DOCUMENT RESUME

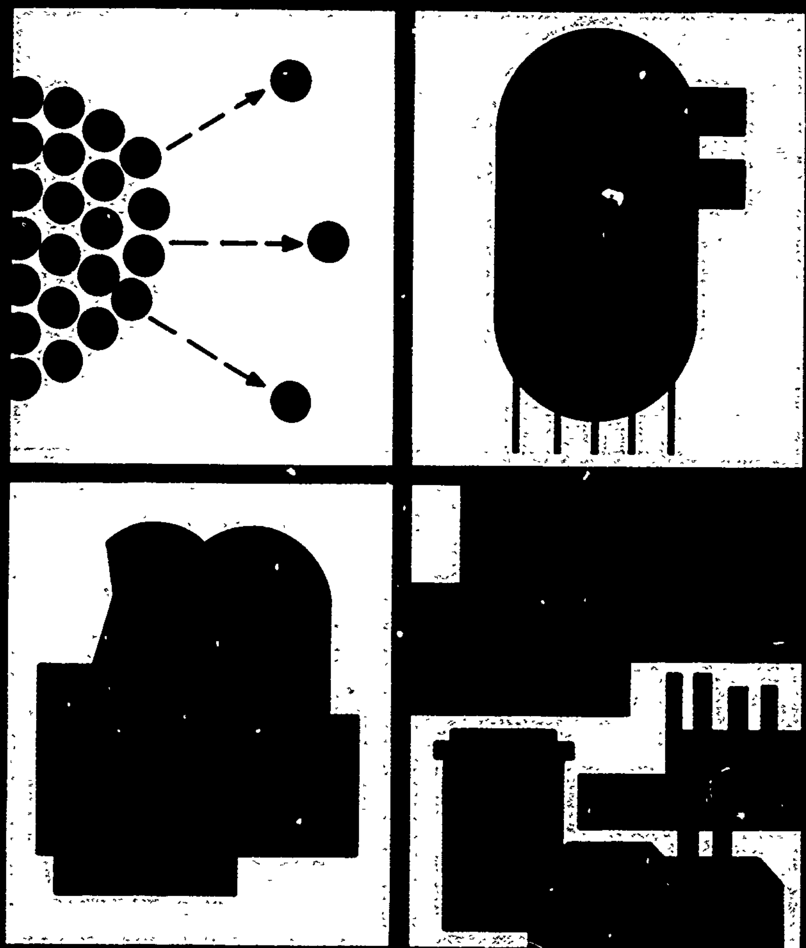
ED 297 942 SE 049 236

TITLE Atoms to Electricity.
INSTITUTION Department of Energy, Washington, DC. Nuclear Energy Office.
REPORT NO DOE/NE-0085
PUB DATE Nov "7
NOTE 94p.; Photographs ar.d drawings may not reproduce well. For previous edition, see ED 257 674.
AVAILABLE FROM Energy-DOE, P.O. Box 62, Oak Ridge, TN 37831 (single copies free, while supply lasts).
PUB TYPE Reports - General (140)

EDRS PRICE MF01/PC04 Plus Postage.
DESCRIPTORS Economics; *Electricity; Energy Education; Foreign Countries; *Hazardous Materials; *Nuclear Energy; *Nuclear Power Plants; *Nuclear Technology; *Waste Disposal; Wastes
IDENTIFIERS *Nuclear Reactors; Nucl-ar Wastes

