Nuclear Power

TODAY

TOMORROW

IN AMERICA

Foreword

How can we meet the world's rapidly growing demand for electric power without further damaging the environment?

That's one of the great challenges that the U.S. Department of Energy addresses in its energy research and development programs. And one of the keys to meeting this challenge is to increase the use of nuclear energy to generate electricity.

Nuclear power plants have been producing electricity in the United States for nearly half a century. Today, more than 100 nuclear power plants generate nearly 20 percent of the nation's electric power. Worldwide, more than 30 countries operate around 450 nuclear power reactors. Several countries, including France, receive more than half their electric power from nuclear energy.

The Department of Energy's Office of Nuclear Energy is preparing the way for new, advanced nuclear power plants and related fuel recycling facilities. The U.S. Congress and the Administration have established numerous initiatives to increase our domestic supplies of energy. The goals are to develop new, efficient, economic, and cleaner ways to use fossil fuels, such as coal and natural gas, and to substantially increase our use of nuclear power and renewable energy resources. All of these efforts and others are essential to ensure that we meet and sustain our growing requirements for electricity, while substantially reducing environmental impacts.

Nuclear energy is an essential element in meeting these objectives. To help facilitate the increased use of nuclear energy, we are:

- Stimulating U.S. industry to build the next generation of safe, clean nuclear power plants.
- Focusing on safely managing the disposition of used nuclear fuel and wastes.
- Seeking global cooperation in the use of safe, clean nuclear power and to strengthen non-proliferation.
- Advancing science and technology to ensure that nuclear power sustains its key role in the nation's energy mix and, as a result, improves our quality of life.

This booklet is a basic introduction to nuclear power, how it works, its challenges, and the benefits it delivers. For more information and continuing updates on Department of Energy plans, programs, and activities, please visit our Web site, *http://www.nuclear.energy.gov*, and note the additional information and contact sources at the back of this booklet.

Dennis Spurgeon,

U.S. Department of Energy
Assistant Secretary for Nuclear Energy

Nuclear Power in America, Today & Tomorrow





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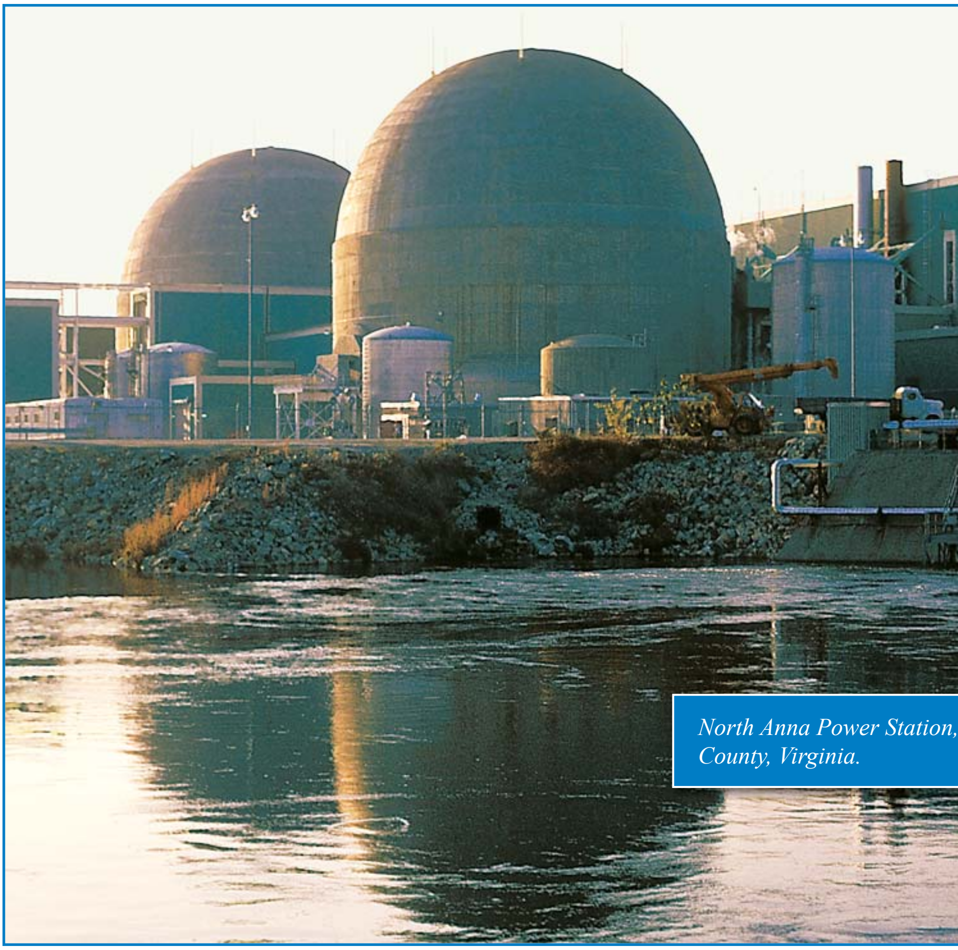


North Anna Power Station, Louisa County, Virginia.

FastFact

The amount of electricity generated by nuclear energy in the United States today (781 billion kilowatt hours in 2005) is greater than the nation's total electricity generation in 1960.

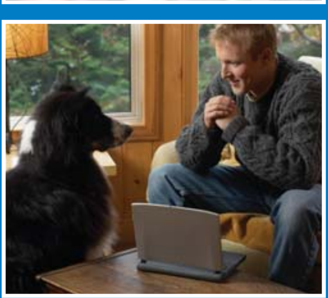
Source: Energy Information Administration, "Electric Power Monthly," May 2006; "Annual Energy Review 2004."

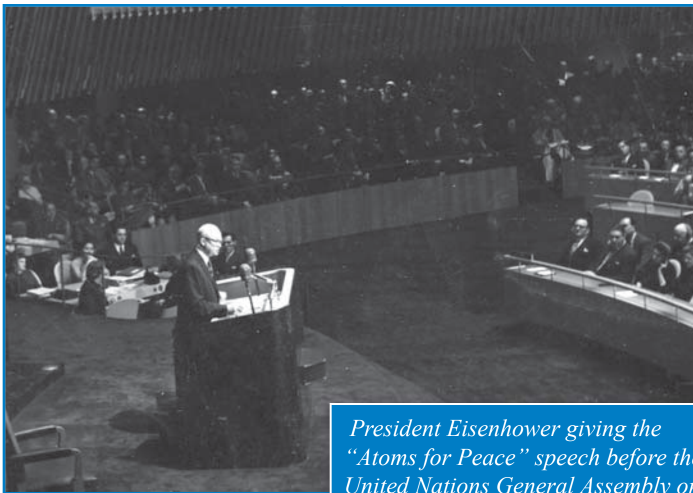
Nuclear Power in the U. S. — An Overview

Electricity powers our digital age. It touches the lives of every American every day. Whenever you turn on a light, watch television, use a computer, or charge a cell phone, you rely on electricity.

Many people are surprised to learn that nuclear power today plays an important role in supplying electricity to Americans. It currently accounts for nearly 20 percent of total U.S. electricity generation. And nuclear energy has been a reliable, economic, safe, and environmentally clean source of electrical energy for the United States for more than 40 years. Nuclear power and coal generate more than two-thirds of America's baseload electricity.

Historically, America has been a leader in nuclear technology for electricity generation. American scientists developed some of the first electricity-producing reactors. In addition, the U.S. government was an early advocate of developing nuclear energy for peaceful civilian purposes.





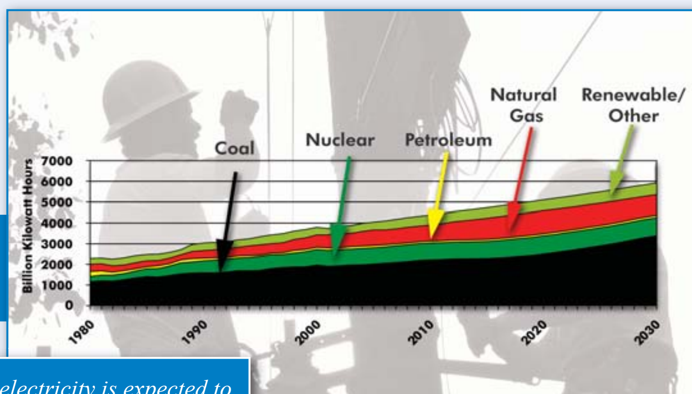
President Eisenhower giving the "Atoms for Peace" speech before the United Nations General Assembly on December 8, 1953.

