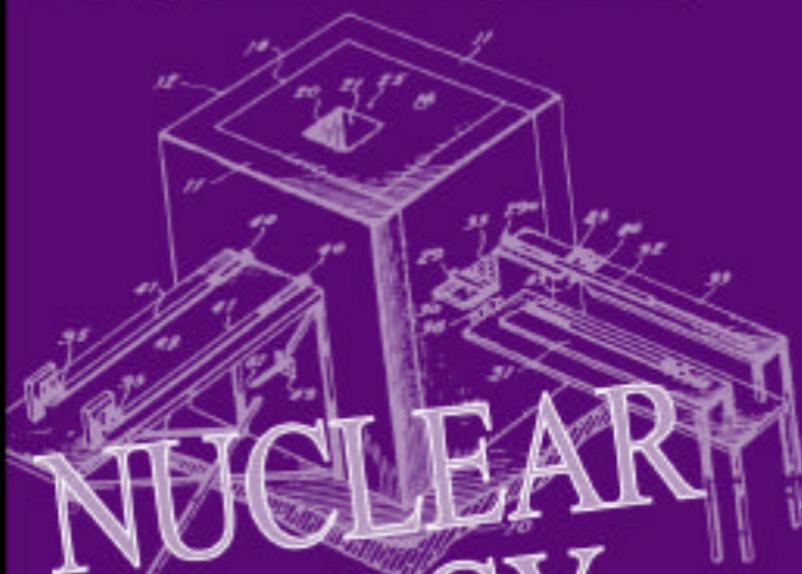
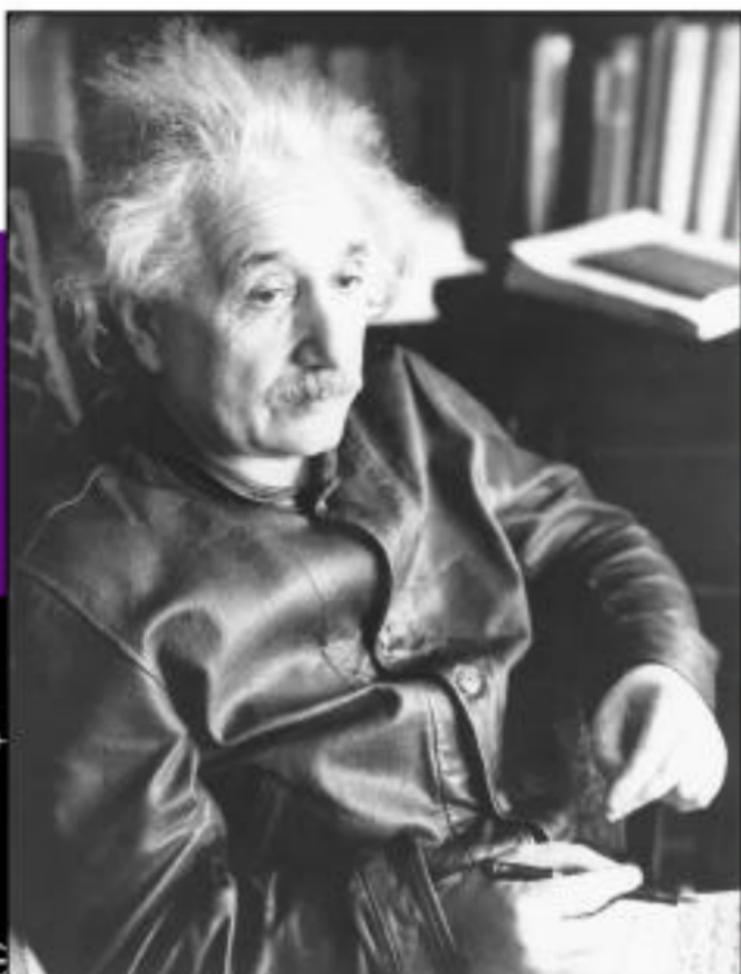


THE HISTORY OF Nuclear Energy



NUCLEAR ENERGY

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

The History of Nuclear Energy

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Albert Einstein (1879-1955)

