania.

The accident at TMI was a serious commercial reactor accident from an economic standpoint. It also pointed out the need to keep seeking ways to improve power plant safety and training. However, the safety systems and protective barriers designed into the facility protected TMI personnel and the public. There were no injuries during the accident, and no offsite property contamination. Recent studies of the population near the TMI plant show no change in the normal incidence of cancer.

What changes has the nuclear industry made since the TMI accident?

The U.S. electric power industry responded quickly to lessons learned from the TMI accident. The NRC reviewed and enhanced training and certification procedures for nuclear power plant operators. As a result, the following changes were made:

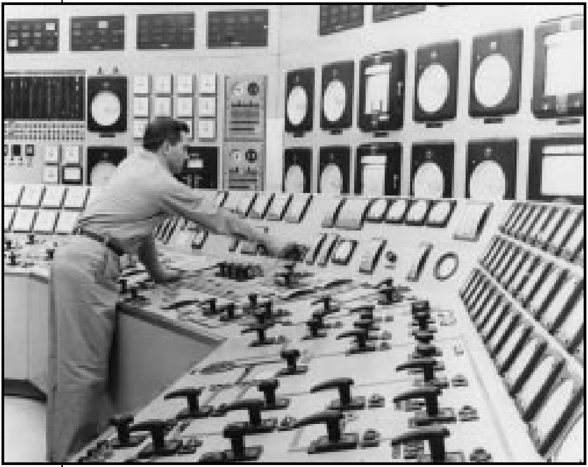
- Training requirements for plant operators are stricter.
- Operator trainees must make higher test scores than before to become licensed operators.
- All licensed operators must complete additional periodic retraining courses to keep their skills at the highest levels.

Many equipment changes also increased safety:

- Control rooms have more instruments to improve monitoring of reactor conditions.
- Communications equipment and procedures are better, and changes in control room layout have improved efficiency.

- Improved monitoring and testing equipment better detect radiation in the air and water. This helps operators track the condition of the reactor when problems occur.

The NRC has also made the rules for emergency procedures stricter. Now each utility must have emergency procedures to report plant status, coordinate personnel, and support reactor operators in case of an accident. Emergency plans and procedures for surrounding communities have been upgraded, and coordination among federal agencies, utilities, and state and local governments has been improved.



Nuclear reactor control room.

Why was the Chernobyl accident so serious?

On April 26, 1986, an accident occurred at the Chernobyl Atomic Power Station in the Soviet Union. It caused serious core damage, a fire, and the release of a large amount of radioactivity into the environment. Many people were hospitalized for radiation exposure, and 31 deaths occurred among the firefighters and emergency personnel who worked at the scene. During the days following the accident, more than 100,000 people were evacuated from the area.

Multiple operator errors, combined with the Chernobyl reactor design, allowed a large amount of radioactivity to escape into the environment. The Chernobyl reactor design was unique to power plants used inside the Soviet Union. It had no containment structure to prevent radioactivity from escaping. The Chernobyl plant also had other design flaws. In addition, operators performing experiments made a series of crucial mistakes that caused an uncontrollable reaction. This destroyed the reactor core and released a large amount of radioactivity. Because of the design flaws and the lack of a containment structure, a plant like Chernobyl could not be licensed to operate in the U.S.

What is nuclear waste?

Nuclear waste is material that is either radioactive itself or contaminated by radioactive elements. It includes the byproducts of mining ore, producing electricity in commercial reactors, processing defense materials, and preparing nuclear medicine.

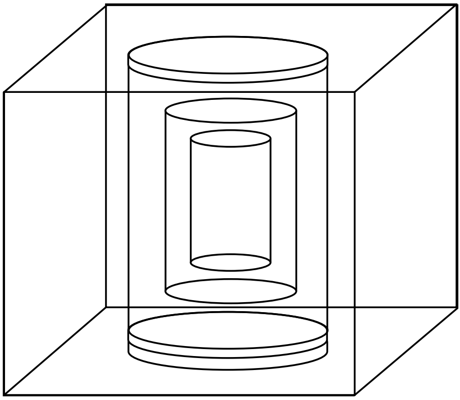
Nuclear waste may be either low level or high level. Many commercial, industrial, and medical users produce low-level waste. This includes items such as discarded protective clothing, filters, mops, brooms, rags, and other slightly contaminated items. Low-level waste has a low level of radioactivity that decays relatively quickly. It reaches background levels of radioactivity within about 100 years or less.

High-level waste comes from the production of electricity in commercial nuclear power plants or during the production of nuclear materials for national defense. At power plants, the spent (used) fuel assemblies hold this waste along with the remaining uranium and plutonium. High-level waste has high-energy radiation.

How does the United States dispose of nuclear waste?

Because of the differences in levels of radioactivity, disposal of low-level and high-level wastes is handled in different ways. Low-level waste is placed in shallow burial sites that are regulated. States that produce low-level waste are responsible for disposing of it.

High-level waste from nuclear power plants is mostly in the form of spent fuel. Spent fuel is now stored in specially designed pools of purified water at the reactor site. The water serves as a radiation shield and removes heat from the spent fuel. Although the present method of storing spent fuel has been proven safe, available storage space is filling up. The Department of Energy is working closely with



Schematic drawing showing multiple barriers of proposed spent fuel storage/disposal configuration.

industry to find the best solution to this problem. Using existing technology, it is possible to design, construct, and safely operate a high-level waste repository. The Department of Energy is currently studying Yucca Mountain in Nevada to determine whether the environmental characteristics of the site make it suitable for permanent high-level waste disposal.

How is high-level waste transported?