In a 1953 speech before the United Nations, President Dwight D. Eisenhower was the first world leader to call for international nuclear energy cooperation (see *From Atoms to Energy: U.S. Nuclear Power History, page 25*).

Since those early years, the global use of nuclear power has steadily progressed, both in the United States and around the world. Technology advances, particularly since the 1970s, have continued to improve how nuclear plants are designed, operated, and made safer.

Nuclear power reactors can be operated on a single load of fuel for long periods of time — well over a year. And nuclear power plants do not release air pollutants or carbon dioxide in the production of electricity, providing an important option for improving air and environmental quality.

U.S. Electricity Generation by Energy Type Over 50 Years
(1980 – 2030)



Nuclear-generated electricity is expected to continue playing an important energy role for the United States in the years ahead.

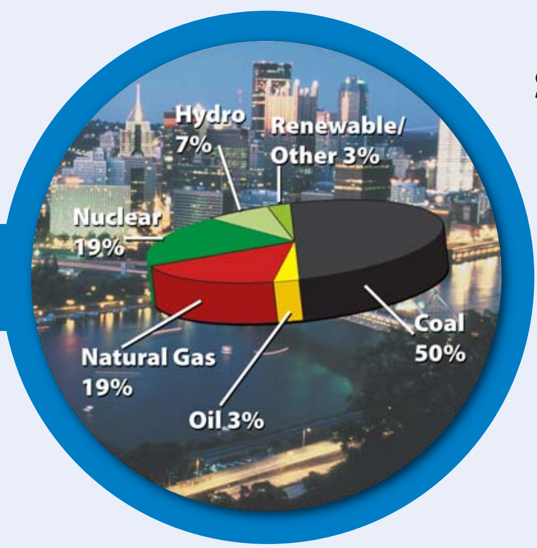
Source: Energy Information Administration, "Annual Energy Outlook, 2006;" "Monthly Electricity Review," May 2006.

However, there is no question nuclear power also presents challenges. While used nuclear fuel and commercial nuclear wastes continue to be safely managed, the nation is still pursuing an acceptable permanent solution. The government is developing a deep geologic repository at Yucca Mountain, Nevada, for permanent disposal of nuclear wastes (see *Nuclear Power and the Environment, page 13*). The Department of Energy (DOE) is also researching ways to reclaim and recycle energy still contained in the used nuclear fuel — these recycling technologies can expand nuclear fuel supplies and provide other benefits in waste management and security.

The U.S. Energy Information Administration (EIA) foresees a continued important role for nuclear generation in the years ahead. EIA projects total U.S. electricity use will grow by 50 percent through 2030, providing power for our growing population, the digital economy, and the way Americans live, work, and play. EIA projects a rise in U.S. nuclear capacity from 99.6 gigawatts (a unit of power equal to one billion watts) in 2004 to 108.8 gigawatts in 2030.

In addition, nuclear power generation is expected to rise from the 2005 level of 781 billion kilowatt hours to 871 billion kilowatt hours in 2030.[1] For nuclear to maintain its present share of U.S. electricity supply in the years ahead, however, even greater growth than that projected by EIA will be required.

One-Year Snapshot: 2005

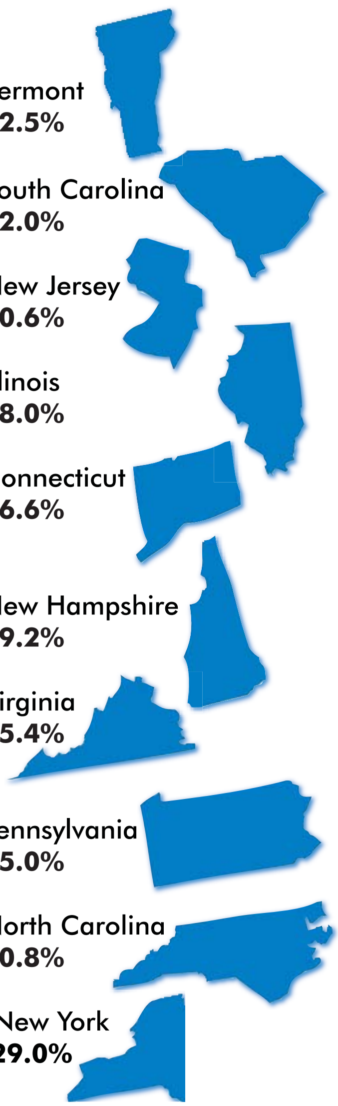


Source: Energy Information Administration, "Electric Power Monthly," May 2006 — Figures are rounded.

Top 10 States—2005

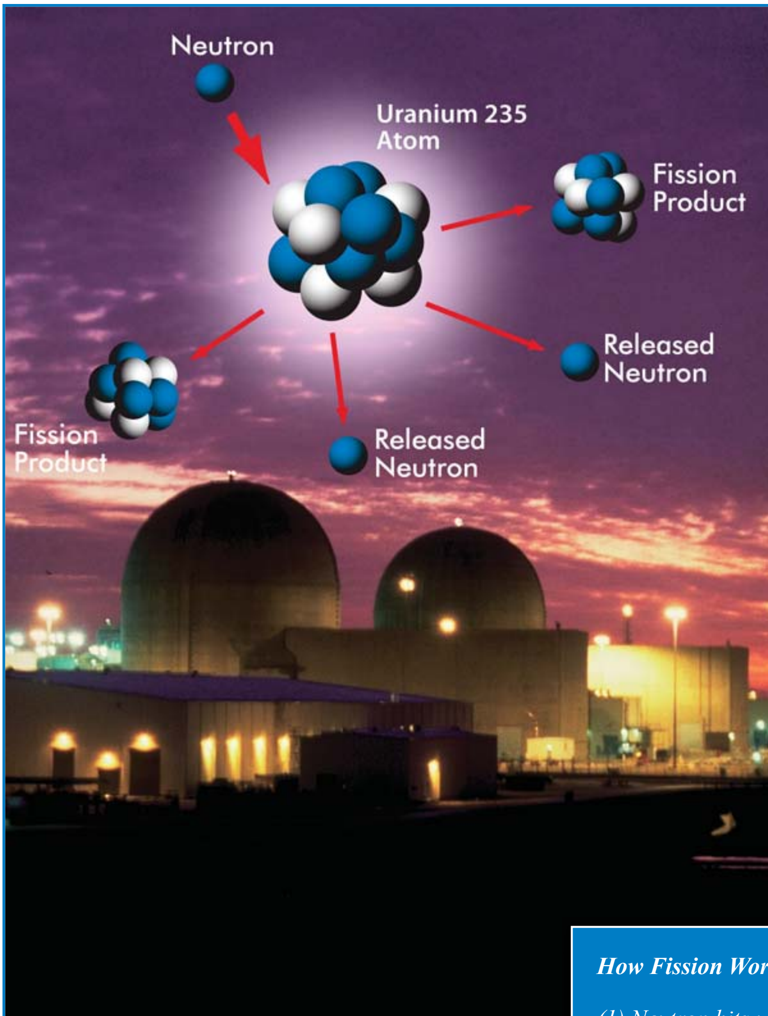
Nuclear Energy Electricity Generation

(Percentage of Total Generation)



1. Vermont **72.5%**
2. South Carolina **52.0%**
3. New Jersey **50.6%**
4. Illinois **48.0%**
5. Connecticut **46.6%**
6. New Hampshire **39.2%**
7. Virginia **35.4%**
8. Pennsylvania **35.0%**
9. North Carolina **30.8%**
10. New York **29.0%**

Source: Energy Information Administration, "Monthly Energy Review," March 2006.



How Fission Works:

(1) Neutron hits uranium nucleus;
(2) Atom "splits" releasing energy;
(3) More neutrons are released, splitting other atoms.

Pictured: The South Texas Project electric generating station.

FastFact

Energy is in the "nucleus" — or core — of a uranium 235 atom. The process of releasing this energy is called "fission."

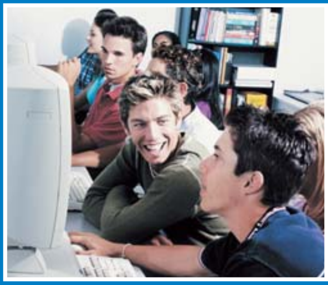
Source: U.S. Department of Energy, Office of Nuclear Energy, "Answers to Questions, Nuclear Energy," page 2.

Nuclear Power in America Today

Electricity is a form of energy Americans use every day but often take for granted. We expect it to be there every time we flip a switch or turn on an appliance. Most of us could hardly imagine a life without electricity. Even so, people seldom think about what electricity is, why we need it, and how it's produced.