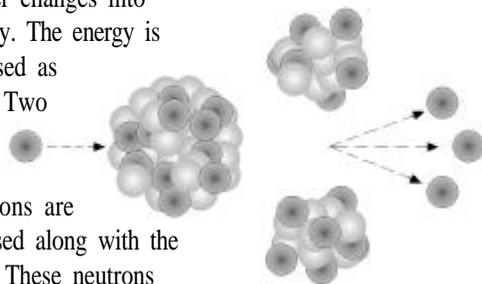
U.S. Department of Energy
Office of Nuclear Energy, Science and Technology
Washington, D.C. 20585

The History Of Nuclear Energy

Although they are tiny, atoms have a large amount of energy holding their nuclei together. Certain *isotopes* of some elements can be split and will release part of their energy as heat. This splitting is called *fission*. The heat released in fission can be used to help generate electricity in powerplants.

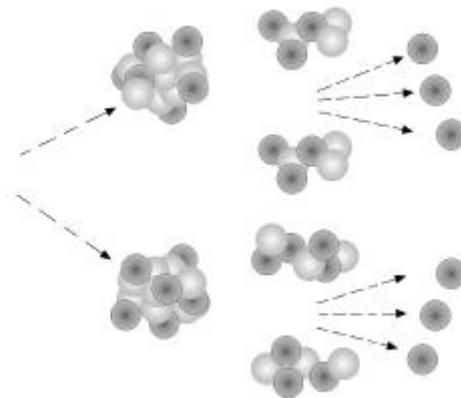
Uranium-235 (U-235) is one of the isotopes that fissions easily. During fission, U-235 atoms absorb loose neutrons. This causes U-235 to become unstable and split into two light atoms called *fission products*.

The combined mass of the fission products is less than that of the original U-235. The reduction occurs because some of the matter changes into energy. The energy is released as heat. Two or three neutrons are released along with the heat. These neutrons may hit other atoms, causing more fission.



A series of fissions is called a *chain reaction*. If enough uranium is brought together under the right conditions, a continuous chain reaction occurs. This is called a *self-sustaining chain reaction*. A self-sustaining chain reaction creates a great deal of heat, which can be used to help generate electricity.

Nuclear powerplants generate electricity like any other steam-electric powerplant. Water is heated, and steam from the boiling water turns turbines and generates electricity. The main difference in the various types of steam-electric plants is the heat source. Heat from a self-sustaining chain reaction boils the water in a nuclear powerplant. Coal, oil, or gas is burned in other powerplants to heat the water.



Preface

The concept of the atom has existed for many centuries. But we only recently began to understand the enormous power contained in the tiny mass.

In the years just before and during World War II, nuclear research focused mainly on the development of defense weapons. Later, scientists concentrated on peaceful applications of nuclear technology. An important use of nuclear energy is the generation of electricity. After years of research, scientists have successfully applied nuclear technology to many other scientific, medical, and industrial purposes.

This pamphlet traces the history of our discoveries about atoms. We begin with the ideas of the Greek philosophers. Then we follow the path to the early scientists who discovered radioactivity. Finally, we reach modern-day use of atoms as a valuable source of energy.

This pamphlet also includes a detailed chronology of the history of nuclear energy and a glossary. We hope the glossary will explain terms that may be new to some readers and that studying the chronology will encourage readers to explore the resources listed in the bibliography. By doing so, you can discover first-hand our nation's efforts to develop and control this powerful technology.

Introduction

It is human nature to test, to observe, and to dream. The history of nuclear energy is the story of a centuries-old dream becoming a reality.