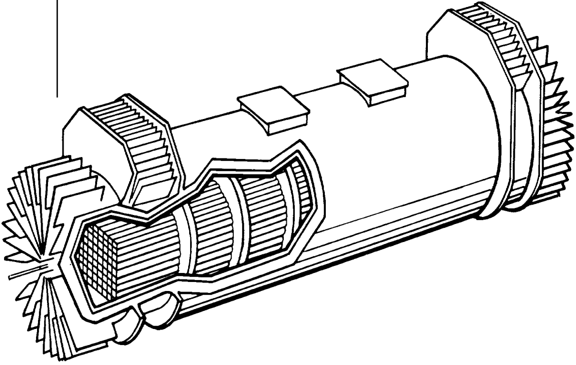
Once a permanent federal waste repository is available, commercial high-level waste will be moved by truck or rail from nuclear power plants. It will go to a packaging and handling facility or to the permanent repository for disposal. The U.S. Department of Transportation (DOT), the NRC, the U.S. Department of Energy (DOE), and state agencies will all play key roles in the transportation of spent fuel to the repository.

DOE's Office of Civilian Radioactive Waste Management will manage the transportation of spent fuel. DOT, NRC, and states will regulate DOE transportation.

What precautions does DOE use to protect the public during the transportation of nuclear waste?

There are risks associated with shipping nuclear waste, as there are with shipping any material.

The greatest risk in transportation is the possibility of a vehicle accident. Stringent regulations governing package design and transport significantly reduce the risks associated with shipping nuclear waste. Before a cask is used to ship spent nuclear fuel, the NRC must certify it for commercial shipments or DOE must certify it for DOE shipments. Certification requires that the cask withstand a series of drop-and-puncture, fire, and water-immersion tests. These tests ensure that the radioactive contents of the cask are safe even under severe accident conditions.



The shipping casks for spent fuel weigh as much as 25 tons and are built to withstand major accidents, such as collision and fire.

Another potential hazard in the transportation of nuclear waste is the sabotage or theft of nuclear material. Federal safeguards and highly trained security personnel help reduce this type of threat.

How are nuclear materials safeguarded?

Strict security precautions protect fuel for nuclear power plants in the U.S. and around the world. This is because uranium and plutonium, which serve as fuel for nuclear power plants, can also be used to make nuclear weapons. However, highly enriched uranium or purified plutonium is required to make a bomb. These materials are not as highly concentrated in commercial nuclear power plants. Nevertheless, it is conceivable that someone could try to steal or divert nuclear fuel. For this reason, security measures are in place to protect the fuel at the power plant and during transportation.

A well-trained security force, physical barriers, electronic surveillance, and visitor screening are all part of the normal security at nuclear power plants. These measures also deter, prevent, and respond to any attempted theft or diversion of nuclear materials. During transportation, careful routing, armed security, and advanced communications equipment ensure that the used fuel safely reaches its destination.

In addition to plant and transportation security, the size, weight, and radioactivity of spent reactor fuel acts as a deterrent to a would-be thief. A typical fuel assembly is about 14 feet in length and weighs up to 1 ton. During shipment, spent-fuel assemblies are encased in casks that weigh nearly 65 tons.

The United States' concern about the misuse of nuclear materials is international in scope. Removing the fissionable material from spent fuel, known as reprocessing, requires advanced technology and large facilities. The U.S. does not currently reprocess commercial nuclear fuel, nor does it export the technology to other countries. Due to nonproliferation concerns, the U.S. has also postponed the development of the breeder reactor, an advanced nuclear power plant design that can make more fuel than it uses.

Under the terms of the Nuclear Nonproliferation Treaty of 1970 and the Nuclear Nonproliferation Act of 1978, the U.S. does not sell nuclear power plant parts to nations that might divert or misuse the nuclear materials in armed conflicts. These treaties require nonnuclear weapons nations to allow international inspection of their nuclear power plants. The nations also agree not to build nuclear explosives. This safeguards all nuclear power plant facilities operated by participating nations — providing an international network of nuclear nonproliferation.

The International Atomic Energy Agency (IAEA) is the international agency that oversees and inspects nuclear power plants around the world. The IAEA has played a major role in supporting international cooperation in the development of nuclear energy for electric power and in safeguarding against the proliferation of nuclear weapons. The goal is to prevent the spread of nuclear weapons while meeting the energy needs of the world's nations.

Wouldn't it be better to use renewable energy sources?

Yes, if they were practical and consistent. Unfortunately, solar radiation producing electricity in solar cells, although improving in efficiency, is not very consistent. We have long nights and cloudy days sometimes. Power from windmills is very good, but again there are few places where the wind blows consistently.

Methods for storing electricity in batteries or by other methods are not very efficient at the present time. Future study and research may help to improve the prospect for renewable energy sources.

What is the future of nuclear energy?

America has come to rely on electricity as a clean, versatile energy form. The need for a secure and economical supply of adequate electrical power has led this country to explore new technologies for producing electricity from many energy resources.

Since the first commercial nuclear power plant began operating in 1957, nuclear energy has grown into a significant energy source in the U.S. and much of the industrialized world. Nuclear energy has shown the potential to be a valuable and safe source of energy well into the 21st century. It could contribute to our national energy policy goal of providing Americans with an adequate supply of energy at reasonable costs. This goal is intended lead the U.S. along a pathway to growing energy stability, security, and strength.

The Department of Energy produces publications to fulfill a statutory mandate to disseminate information to the public on all energy sources and energy conservation technologies. These materials are for public use and do not purport to present an exhaustive treatment of the subject matter.

This is one in a series of publications on nuclear energy.

U.S. Department of Energy

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