Basically, electricity is energy created from the motion of electrons. Power plants that use natural resources — mostly fossil fuels, nuclear fuel, hydropower, and renewable energy sources — produce large amounts of electricity.

Atoms are the building blocks of all matter. Nuclear energy is stored in the **nucleus** — or core — of an atom. This energy must be released from the core in order to make electricity. The process of releasing energy in a reactor is called **fission**.



Fast Fact

One ton of uranium can produce more than 40 million kilowatt hours of electricity, equal to burning 16,000 tons of coal or 80,000 barrels of oil.

Source: U.S. Department of Energy, Office of Nuclear Energy, www.nuclear.energy.gov

In nuclear fission, a neutron is absorbed by a uranium atom, causing it to split (fission) into two or more fragments while releasing several (average two and a half) additional neutrons along with a great amount of energy. The released neutrons go on to bombard other uranium atoms. Under controlled conditions, this release of energy can be used to fuel the production of electricity.

Uranium is the fuel most widely used by nuclear plants for fission. It is a common element in the earth's crust. Nuclear power plants use a specific kind of uranium atom — **U-235** — as a fuel because its atoms are easily split apart. Natural uranium is usually enriched to increase the concentration of U-235 (from 1 percent to about 4 percent), which is used in most power reactors.

Most domestic uranium is mined in the western United States. EIA estimates U.S. reserves are as much as 424 million tons of ore.[2] Major reserves are found in Wyoming, New Mexico, Arizona, Colorado, Utah, and Texas. The World Nuclear Association (WNA) estimates the United States ranks eighth among nations in uranium reserves, with about 3 percent of the world total.

Uranium is converted into tough **ceramic pellets** about the size of a pencil eraser. Each small pellet contains the same amount of energy as 150 gallons of oil.[3] Thousands of these energy-rich pellets are loaded into **fuel rods**, which are bundled together to form **fuel assemblies** that are loaded into the nuclear plant's reactor to form a fuel core. A typical fuel rod contains about 200 fuel pellets and is 12 feet long; a large reactor may have nearly 200 fuel assemblies composed of thousands of fuel rods and millions of fuel pellets.

Uranium fuel is formed into ceramic pellets.

The fuel core is sealed inside a massive steel **reactor vessel**, a large steel container often weighing 300 tons or more. When the fission rate is increased, heat is generated. The heat supplied by the reactor

The 1,300 megawatt Grand Gulf nuclear plant in Mississippi. The large cooling tower (foreground) removes excess heat from the plant's cooling water.

turns water into steam, which drives turbines to turn generators to produce electricity. The electricity travels through transmission and distribution power lines to homes, businesses, industries, and millions of other users.

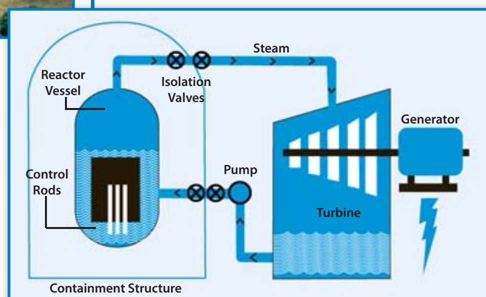
In a nuclear power reactor, control rods slide up and down in between fuel assemblies, regulating the level of the nuclear reaction. The reactor coolant is generally purified water, used to transfer the heat from the fission reaction to the production of steam. The **containment building**, a structure made of steel-reinforced concrete, houses the reactor and has walls several feet thick.

In the United States, two basic types of water-cooled reactors are used at nuclear power plants — **Boiling Water Reactors** (BWRs) and **Pressurized Water Reactors** (PWRs). Because both types are cooled with ordinary water, they are known as **Light Water Reactors** (LWRs). Of the 104 operating U.S. nuclear power reactors, 69 are PWRs and 35 are BWRs.

The efficiency of U.S. nuclear power plants has steadily increased. Higher efficiencies and power uprates have increased electricity production equal to adding 17 new 1,000 megawatt power plants

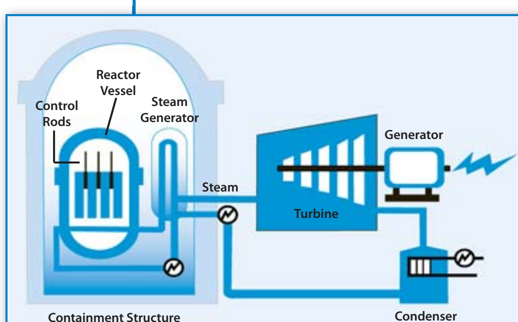
U. S. Nuclear Reactor Types

Boiling Water Reactor (BWR)



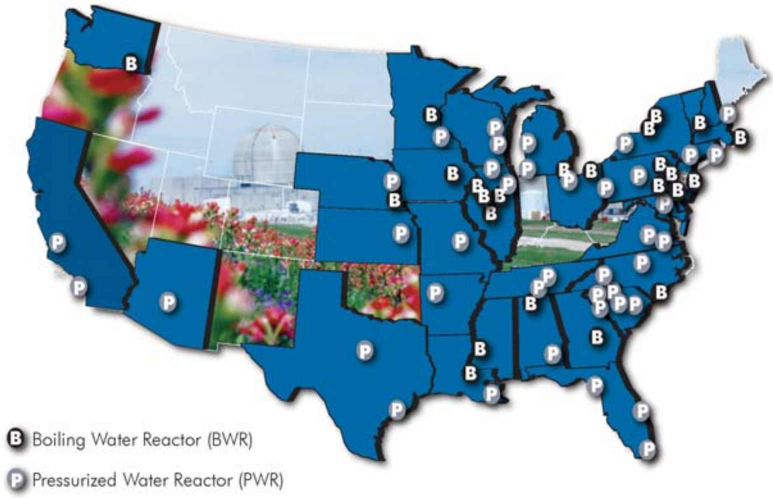
BWRs use heat from the reactor core to boil the reactor's coolant water into the steam that is used to generate electricity.

Pressurized Water Reactor (PWR)



PWRs heat water under pressure within the reactor. The heat is transferred to a separate cycle, where steam is generated and used to drive a turbine and electric generator.

Location of 104 U.S. Nuclear Power Reactors*



Source: Based on data from the International Nuclear Safety Center, Argonne National Laboratory, GE Nuclear Energy, and other sources.

** Map indicates locations only; some sites have more than one reactor.*

to the nation's electricity grid since 1996.[4] Nuclear energy's contribution to America's electricity supply has benefited from nuclear plant **power uprates**, **license renewals**, **reduced outages**, and **efficient fuel use**.

Power uprates increase the maximum power level at which a commercial nuclear power plant can operate. Uprates at U.S. nuclear power plants have added an additional 4,183 megawatts of electricity.[5]

Many operating U.S. nuclear plants are expected to extend their life through license renewals by the NRC. The Atomic Energy Act and NRC regulations limit commercial power reactor licenses to an initial 40 years but also permit such licenses to be renewed for an additional 20 years through a vigorous regulatory review process. The timely renewal of licenses may be important to ensuring an adequate energy supply for the United States during the first half of the 21st century. Currently, the Commission has renewed about one-third of total U.S. reactor licenses.

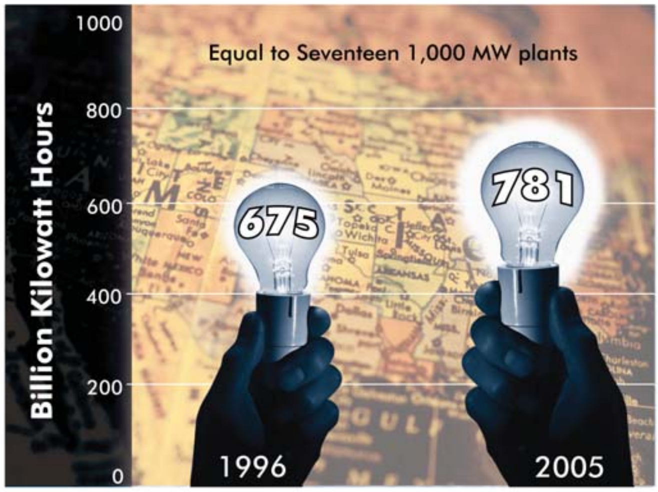
U.S. reactors shut down once every 18–24 months to refuel about one-third of the reactor fuel core. Over the past decade, maintenance improvements have reduced the average refueling time from three months to one.

In addition to uranium that is mined and enriched, a major source of nuclear fuel comes from an innovative source. In 1993, the United States and Russia signed an agreement to convert highly enriched, weapons-grade uranium from dismantled Soviet warheads into low enriched uranium for use by U.S. nuclear plants. About 10 percent of U.S. electricity is currently being generated by material from this "Megatons to Megawatts" program.