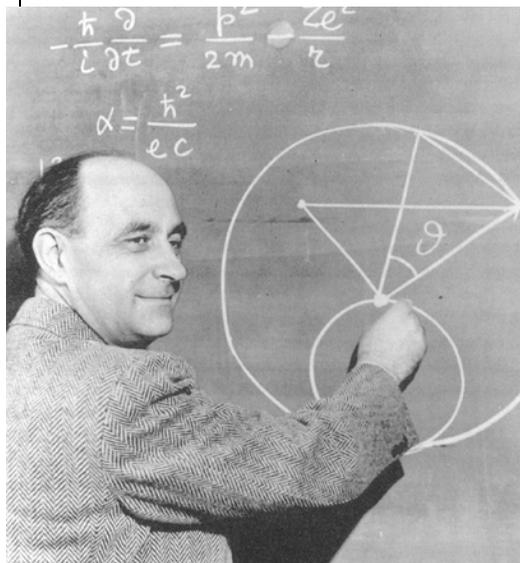
Ancient Greek philosophers first developed the idea that all matter is composed of invisible particles called *atoms*. The word atom comes from the Greek word, *atomos*, meaning indivisible. Scientists in the 18th and 19th centuries revised the concept based on their experiments. By 1900, physicists knew the atom contains large quantities of energy. British physicist Ernest Rutherford was called the father of nuclear science because of his contribution to the theory of atomic structure. In 1904 he wrote:

If it were ever possible to control at will the rate of disintegration of the radio elements, an enormous amount of energy could be obtained from a small amount of matter.

Albert Einstein developed his theory of the relationship between mass and energy one year later. The mathematical formula is $E=mc^2$, or “energy equals mass times the speed of light squared.” It took almost 35 years for someone to prove Einstein’s theory.

The Discovery Of Fission

In 1934, physicist Enrico Fermi conducted experiments in Rome that showed neutrons could split many kinds of atoms. The results surprised even Fermi himself. When he bombarded uranium with neutrons, he did not get the elements he expected. The elements were much lighter than uranium.



Enrico Fermi, an Italian physicist, led the team of scientists who created the first self-sustaining nuclear chain reaction.

In the fall of 1938, German scientists Otto Hahn and Fritz Strassman fired neutrons from a source containing the elements *radium* and *beryllium* into uranium (atomic number 92). They were surprised to find lighter elements, such as *barium* (atomic number 56), in the leftover materials.

These elements had about half the atomic mass of uranium. In previous experiments, the leftover materials were only slightly lighter than uranium.

Hahn and Strassman contacted Lise Meitner in Copenhagen before publicizing their discovery. She was an Austrian colleague who had been forced to flee Nazi Germany. She worked with Niels Bohr and her nephew, Otto R. Frisch. Meitner and Frisch thought the barium and other light elements in the leftover material resulted from the uranium splitting — or fissioning. However, when she added the atomic masses of the fission products, they did not total the uranium's mass. Meitner used Einstein's theory to show the lost mass changed to energy. This proved fission occurred and confirmed Einstein's work.

The First Self-Sustaining Chain Reaction

In 1939, Bohr came to America. He shared with Einstein the Hahn-Strassman-Meitner discoveries. Bohr also met Fermi at a conference on theoretical physics in Washington, D.C. They discussed the exciting possibility of a self-sustaining chain reaction. In such a process, atoms could be split to release large amounts of energy.

Scientists throughout the world began to believe a self-sustaining chain reaction might be possible. It would happen if enough uranium could be brought together under proper conditions. The amount of uranium needed to make a self-sustaining chain reaction is called a *critical mass*.

Fermi and his associate, Leo Szilard, suggested a possible design for a uranium chain reactor in 1941. Their model consisted of uranium placed in a stack of graphite to make a cube-like frame of fissionable material.



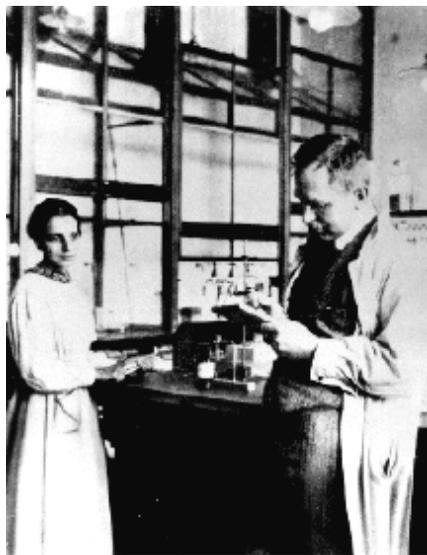
Leo Szilard

Early in 1942, a group of scientists led by Fermi gathered at the University of Chicago to develop their theories. By November 1942, they were ready for construction to begin on the world's first nuclear reactor, which became known as *Chicago Pile-1*. The pile was erected on the floor of a squash court beneath the University of Chicago's athletic stadium. In addition to uranium and graphite, it contained control rods made of *cadmium*. Cadmium is a metallic element that absorbs neutrons. When the rods were in the pile, there were fewer neutrons to fission uranium atoms. This slowed the chain reaction. When the rods were pulled out, more neutrons were available to split atoms. The chain reaction sped up.