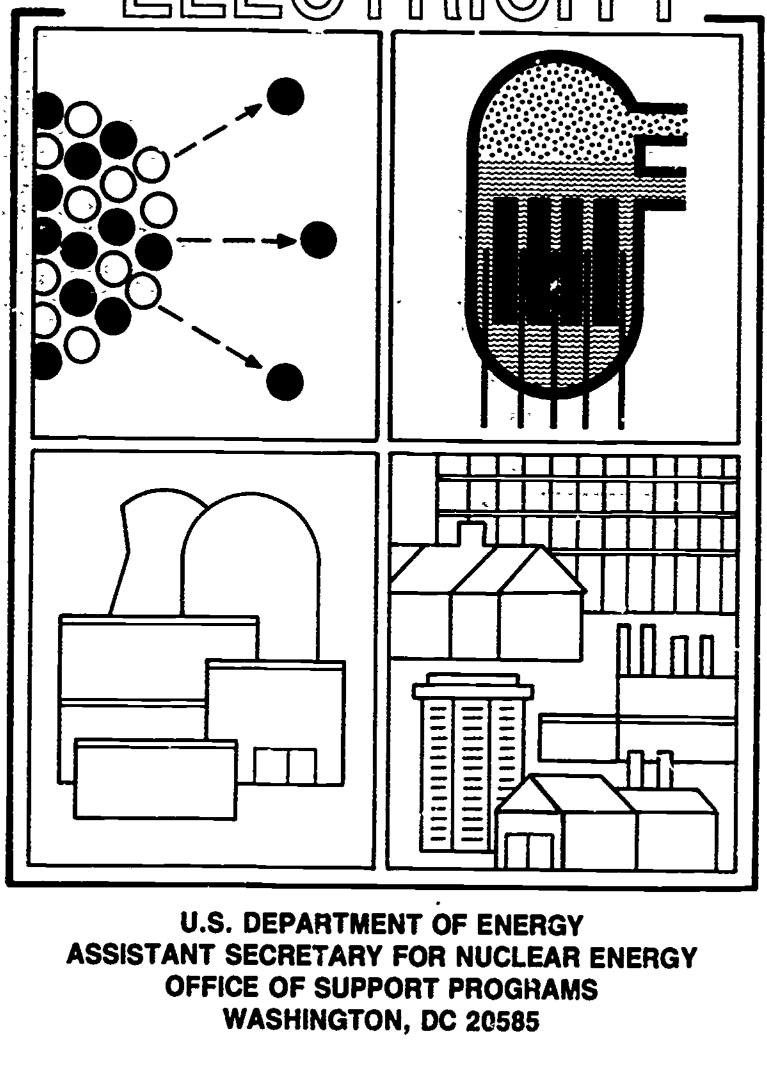
ABSTRACT

This booklet explains the basic technology of nuclear fission power reactors, the nuclear fuel cycle, and role of nuclear energy as one of the domestic energy resources being developed to meet the national energy demand. Major topic areas discussed include: (1) "The Role of Nuclear Power"; (2) "The Role of Electricity"; (3) Generating Electricity with the Atom"; (4) "Nuclear Power and Radiation"; (5) "Types of Nuclear Reactors (boiling-water, pressurized-water, and high temperature gas-cooled reactors)"; (6) "Breeder Reactors"; (7) "Nuclear Fuel-mining to Reactor"; (8) "Nuclear Fuel-reactor to Waste Disposal"; (9) "Transporting Radioactive Materials"; (10) "The Economics of Nuclear Power"; (11) "Nuclear Electricity in Other Countries"; and (12) a conclusion. Lists are included for selected books, reports, articles and pamphlets, films, and illustrations, and a glossary of related terms. (RT)



DOE/NE-0085
November 1987

ATOMS TO ELECTRICITY



U.S. DEPARTMENT OF ENERGY
ASSISTANT SECRETARY FOR NUCLEAR ENERGY
OFFICE OF SUPPORT PROGRAMS
WASHINGTON, DC 20585

List of Illustrations

List of Tables

Introduction

In the mid-1970s, the United States and much of the rest of the world found itself in the midst of a serious energy crisis. Fuel costs had risen dramatically. A major portion of the energy use in the United States was based on a potentially unavailable fuel source: imported oil. The security of the Nation's economy depended on decisions about energy prices and energy supplies made in other countries thousands of miles away.

Cutting back on U.S. dependence on imported oil, most experts agreed, required two actions: first, conserving energy, especially the use of oil; and second, relying more heavily on energy resources available in the United States. These changes have brought a new importance to the role of electricity in our national economy.

As Americans cut back on their direct use of oil, they turned to electric power to meet more and more of their energy needs. Electricity, which accounted for 25 percent of our national energy use in 1970, increased its share to over 30 percent by 1980. Many energy projections now expect electricity to account for nearly 50 percent by the turn of the century.