Source: www.usec.com/v2001_02/HTML/megatons_howitworks.asp.

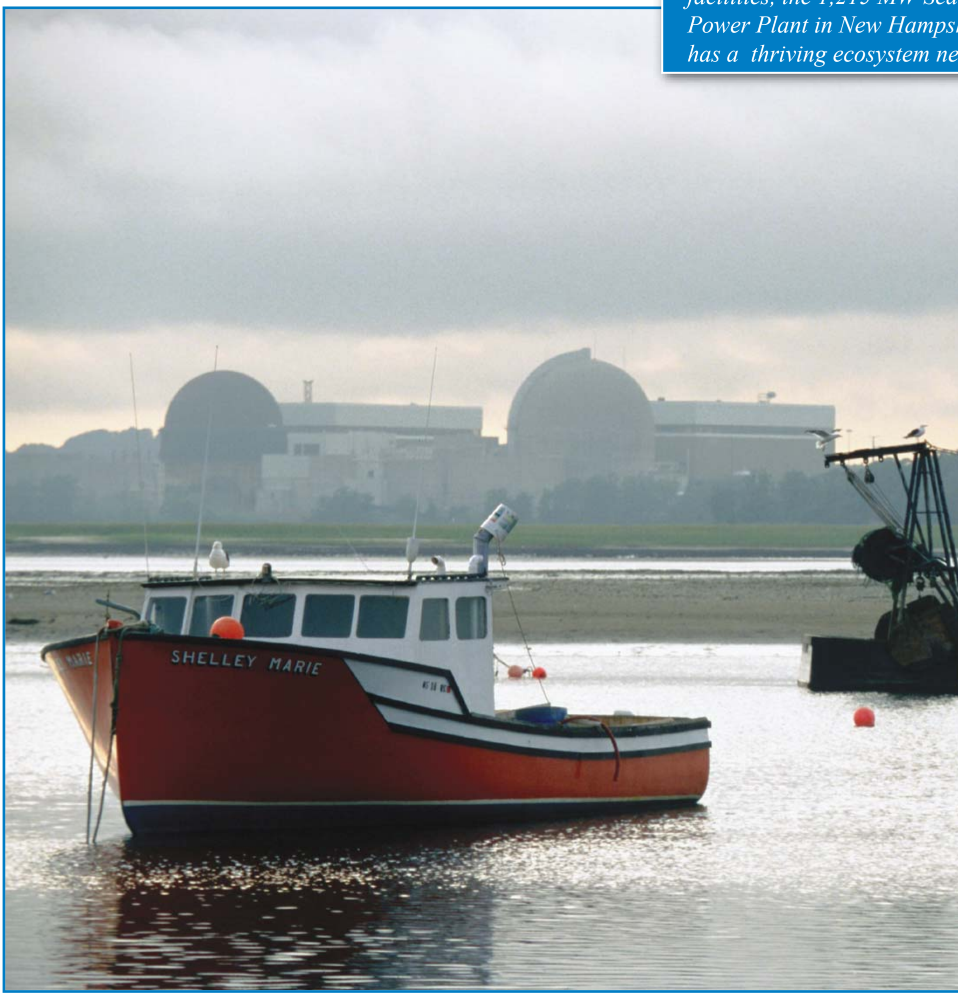
In addition, U.S. nuclear facilities have been steadily upgraded with extensive technology and operational improvements, allowing plants to operate more efficiently and safely. Efficiency gains have extended fuel life and reduced the amount of spent fuel that must be stored for disposal. The combined end result of these trends has been the production of more electric power from the same number of nuclear plants.

Increased Electricity Production by U.S. Nuclear Plants, 1996 – 2005



Source: Energy Information Administration net generation data, "Electric Power Monthly," May 2006; and U.S. Department of Energy, Office of Nuclear Energy.

New fuel is loaded into the core of a nuclear plant reactor.



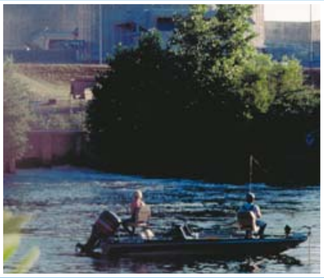
Like many modern nuclear facilities, the 1,215 MW Seabrook Power Plant in New Hampshire has a thriving ecosystem nearby.

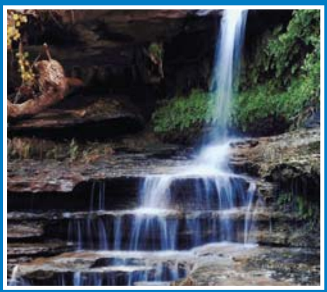
FastFact

Emission-free nuclear power plant electricity generation helps the United States avoid 175 million tons of carbon dioxide emissions annually.

Source: "Nuclear Power 2010, Program Status," presentation on April 29, 2005 by Thomas P. Miller, U.S. Department of Energy, Office of Nuclear Energy.

Nuclear Power and the Environment





Nuclear energy is the largest producer of electric power without emitting any significant pollution or greenhouse gases. The second largest is hydroelectric power (about 7 percent), followed by wind and solar power (about 2 percent). Since nothing is burned in the generation of nuclear electricity, no harmful emissions are vented into the atmosphere. This is why nuclear power plants do not have smokestacks common to fossil fuel generation facilities. Some nuclear power plants use large cooling towers (**see photo, page 9**) to remove excess heat from cooling water before it is returned to the waterways; the discharge is water vapor, not smoke or radioactive matter.

This gives nuclear power plants an important environmental advantage. No releases, such as sulfur dioxide (SO_2) or nitrogen oxide (NO_x), which can cause acid rain; or carbon dioxide (CO_2), a major greenhouse gas, come from nuclear plants.

Without nuclear plants, the additional use of fossil fuels would release an estimated 175 million tons[6] more carbon dioxide each year. That is the equivalent of the amount of CO_2 released by nearly one-quarter of America's 127 million passenger cars.[7]

Air Emission Levels in the Production of 1 Megawatt Hour (MWH) of Electricity

(Pounds of Emissions per MWH)

Emission	Coal	Oil	Natural Gas	Nuclear
Carbon Dioxide	2249	1672	1135	0
Sulfur Dioxide	13	12	0.1	0
Nitrogen Oxides	6	4	1.7	0

Source: Energy Information Administration, "Nuclear Power and the Environment," www.eia.doe.gov/cneaf/nuclear/page/nuclearenvissues.html.

Management of all radioactive materials, emissions, and wastes at nuclear power plants is regulated by the NRC, which has on-site personnel to monitor safety.

There are essentially two types of wastes at nuclear power plants:

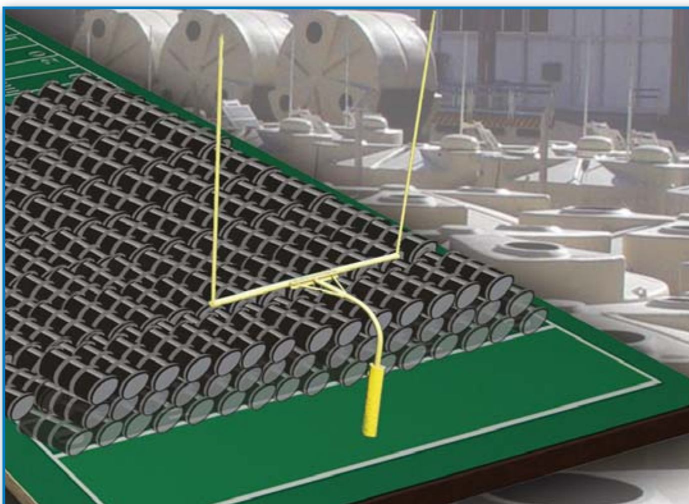
Low-level waste — Generally from protective clothing, tools, or other disposable items that pick up small amounts of radioactive particles, these wastes are collected, packaged, and stored to prevent contact with the outside environment. Periodically, these wastes are shipped to licensed and approved facilities for disposal.

High-level waste — While refueling, some of the fuel assemblies are shifted to optimize efficiency; some are withdrawn and replaced by new fuel. Spent fuel is moved underwater to fuel storage pools, where radiation and heat steadily subside. Eventually, these assemblies are carefully loaded into huge, shielded containers that are removed from the plant for on-site storage pending permanent disposition.

Federal law directs DOE to enter into contracts with the operators of nuclear power plants to dispose of used fuel in a deep-geological repository to be constructed at Yucca Mountain, Nevada. DOE currently is working to obtain authorization from the NRC to begin construction. In order to obtain this authorization, DOE must demonstrate that the disposal of the used fuel will meet all regulatory requirements, including the radiological protection standard established by the Environmental Protection Agency (EPA).