On the morning of December 2, 1942, the scientists were ready to begin a demonstration of Chicago Pile-1. Fermi ordered the control rods to be withdrawn a few inches at a time during the next several hours. Finally, at 3:25 p.m., Chicago time, the nuclear reaction became self-sustaining. Fermi and his group had successfully transformed scientific theory into technological reality. The world had entered the nuclear age.

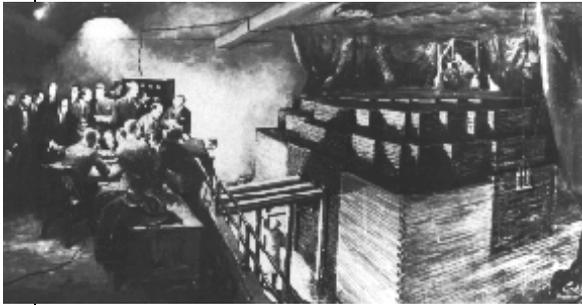
The Development Of Nuclear Energy For Peaceful Applications

The first nuclear reactor was only the beginning. Most early atomic research focused on developing an effective weapon for use in World War II. The work was done under the code name *Manhattan Project*.



Lise Meitner and Otto R. Frisch

However, some scientists worked on making *breeder reactors*, which would produce fissionable material in the chain reaction. Therefore, they would create more fissionable material than they would use.



Enrico Fermi led a group of scientists in initiating the first self-sustaining nuclear chain reaction. The historic event, which occurred on December 2, 1942, in Chicago, is recreated in this painting.

After the war, the United States government encouraged the development of nuclear energy for peaceful civilian purposes. Congress created the Atomic Energy Commission (AEC) in 1946. The AEC authorized the construction of Experimental Breeder Reactor I at a site in Idaho. The reactor generated the first electricity from nuclear energy on December 20, 1951.

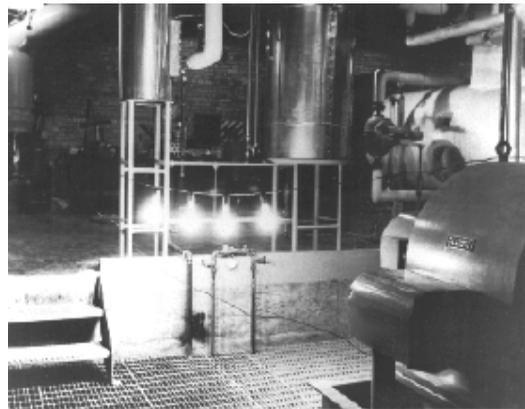
A major goal of nuclear research in the mid-1950s was to show that nuclear energy could produce electricity for commercial use. The first commercial electricity-generating plant powered by nuclear energy was located in Shippingport, Pennsylvania. It reached its full design power in 1957. Light-water reactors like Shippingport use ordinary water to cool the reactor core during the chain reaction. They were the best design then available for nuclear powerplants.

Private industry became more and more involved in developing light-water reactors after Shippingport became operational.

Federal nuclear energy programs shifted their focus to developing other reactor technologies.

The nuclear power industry in the U.S. grew rapidly in the 1960s. Utility companies saw this new form of electricity production as economical, environmentally clean, and safe. In the 1970s and 1980s, however, growth slowed. Demand for electricity decreased and concern grew over nuclear issues, such as reactor safety, waste disposal, and other environmental considerations.

Still, the U.S. had twice as many operating nuclear powerplants as any other country in 1991. This was more than one-fourth of the world's operating plants. Nuclear energy supplied almost 22 percent of the electricity produced in the U.S.