As electric power has grown in importance, the number of potential fuel sources to produce it have declined. Large sites for hydroelectric plants have essentially been exhausted. Because oil supplies were so unreliable in the 1970s, the Fuel Use Act of 1978 prohibited the use of this fuel in new electricity-generating plants. Although oil and gas reached competitive prices during mid-1986, many experts still consider supplies too valuable and unreliable to use for fuel in new powerplants. This means that the Nation must rely primarily on two domestic energy sources—coal and uranium to meet the growing needs for electricity over the next few decades.

This booklet explains the basic technology of nuclear fission power reactors, the nuclear fuel cycle and the role of nuclear energy as one of the domestic energy resources being developed to help meet our national energy demand. Nuclear power accounted for over 16 percent of the U.S. electric energy supply in 1986 and was second only to coal as a source of our electric power. In the 1990s, nuclear energy is expected to provide almost 20 percent of the Nation's electricity.

The Role of Nuclear Power

The Beginnings

On December 20, 1951, at a Government laboratory in Idaho, man's ability to use an energy hidden in nature entered a new era. An experimental plant called the Experimental Breeder Reactor-I generated enough electricity to light four 200-watt light bulbs (Figure 1). With that success, man had harnessed a new energy source that was neither mechanical, like the power of wind or falling water, nor chemical, like the burning of coal, oil, or gas. This electricity was created by nuclear energy.

The importance of this breakthrough was evident to scientists and energy experts around the world. Nuclear fission energy—the heat released when the nucleus of an atom "fissions," or splits into two small pieces—expanded human potential beyond the limits of such fuels as coal, oil, gas, and the energy of hydropower. It offered the promise of abundant electricity at relatively low cost and of providing power without the environmental effects that accompany the burning of fossil fuels. Government officials, scientists, journalists, and industry leaders alike saw this development as the beginning of a new age—the "atomic age."

The Growth of Nuclear Power

During the 1950s, there was no shortage of inexpensive fossil fuels for electricity-generating plants, so there was little obvious need to develop an alternative fuel source. The first few nuclear powerplants were essentially demonstrations of the technology, co-sponsored by utilities and the former U.S. Atomic Energy Commission (Figure 2).

In 1960, however, the first nuclear powerplant financed entirely by a utility—Unit 1 of the Dresden Nuclear Power Station, owned by the Commonwealth Edison Company—began operating near Chicago. In the next 6 years, 28 other utilities followed suit with a total of 38 new nuclear units. They were

Figure 1. On December 20, 1951, four electric light bulbs at the Atomic Energy Commission's National Reactor Testing Station in Idaho were powered by this generator (right), which operated on heat from the Experimental Breeder Reactor-I. (Credit: Argonne National Laboratory)

turning to nuclear for two reasons: to take advantage of the cost savings made possible by nuclear energy and, in some cases, to conserve fossil fuels. By the early 1970s, utilities were announcing plans for new nuclear powerplants as frequently as for coal-fueled powerplants.

In the mid-1970s, the rapid-growth era for new nuclear powerplants came to an end. The United States responded to the Mideast oil embargo and other shocks to its economy by using less energy than had previously been projected. The economic slowdown of the late 1970s and early 1980s further reduced energy demand. The 7 percent yearly increase in electric energy