Once a geologic repository is available, commercial spent fuel will be moved by trucks and/or rail to Yucca Mountain for storage and disposal. Stringent regulations govern the design, construction, and use of spent fuel shipping casks, which weigh as much as 125 tons and are designed to withstand major accidents, collisions, and fire. Longer-term, DOE is pursuing a recycling strategy for used fuel that would recover and reuse its energy content and reduce the volume and toxicity of waste that requires disposal in a deep geological repository.

Dry cask storage allows spent fuel that has already been cooled for at least one year to be surrounded by inert gas in a leak-tight steel cylinder.



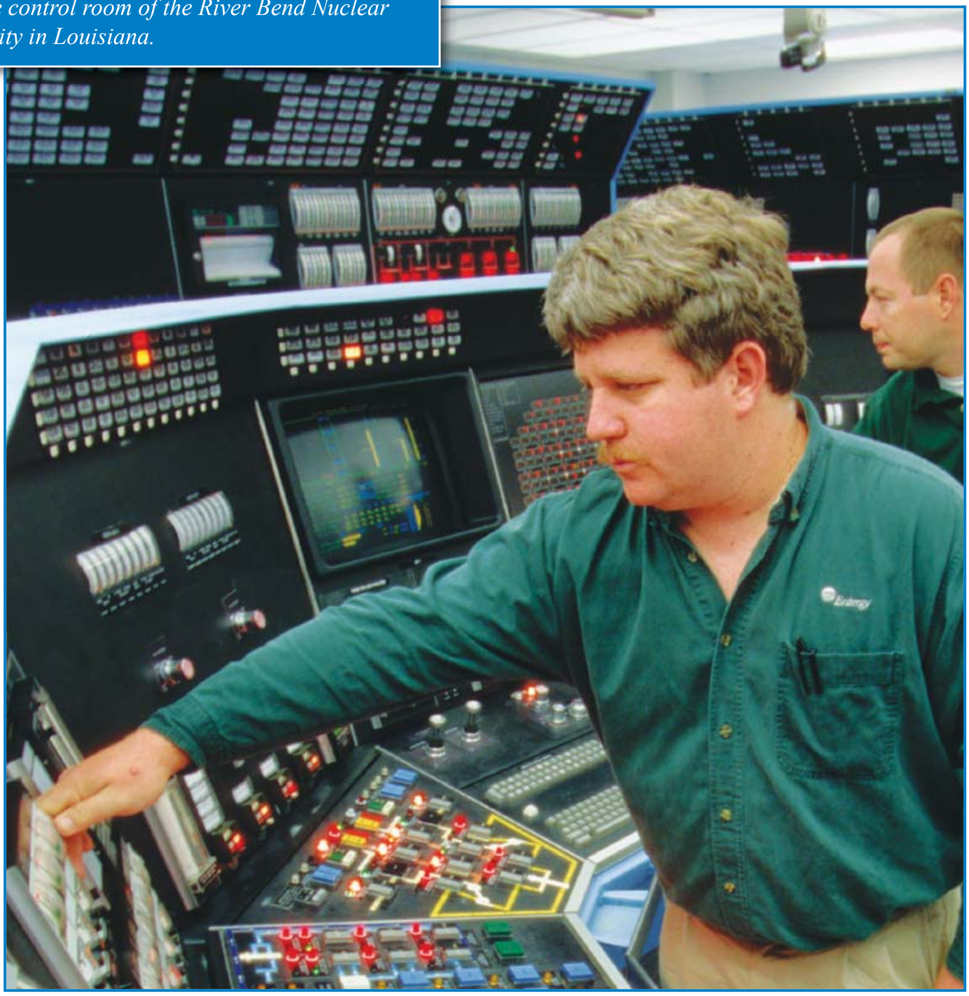
Background image courtesy of Pierre Auger Observatory.

Fast Fact

The total spent fuel from all U.S. commercial nuclear power plants since the first facility started operating more than a half-century ago would collectively occupy a facility the size of one football field to a height of 15 feet.

Source: "Nuclear Energy: Poised for Expansion," Harold McFarlane, Idaho National Laboratory, May 2006.

Workers continuously monitor plant operations in the control room of the River Bend Nuclear Facility in Louisiana.



FastFact

Less than one-tenth of one percent of the average American's exposure to radiation comes from nuclear power operations.

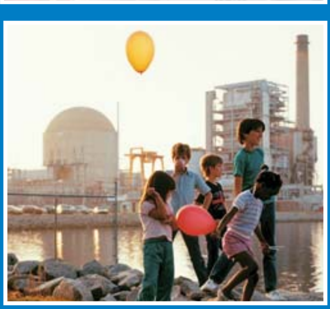
Source: "Nuclear Powerplant Safety-Operations," page 9, U.S. Department of Energy, Office of Nuclear Energy.

Nuclear Power — Safety and Health

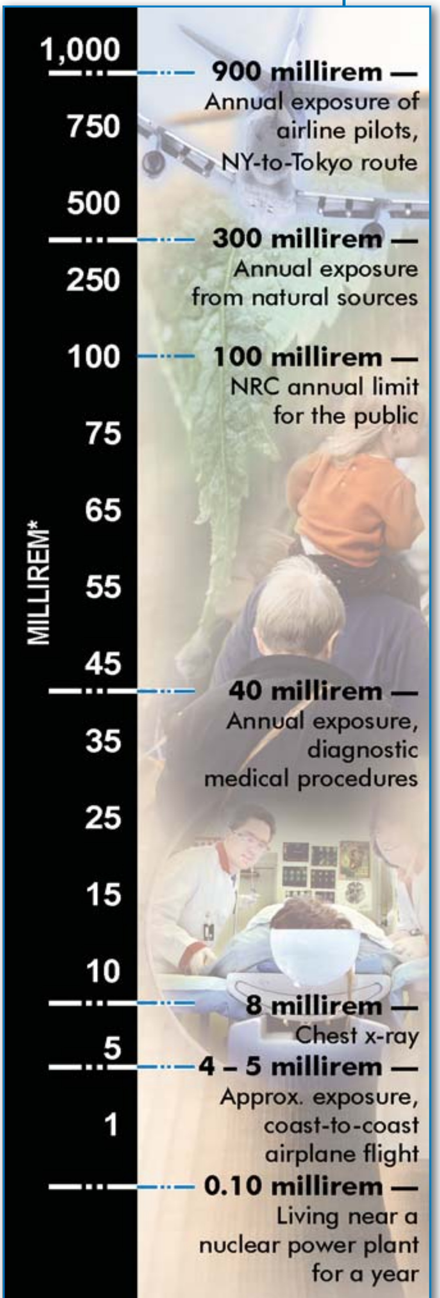
Safeguarding the safety and health of workers and the general public is the fundamental requirement for nuclear power generation in the United States. As a result, strict licensing and regulation, good engineering and design practices, intensive personnel training, and thorough environmental monitoring procedures are in place to help ensure that nuclear plants continue to operate safely.

Statistics show that U.S. commercial nuclear power plants have operated safely for more than a half-century. The success of efforts to maintain this record also stem from continuing to apply technology advances to improve plant safety and health conditions. These are critical factors in nuclear energy's ability to fulfill its potential in the years ahead.

Among the highest priorities for safe nuclear plant operation is minimizing radiation exposure to workers and the public. U.S. nuclear power plants are designed to protect against harmful radiation releases through multiple safety systems, many of which have continually improved through technological development.



Radiation Exposures in Perspective



Source: Information compiled from the Nuclear Regulatory Commission, www.nrc.gov/reading-rm/doc-collections/fact-sheets/bio-effects-radiation.html and the Health Physics Society, www.hps.org/publicinformation/ate/q5822.html.

** One millirem = 1/1,000 of a rem, a measure of ionizing radiation.*

State and federal regulations limit the amount of radiation that can be emitted by nuclear power plants. Multiple physical barriers (thick steel and concrete) within the plant, along with air handling and filtration systems, protect against the release of radioactive materials. The construction and operation of all U.S. nuclear plants must be licensed by the NRC. The NRC also is responsible for inspection and enforcement, standards development, and research into the kinds of regulations that will best ensure safety.

Extensive training and experience are necessary to pass the NRC's examination for reactor operators. To maintain their license, reactor operators must pass an annual practical plant operation exam and a biennial written exam. Training may include simulator and on-the-job training, classroom instruction, and individual study.