The Experimental Breeder Reactor I generated electricity to light four 200-watt bulbs on December 20, 1951. This milestone symbolized the beginning of the nuclear power industry.

At the end of 1991, 31 other countries also had nuclear powerplants in commercial operation or under construction. That is an impressive world-wide commitment to nuclear power technology.

During the 1990s, the U.S. faces several major energy issues and has developed several major goals for nuclear power, which are:

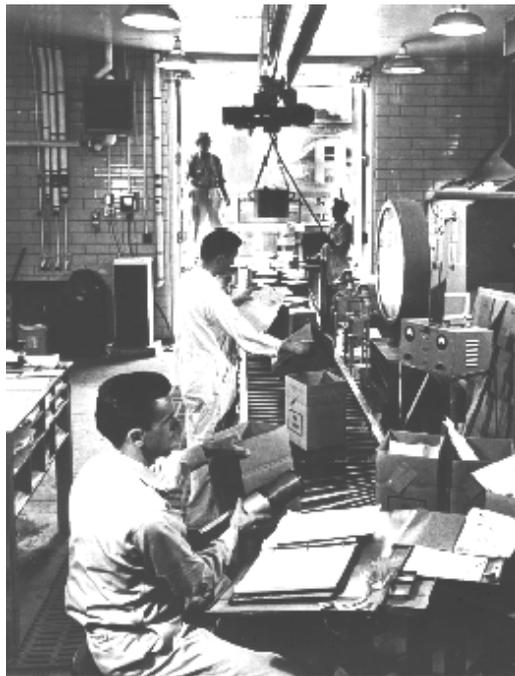
- ◆ To maintain exacting safety and design standards;
- ◆ To reduce economic risk;
- ◆ To reduce regulatory risk; and
- ◆ To establish an effective high-level nuclear waste disposal program.

Several of these nuclear power goals were addressed in the Energy Policy Act of 1992, which was signed into law in October of that year.

The U.S. is working to achieve these goals in a number of ways. For instance, the U.S. Department of Energy has undertaken a number of joint efforts with the nuclear industry to develop the next generation of nuclear powerplants. These plants are being designed to be safer and more efficient. There is also an effort under way to make nuclear plants easier to build by standardizing the design and simplifying the licensing requirements, without lessening safety standards.

In the area of waste management, engineers are developing new methods and places to store the radioactive waste produced by nuclear plants and other nuclear processes. Their goal is to keep the waste away from the environment and people for very long periods of time.

Scientists are also studying the power of nuclear fusion. Fusion occurs when atoms join — or fuse — rather than split. Fusion is the energy that powers the sun. On earth, the most promising fusion fuel is deuterium, a form of hydrogen. It comes from water and is plentiful. It is also likely to create less radioactive waste than fission. However, scientists are still unable to produce useful amounts of power from fusion and are continuing their research.



In Oak Ridge, Tennessee, workers package isotopes, which are commonly used in science, industry, and medicine.

Research in other nuclear areas is also continuing in the 1990s. Nuclear technology plays an important role in medicine, industry, science, and food and agriculture, as well as power generation. For example, doctors use radioisotopes to identify and investigate the causes of disease.

They also use them to enhance traditional medical treatments. In industry, radioisotopes are used for measuring microscopic thicknesses, detecting irregularities in metal casings, and testing welds. Archaeologists use nuclear techniques to date prehistoric objects accurately and to locate structural defects in statues and buildings. Nuclear irradiation is used in preserving food. It causes less vitamin loss than canning, freezing, or drying.

Nuclear research has benefited mankind in many ways. But today, the nuclear industry faces huge, very complex issues. How can we minimize the risk? What do we do with the waste? The future will depend on advanced engineering, scientific research, and the involvement of an enlightened citizenry.

Chronology of Nuclear Research and Development

The '40s

1942 December 2. The first self-sustaining nuclear chain reaction occurs at the University of Chicago.

1945 July 16. The U.S. Army's Manhattan Engineer District (MED) tests the first atomic bomb at Alamogordo, New Mexico, under the code name *Manhattan Project*.