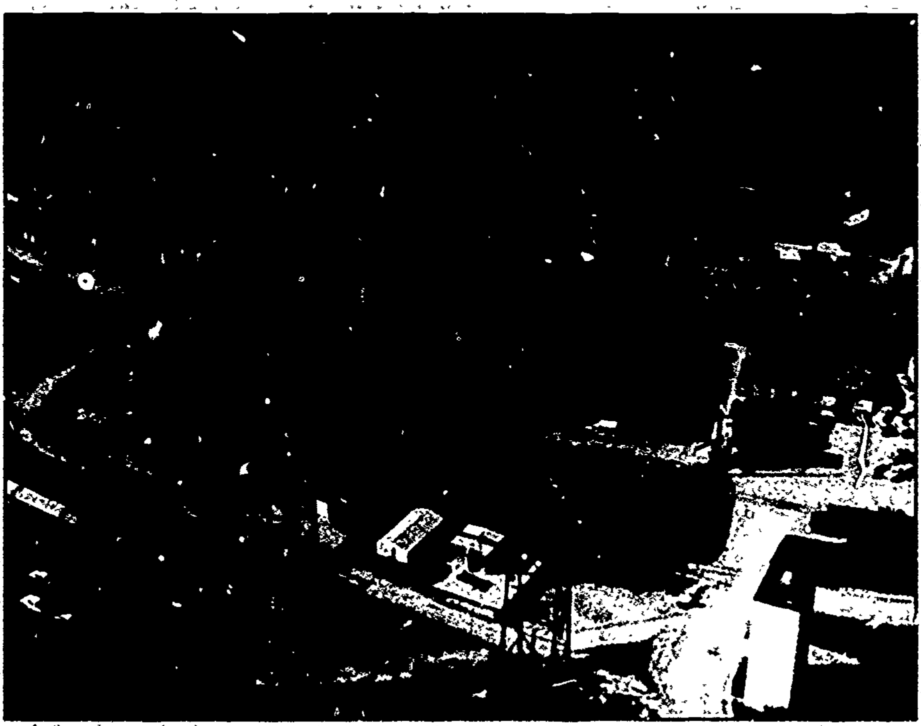


Figure 2. *The 60,000-kilowatt Shippingport Atomic Power Station, Shippingport, Pennsylvania, was the first large-scale, central-station nuclear powerplant in the United States and the first plant of such size in the world operated solely to produce electric power. The plant, a joint project of the U.S. Atomic Energy Commission and Duquesne Light Company, began operating in 1957. (Credit: U.S. Department of Energy)*

demand, which had remained essentially constant for over two decades, dropped to near zero in 1974. With minor fluctuations, the average annual growth since then has been about 3.5 percent, or half the rate of earlier years. Many utilities were hard-pressed to embark on large construction projects because of high inflation rates and even higher increases in fossil fuel costs. Facing a slowdown in the growth of electrical demand, utilities began cutting back on their plans for additional generating units, both coal and nuclear.

Nuclear Power Today and Tomorrow

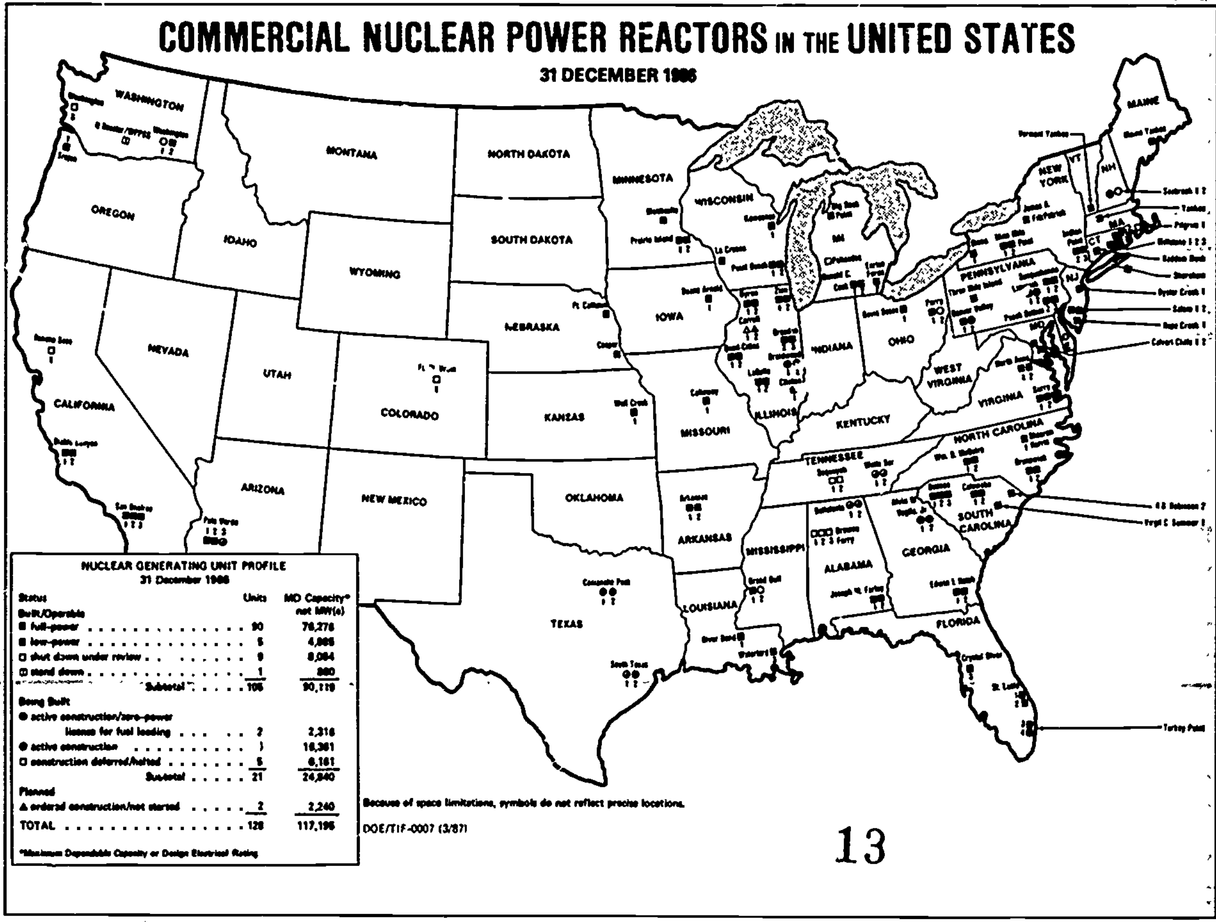
In 1986, nuclear power provided 16.6 percent of the Nation's electricity. By the summer of 1987, there were 109 commercial nuclear powerplants licensed to operate (Figure 3). Because electricity accounts for some 36 percent of the total energy use in the country, nuclear power contributes almost 6 percent of that total. The capacity of today's nuclear plants—about 90 million kilowatts—is greater than that of the entire U.S. electric capability in 1953.