In addition to receiving preliminary training, reactor operators undergo frequent, periodic, refresher training. Refresher training usually is taken on plant simulators designed specifically to replicate procedures and situations that might be encountered at the trainee's plant.

The routine operations of a nuclear power plant result in some radiation emissions. The amount of radiation exposure received by the average American from nuclear power plants is far less than that received from unavoidable natural sources such as radon and cosmic radiation, and from activities in everyday life (dental and medical x-rays, smoke detectors, television sets, etc.). In addition, nuclear plant workers — who are allowed higher, but still safe, radiation exposure by the NRC — may receive exposures that are, on average, about one-third of that received annually by airline pilots flying regularly at high altitudes, where the atmosphere's shielding effect for cosmic radiation is reduced.[8]

The physical security of nuclear power plants is also a primary objective. Nuclear plants are among the nation's best protected privately operated facilities and are required by law to maintain extensive security measures. This helps ensure continued safe operation and security of nuclear materials, as well as potential attacks. Plants employ well-trained security forces, set up physical barriers and elaborate electronic surveillance systems, and screen visitors to keep unauthorized persons from entering the site. Ongoing NRC inspections and oversight help ensure a high level of performance and readiness as well as compliance with regulations and requirements of the license for each facility. Combining these factors, nuclear plants are prepared to withstand a combination of extreme and highly unlikely events, including accidents, natural disasters, and terrorism.

Nuclear technicians operate nuclear test and research equipment, monitor radiation, and assist nuclear operations to ensure safety regulations are met.

No discussion of U.S. nuclear plant safety would be complete without taking into account the March 1979 accident at Unit 2 of the Three Mile Island (TMI) plant near Harrisburg, Pennsylvania. In that incident, instrumentation malfunctioned and incorrectly showed the reactor was filling up with water, when it was actually losing coolant.

Most experts have concluded that the equipment malfunction was exacerbated by human error. Ultimately, the plant's safety systems protected public health and safety.

TMI remains the most serious and costly accident in U.S. commercial nuclear power plant history. However, the incident became a catalyst for action by the nuclear power industry that led to a full review, and subsequent improvements, in plant design, safety, emergency planning, and operations maintenance.

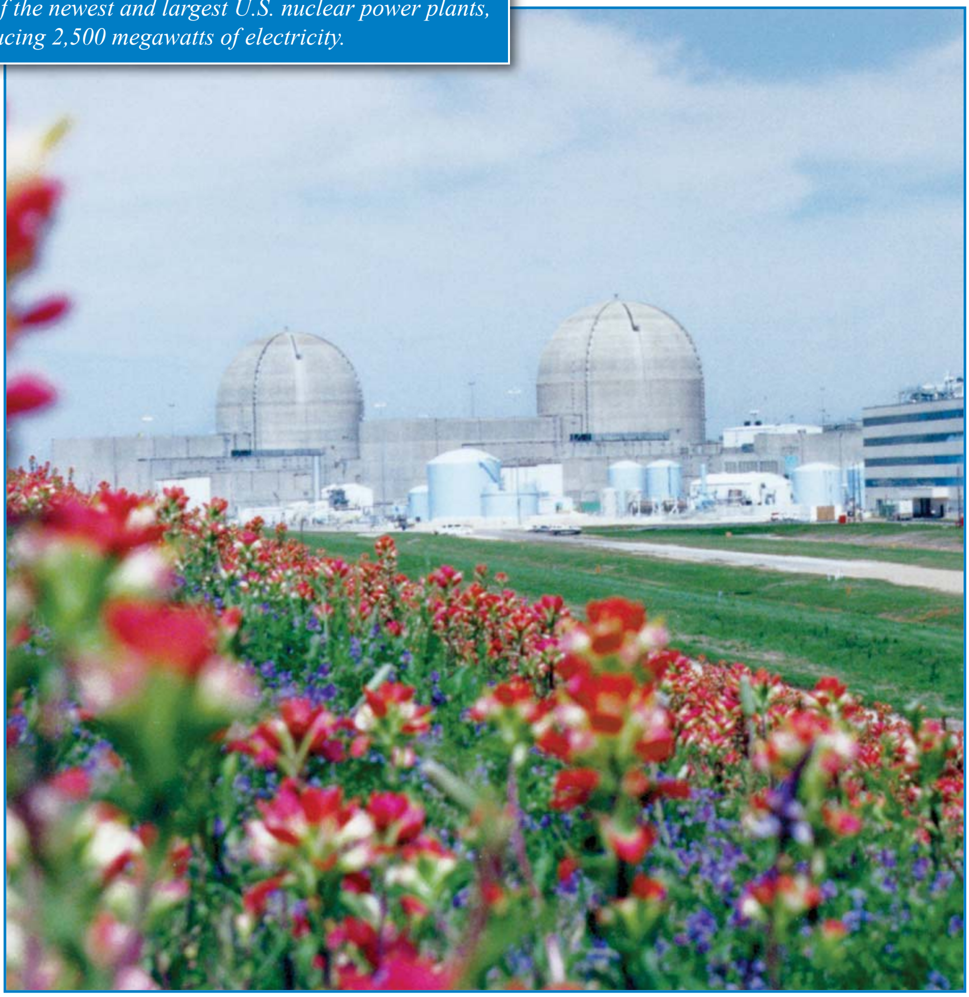
Continuous improvements have resulted in nuclear power being one of our safest and most reliable energy technologies. In addition, new nuclear fuel has been processed, fabricated, and safely shipped across the United States for more than half a century. In total, nuclear power's overall safety record is one of the best of any industry in the nation.

Fast Fact

Natural sources — such as radon and cosmic and terrestrial radiation — account for about 82 percent of the total annual average radiation exposure to the U.S. population.

Source: Nuclear Regulatory Commission, www.nrc.gov/reading-rm/doc-collections/fact-sheets/bio-effects-radiation.html.

The South Texas Project electric generating station is one of the newest and largest U.S. nuclear power plants, producing 2,500 megawatts of electricity.



FastFact

The United States leads the world in nuclear energy generation.

Source: Energy Information Administration, http://www.eia.doe.gov/cneaf/nuclear/page/nuc_generation/gensum.html.

Nuclear Power Tomorrow

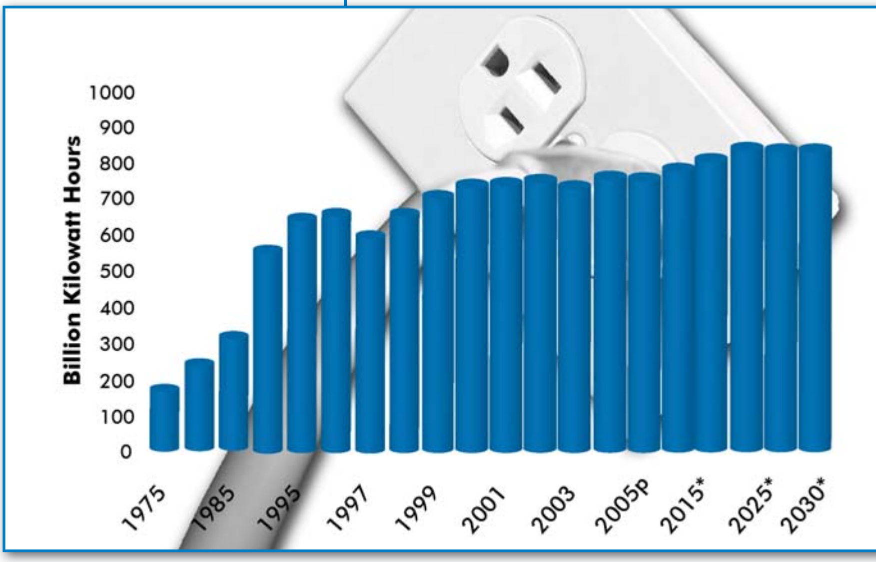
America and the world will require large and steadily increasing amounts of electricity in the years ahead to sustain healthy economies and to maintain and improve the quality of life. Using a variety of domestic energy resources, including nuclear energy, offers a balanced and secure option for meeting these practical needs.

Society in the 21st century expects and depends upon energy production to be sustainable, minimizing impacts to the environment, communities, and the health and safety of workers and the public.

U.S. nuclear power is poised to play a continuing and expanded role in providing reliable electricity to Americans. The U.S. Energy Information Administration projects increased nuclear power use between now and 2030, and recent power company announcements show the potential for greater growth.

Building on the operational success of recent years, utilities in the United States are moving toward constructing new nuclear power plants. With improved design and construction, these facilities will have new safety features, and increased efficiency. And nuclear power offers an important, emissions-free option to help improve air quality and combat global warming.