1945 August 6. The atomic bomb nicknamed *Little Boy* is dropped on Hiroshima, Japan. Three days later, another bomb, *Fat Man*, is dropped on Nagasaki, Japan. Japan surrenders on August 15, ending World War II.

1946 August 1. The Atomic Energy Act of 1946 creates the Atomic Energy Commission (AEC) to control nuclear energy development and explore peaceful uses of nuclear energy.

1947 October 6. The AEC first investigates the possibility of peaceful uses of atomic energy, issuing a report the following year.

1949 March 1. The AEC announces the selection of a site in Idaho for the National Reactor Testing Station.

The '50s

1951 December 20. In Arco, Idaho, Experimental Breeder Reactor I produces the first electric power from nuclear energy, lighting four light bulbs.

1952 June 14. Keel for the Navy's first nuclear submarine, *Nautilus*, is laid at Groton, Connecticut.

1953 March 30. *Nautilus* starts its nuclear power units for the first time.

1953 December 8. President Eisenhower delivers his "Atoms for Peace" speech before the United Nations. He calls for greater international cooperation in the development of atomic energy for peaceful purposes.

1954 August 30. 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.

1955 January 10. The AEC announces the Power Demonstration Reactor Program. Under the program, AEC and industry will cooperate in constructing and operating experimental nuclear power reactors.

1955 July 17. Arco, Idaho, population 1,000, becomes the first town powered by a nuclear powerplant, the experimental boiling water reactor BORAX III.

1955 August 8-20. Geneva, Switzerland, hosts the first United Nations International Conference on the Peaceful Uses of Atomic Energy.

1957 July 12. The first power from a civilian nuclear unit is generated by the Sodium Reactor Experiment at Santa Susana, California. The unit provided power until 1966.

1957 September 2. The Price-Anderson Act provides financial protection to the public and AEC licensees and contractors if a major accident occurs at a nuclear powerplant.



The Nautilus—the First Atomic-Powered Sub

1957 October 1. The United Nations creates the International Atomic Energy Agency (IAEA) in Vienna, Austria, to promote the peaceful use of nuclear energy and prevent the spread of nuclear weapons around the world.

1957 December 2. The world's first large-scale nuclear powerplant begins operation in Shippingport, Pennsylvania. The plant reaches full power three weeks later and supplies electricity to the Pittsburgh area.

1958 May 22. Construction begins on the world's first nuclear-powered merchant ship, the *N.S. Savannah*, in Camden, New Jersey. The ship is launched July 21, 1959.

1959 October 15. Dresden-1 Nuclear Power Station in Illinois, the first U.S. nuclear plant built entirely without government funding, achieves a self-sustaining nuclear reaction.

The '60s

1960 August 19. The third U.S. nuclear powerplant, Yankee Rowe Nuclear Power Station, achieves a self-sustaining nuclear reaction.

Early 1960s. Small nuclear-power generators are first used in remote areas to power weather stations and to light buoys for sea navigation.

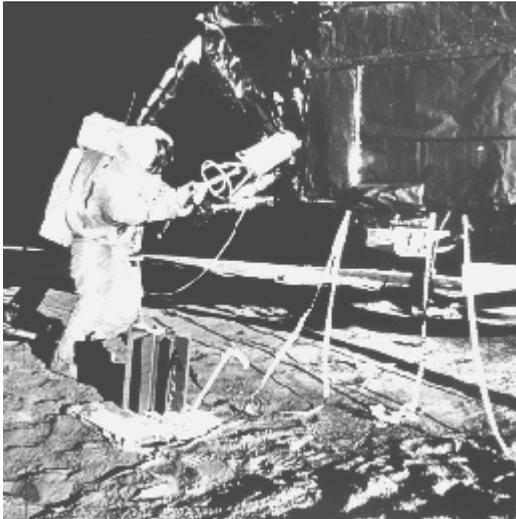


NS Savannah

1961 November 22. The U.S. Navy commissions the world's largest ship, the *U.S.S. Enterprise*. It is a nuclear-powered aircraft carrier with the ability to operate at speeds up to 30 knots for distances up to 400,000 miles (740,800 kilometers) without refueling.

1964 August 26. President Lyndon B. Johnson signs the Private Ownership of Special Nuclear Materials Act, which allows the nuclear power industry to own the fuel for its units. After June 30, 1973, private ownership of the uranium fuel is mandatory.

1963 December 12. Jersey Central Power and Light Company announces its commitment for the Oyster Creek nuclear powerplant, the first time a nuclear plant is ordered as an economic alternative to a fossil-fuel plant.



An atomic battery operated on the moon continuously for three years. Nuclear electric power arrived on the moon for the first time on November 19, 1969, when the Apollo 12 astronauts deployed the AEC's SNAP-27 nuclear generator on the lunar surface.

1964 October 3. Three nuclear-powered surface ships, the *Enterprise*, *Long Beach*, and *Bainbridge*, complete "Operation Sea Orbit," an around-the-world cruise.

1965 April 3. The first nuclear reactor in space (SNAP-10A) is launched by the United States. SNAP stands for Systems for Nuclear Auxiliary Power.

The '70s

1970 March 5. The United States, United Kingdom, Soviet Union, and 45 other nations ratify the Treaty for Non-Proliferation of Nuclear Weapons.

1971 Twenty-two commercial nuclear powerplants are in full operation in the United States. They produce 2.4 percent of U.S. electricity at this time.

1973 U.S. utilities order 41 nuclear powerplants, a one-year record.

1974 The first 1,000-megawatt-electric nuclear powerplant goes into service – Commonwealth Edison's Zion 1 Plant.

1974 October 11. The Energy Reorganization Act of 1974 divides AEC functions between two new agencies — the Energy Research and Development Administration (ERDA), to carry out research and development, and the Nuclear Regulatory Commission (NRC), to regulate nuclear power.

1977 April 7. President Jimmy Carter announces the United States will defer indefinitely plans for reprocessing spent nuclear fuel.

1977 August 4. President Carter signs the Department of Energy Organization Act, which transfers ERDA functions to the new Department of Energy (DOE).

1977 October 1. DOE begins operations.

1979 March 28. The worst accident in U.S. commercial reactor history occurs at the Three Mile Island nuclear power station near Harrisburg, Pennsylvania. The accident is caused by a loss of coolant from the reactor core due to a combination of mechanical malfunction and human error. No one is injured, and no overexposure to radiation results from the accident. Later in the year, the NRC imposes stricter reactor safety regulations and more rigid inspection procedures to improve the safety of reactor operations.

1979 Seventy-two licensed reactors generate 12 percent of the electricity produced commercially in the United States.

The '80s

1980 March 26. DOE initiates the Three Mile Island research and development program to develop technology for disassembling and de-fueling the damaged reactor. The program will continue for 10 years and make significant advances in developing new nuclear safety technology.

1982 October 1. After 25 years of service, the Shippingport Power Station is shut down. Decommissioning would be completed in 1989.

1983 January 7. 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 powerplants. It also establishes fees for owners and generators of radioactive waste and spent fuel, who pay the costs of the program.

1983 Nuclear power generates more electricity than natural gas.

1984 The atom overtakes hydropower to become the second largest source of electricity, after coal. Eighty-three nuclear power reactors provide about 14 percent of the electricity produced in the United States.

1985 The Institute of Nuclear Power Operations forms a national academy to accredit every nuclear powerplant's training program.

1986 The Perry Power Plant in Ohio becomes the 100th U.S. nuclear powerplant in operation.

1986 April 26. Operator error causes two explosions at the Chernobyl No. 4 nuclear powerplant in the former Soviet Union. The reactor has an inadequate containment building, and large amounts of radiation escape. A plant of such design would not be licensed in the United States.

1987 December 22. The Nuclear Waste Policy Act (NWPA) is amended. Congress directs DOE to study only the potential of the Yucca Mountain, Nevada, site for disposal of high-level radioactive waste.