U.S. Nuclear Power Trends
(1975 – 2030)



Source: Energy Information Administration, Annual Energy Outlook 2006.
*P = preliminary; * = projected*

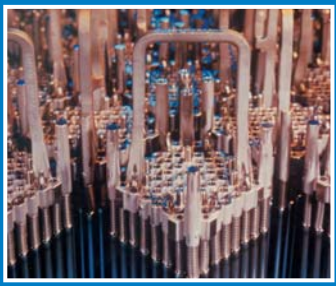
These new reactors, often referred to as Generation III+ reactors because they represent improved modifications over early designs and those currently in operation, are simpler, safer, and less expensive to operate. New designs employ passive safety features — like gravity and natural circulation — that enable them to shut down safely without operator action in the event of an emergency.

Meanwhile, the use of nuclear power is expanding around the world. About 450 reactors producing 16 percent of world electricity operate in 30 countries comprising two-thirds of the world's population. Under current plans, these nations will construct as many as 180 reactors by 2030 to meet world electricity demand, which will double over its present level, according to the International Energy Agency (IEA).

In the final analysis, few sources can meet all of America's future energy needs. Nuclear will serve as a valuable and safe contributor to the U.S. energy mix well into the 21st century, and all Americans will benefit as a result.

Appendix A

The Nuclear Fuel Cycle



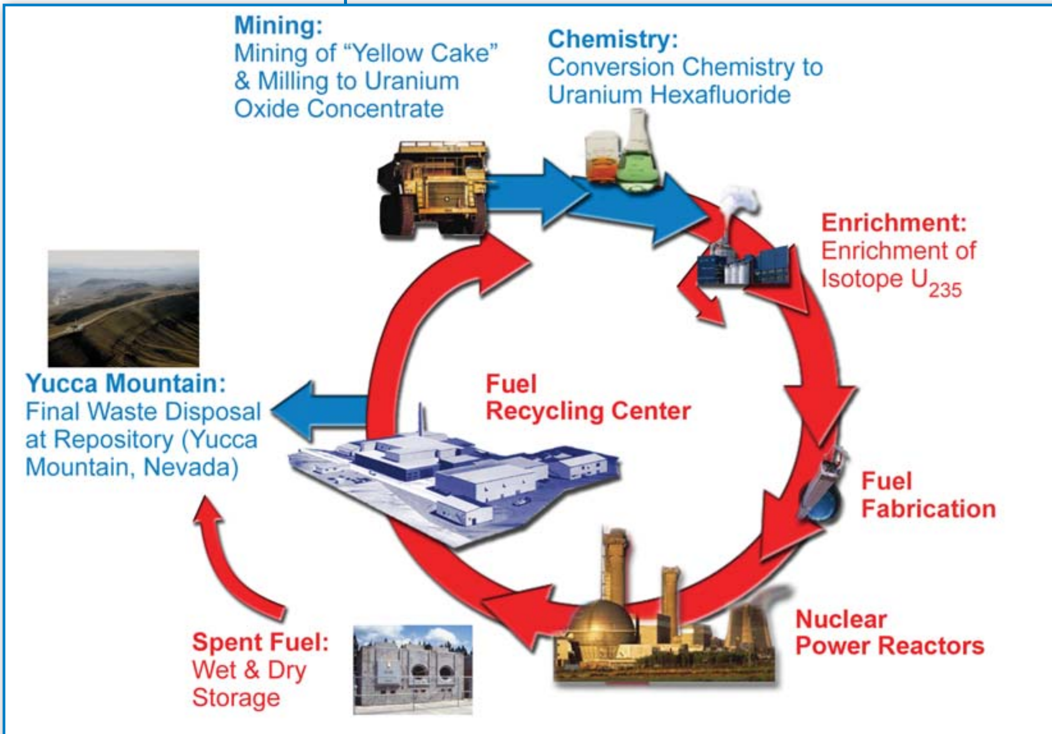
The steps involved in mining uranium, processing it into a fuel, using it at a power plant, safely managing used fuel, and storing radioactive waste is called the **nuclear fuel cycle.**

The fuel cycle consists of the following steps: (1) uranium mining and milling; (2) conversion; (3) enrichment; (4) fuel rod fabrication; (5) power reactor operations; and (6) recycling or waste management and disposal.

Uranium ore is usually mined by either surface or underground techniques similar to those used for other minerals. Ore is transported to a conventional mill, often located close to a mine, where the uranium is extracted. This concentrated uranium is often referred to as yellowcake.

The yellowcake is sent to the conversion plant where it is transformed to a uranium hexafluoride that is suitable for the enrichment process.

The Nuclear Fuel Cycle (Open & Closed)



Fast Fact

Since 1982, nuclear power has been second only to coal as an energy source for the production of electricity in the United States.

Source: "Answers to Questions About Nuclear Energy," page 1, U.S. Department of Energy, Office of Nuclear Energy.

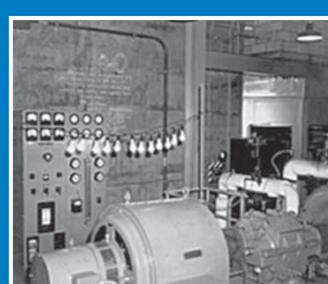
The uranium hexafluoride is transported to an enrichment facility where the concentration of the fissionable part — uranium-235 — is increased from its natural state of about 0.7 percent to 3 to 5 percent. This is the concentration required for most commercial reactor fuel.

The enriched uranium hexafluoride is transported to a fuel fabrication plant, where it is converted to uranium dioxide powder and pressed into small ceramic pellets. The pellets are then loaded into metal rods, which are fabricated into large fuel assemblies. The fuel is then transported to power plants using all major transportation modes (rail, ships, and trucks). At the power plant, the fuel releases energy through the fission process, and this heat is used to produce steam that spins a turbine and an electric generator.

The United States currently operates an **open fuel cycle**, which means spent fuel is destined for disposal. Other nations use a **closed fuel cycle**, which recycles spent fuel to recover fuel for reuse and separates waste for disposal. The United States is now pursuing a nuclear fuel recycling strategy to recover fuel and reduce the volume of fuel wastes for disposal.

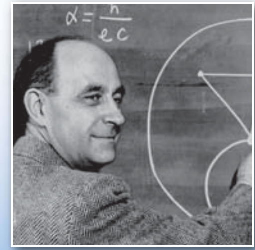
Appendix B — From Atoms to Energy

U.S. Nuclear Power History



Nuclear *fission*, or the splitting of the nucleus of atoms, was first observed in 1934 by Italian physicist Enrico Fermi. In 1938, two German scientists — Otto Hahn and Fritz Strassman — further demonstrated the principle. In December 1942, after immigrating to the United States, Fermi designed the first experimental nuclear reactor and produced the first controlled chain reaction using uranium. This was the beginning of the nuclear age.

After World War II, scientists concentrated on peaceful applications of nuclear technology — in medicine, agriculture, research, and energy production. The use of fission to produce commercial electricity became a U.S. national priority by the early 1950s. The earliest U.S. nuclear plants, built during the 1950s and 1960s, used technology based on propulsion units in nuclear-powered submarines, such as the *Nautilus*. In fact, today there are an equal number of reactors operating in U.S. Navy vessels as there are in commercial nuclear power plants across America.[9] Both Navy and commercial U.S. reactors have an enviable and efficient record of operations for more than a half-century.



1940s

December 2, 1942

Physicist Enrico Fermi and his team build the first experimental nuclear reactor at the University of Chicago.

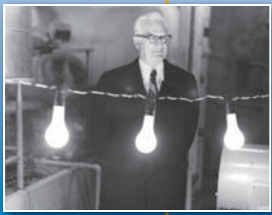
August 1, 1946

President Harry S. Truman signs Atomic Energy Act creating Atomic Energy Commission (AEC) as lead federal nuclear agency.

1950s

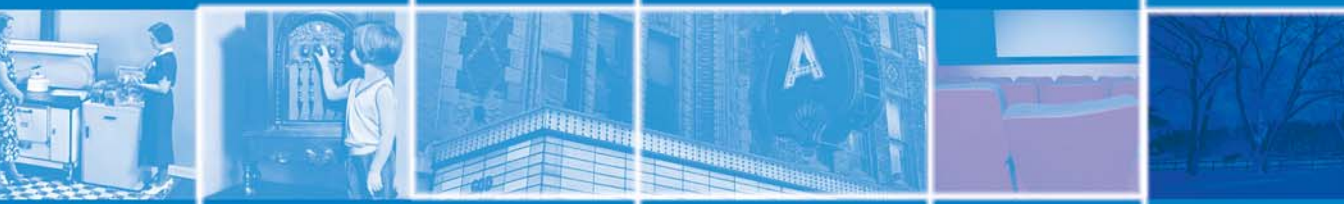
December 20, 1951

In Arco, Idaho, Experimental Breeder Reactor I produces the first electric power from nuclear fission, lighting four light bulbs.



May 31, 1953

The first atomic reactor to specifically produce power, the Submarine Thermal Reactor, begins operation near Idaho Falls, Idaho. The prototype reactor for the *U.S.S. Nautilus* was developed by the Argonne National Laboratory and Westinghouse.



1960s

December 12, 1963

Jersey Central Power and Light Company announces its commitment for the Oyster Creek nuclear power plant, the first time a nuclear plant is ordered as an economical alternative to a fossil-fuel plant.

1970s

1974

The first 1,000 megawatt electric nuclear power plant goes into service, Commonwealth Edison's Zion 1 facility.

October 11, 1974

The Energy Reorganization Act of 1974 divides AEC functions between two new agencies — the Energy Research and Development Administration (ERDA) to carry out R&D; and the Nuclear Regulatory Commission (NRC) to regulate nuclear power, technologies, and material.

August 4, 1977

President Jimmy Carter signs the Department of Energy Organization Act, transferring ERDA functions to the new U.S. Department of Energy (DOE). DOE begins operations on October 1, 1977.

U.S. Nuclear Electricity Generation, 1940 – 1990

A Timeline of Significant Events

Source: U. S. Department of Energy, Office of Nuclear Energy, "The History of Nuclear Energy."

1950s

December 8, 1953

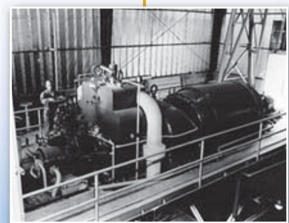
President Dwight D. Eisenhower delivers his *Atoms for Peace* speech before the United Nations, calling for greater international cooperation in the peaceful development of atomic energy.

August 30, 1954

President Eisenhower signs the Atomic Energy Act of 1954, the first major amendment of the original Atomic Energy Act, giving the civilian nuclear power program further access to nuclear technology.

January 10, 1955

The AEC announces the Power Demonstration Reactor Program, under which the Commission and industry will cooperate in constructing and operating experimental nuclear power reactors.



July 17, 1955

Arco, Idaho, population 1,000, becomes the first town anywhere to receive electricity from a nuclear power plant, the experimental boiling water reactor BORAX III.

May 4, 1956

For the first time, the AEC authorizes the construction of private nuclear power plants. Following this authorization, Consolidated Edison Co. and Commonwealth Edison Co. build small plants in Indian Point, NY, and Grundy County, IL, respectively.

December 2, 1957

The world's first large-scale nuclear power plant begins operation in Shippingport, Pennsylvania, providing power to the Pittsburgh area.

1970s

March 28, 1979

The most serious accident in U.S. commercial reactor history occurs at Unit 2 of the Three Mile Island nuclear power station in Pennsylvania. No workers or citizens living in the vicinity of the plant received physical injuries. The accident led to widespread safety and operational advances.

1980s

January 7, 1983

The Nuclear Waste Policy Act (NWPA) establishes a program to site a repository for the disposal of high-level radioactive waste, including spent fuel from nuclear power plants. It also establishes fees for owners and generators of radioactive waste and spent fuel, who pay the costs of the program.

1983

For the first time, nuclear power (294 billion kilowatt hours) generates more U.S. electricity than natural gas (274 billion kilowatt hours).

1984

Nuclear energy (328 billion kilowatt hours) surpasses hydropower (324 billion kilowatt hours) as the second largest source of electricity after coal.

U.S. Nuclear Electricity Generation, 1990 – 2005

President Ronald W. Reagan signs Nuclear Waste Policy Act.

October 24, 1992

The Energy Policy Act of 1992 is signed into law, streamlining the licensing process for nuclear power plants and providing comprehensive energy reforms and priorities.

1990

America's 110 nuclear power plants set a new record — 577 billion kilowatt hours of power generation.

1990s

A Timeline of Significant Events

Source: U. S. Department of Energy, Office of Nuclear Energy, "The History of Nuclear Energy."

2000s

2004

Since the last commercial reactor (Watts Barr) to be built in the United States began operations in 1996, the improved efficiencies of America's nuclear power plants are equal to 17 new generation facilities being added to the nation's electricity grid.

2004 – 2005

Three groups of electric utility companies, and other firms, are formed to study construction of new nuclear power plants in the United States. Other utility companies announce their interests in building, operating, or participating in construction and operation of new nuclear power plants.

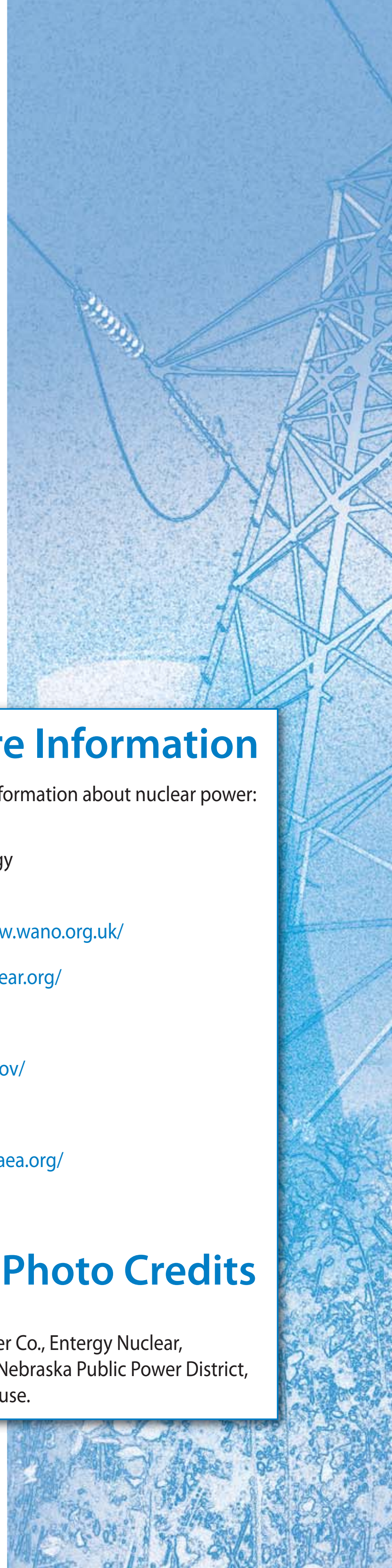
Energy Policy Act becomes law.

August 8, 2005

President George W. Bush signs into law the Energy Policy Act of 2005, which includes provisions to encourage expansion of nuclear power in the United States during the 21st century.

End Notes

[1] U.S. Energy Information Administration, "Annual Energy Outlook 2006."
[2] U.S. Energy Information Administration, www.eia.doe.gov/cneaf/nuclear/page/reserves/ures.html.
[3] U.S. Energy Information Administration, www.eia.doe.gov/kids/energyfacts/sources/non-renewable/nuclear.html.
[4] U.S. Department of Energy, Office of Nuclear Energy.
[5] U.S. Nuclear Regulatory Commission, http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/power-uprates.html.
[6] U.S. Department of Energy, Office of Nuclear Energy, "Nuclear Power 2010, Program Status Report," by Thomas P. Miller.
[7] Number of U.S. passenger cars from "Transportation Energy Data Book," Edition 22, published by the Center for Transportation Analysis, Oak Ridge National Laboratory. Based on 5.48 metric tons (6.028 short tons) of carbon dioxide equivalent emitted by the average passenger vehicle; source: Environmental Protection Agency, www.epa.gov/oms/climate/420f05004.htm.
[8] U.S. Department of Energy, Office of Nuclear Energy, "Answers to Questions About Nuclear Energy," page 6.
[9] Statement of Admiral Frank L. Bowman, U.S. Navy Director, Naval Reactors, U.S. Department of Energy, before the Senate Energy and Water Development Subcommittee, March 23, 2004.



For More Information

Contact these organizations for more information about nuclear power:

U.S. Department of Energy, Office of Nuclear Energy
http://www.nuclear.energy.gov

World Association of Nuclear Operators http://www.wano.org.uk/

World Nuclear Association http://www.world-nuclear.org/

American Nuclear Society http://www.ans.org/

Nuclear Regulatory Commission http://www.nrc.gov/

International Energy Agency http://www.iea.org/

International Atomic Energy Agency http://www.iaea.org/

Nuclear Energy Agency http://www.nea.fr/

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