1988 U.S. electricity demand is 50 percent higher than in 1973.

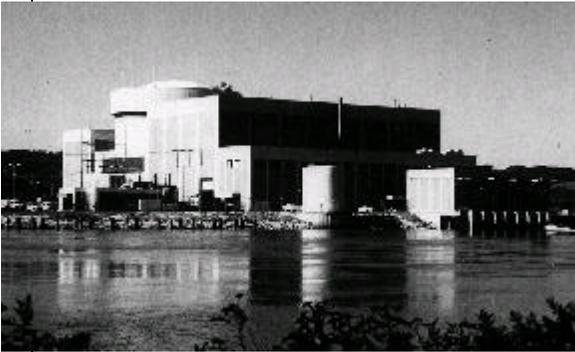
1989 One hundred and nine nuclear powerplants provide 19 percent of the electricity used in the U.S.; 46 units have entered service during the decade.

1989 April 18. The NRC proposes a plan for reactor design certification, early site permits, and combined construction and operating licenses.

The '90s

1990 March. DOE launches a joint initiative to improve operational safety practices at civilian nuclear powerplants in the former Soviet Union.

1990 America's 110 nuclear powerplants set a record for the amount of electricity generated, surpassing all fuel sources combined in 1956.



The Omaha Public District Fort Calhoun Nuclear Power Station located at Fort Calhoun, Nebraska

1990 April 19. The final shipment of damaged fuel from the Three Mile Island nuclear plant arrives at a DOE facility in Idaho for research and interim storage. This ends DOE's 10-year Three Mile Island research and development program.

1991 One hundred and eleven nuclear powerplants operate in the United States with a combined capacity of 99,673 megawatts. They produce almost 22 percent of the electricity generated commercially in the United States.

1992 One hundred and ten nuclear powerplants account for nearly 22 percent of all electricity used in the U.S.

1992 February 26. DOE signs a cooperative agreement with the nuclear industry to co-fund the development of standard designs for advanced light-water reactors.

1992 October 24. The Energy Policy Act of 1992 is signed into law. The Act makes several important changes in the licensing process for nuclear powerplants.

1992 December 2. The 50th anniversary of the historic Fermi experiment is observed worldwide.

1993 March 30. The U.S. nuclear utility consortium, the Advanced Reactor Corporation (ARC), signs a contract with Westinghouse Electric Corporation to perform engineering work for an advanced, standardized 600-megawatt pressurized-water reactor. Funding for this next-generation plant comes from ARC, Westinghouse, and DOE.

1993 September 6. The U.S. nuclear utility consortium, ARC, signs a contract with General Electric Company for cost-shared, detailed engineering of a standardized design for a large, advanced nuclear powerplant. The engineering is being funded under a joint program among utilities, General Electric, and DOE.

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Glossary

atom The smallest unit of an element. It is made up of electrons, protons, and neutrons. Protons and neutrons make up the atom's nucleus. Electrons orbit the nucleus.

breeder reactor A nuclear reactor that makes more fuel than it uses. It is designed so that one of the fission products of the U-235 used in fission is plutonium-239 (Pu-239). Pu-239 is also a fissionable isotope.

cadmium A soft, blue-white metal. The control rods in the first nuclear power reactor were made of cadmium because it absorbs neutrons.

chain reaction A continuous fissioning of atoms.

critical mass The amount of uranium needed to cause a self-sustaining chain reaction.

deuterium An isotope of hydrogen used in fusion.

fission The process in which the nucleus of an atom is split to produce heat.

fission products Light atoms that result from fission. The combined mass of fission products is less than that of the original whole atom because energy and neutrons are released.

fusion The process in which atoms are joined to produce energy.

isotope A form of an element that contains an unusual number of neutrons in its nucleus.

light-water reactor (LWR) The typical commercial nuclear power reactor. It uses ordinary water (light water) to produce steam. The steam turns turbines and generates electricity.

Manhattan Project The code name for production of the atomic bombs developed during World War II. The name comes from the Manhattan Engineering District, which ran the program.

radioisotope A radioactive isotope of an element.

radium-beryllium source A combination of the elements radium and beryllium. Radium is a rare, brilliant-white, luminescent, highly radioactive metal. Beryllium is a high-melting, lightweight, corrosion-resistant, steel-gray metal.

self-sustaining chain reaction A continuous chain reaction.

uranium A heavy, silver-white, radioactive metal.

uranium-235 (U-235) An isotope of uranium that is used as fuel in nuclear powerplants.

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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