The role of nuclear power is particularly important in many regions of the country with high fossil fuel costs. In New England, where the principal alternative to generating electricity by nuclear power is through the use of imported oil, nuclear energy provided 36.3 percent of the total electricity generated in 1985 (Figure 4). In Virginia, nuclear-generated electric power accounted for 53 percent; in New Jersey, 49 percent; in Vermont, 79 percent; in South Carolina, 61 percent; and in Minnesota, 38 percent.

About 24 other nuclear units are under construction or being planned by the Nation's utilities. Assuming that they are completed in the 1990s, nuclear power will provide enough electricity to meet over 20 percent of our electrical needs in the United States.

Beyond the approximately 130 plants operating or under construction, the outlook for nuclear power in the United States remains uncertain. The number of additional U.S. nuclear powerplants built in the next few decades will depend on several factors:

- the overall need for new electricity-generating stations as a result of electrical demand growth;
- utilities' decisions to replace obsolete and inefficient powerplants;



NUCLEAR GENERATING UNIT PROFILE
31 December 1986

Status	Units	MD Capacity* net MW(e)
Built/Operable		
■ full-power	90	76,276
■ low-power	5	4,985
□ shut down under review	9	8,084
⊡ stand down	1	860
Subtotal	105	90,119
Being Built		
● active construction/zero-power license for fuel loading	2	2,318
● active construction	14	16,361
○ construction deferred/halted	5	6,161
Subtotal	21	24,840
Planned		
▲ ordered construction/not started	2	2,240
TOTAL	128	117,196

*Maximum Dependable Capacity or Design Electrical Rating

Figure 3. *Commercial nuclear powerplants in the United States.*

Figure 4. Oconee Nuclear Station, Unit 2, set a record in February 1985 for the longest continuous operation of a nuclear powerplant: 439 days. During that run, it generated over 8.6 billion kilowatt-hours of electricity, which is the equivalent of 16 million barrels of oil. The plant has the capacity to produce 860,000 kilowatts of electricity. (Credit: Duke Power Company)

- the degree to which electric power will be used to substitute for oil and other fossil fuels;
- the ability to reduce the construction costs and the economic risks in building nuclear plants;
- changes in the nuclear regulatory climate; and
- public confidence in the safety of nuclear power.

With 130 plants already in operation or under construction, nuclear power clearly represents a major energy source. It will continue as a crucial part of U.S. energy security and National economy well into the 21st century.

The Role of Electricity

Ever since Michael Faraday invented an electric generator in the early 1800s, the industrialized world has been using an increasing amount of its energy in the form of electricity. Faraday demonstrated that a wire loop rotating in a magnetic field will generate electricity—that is, the mechanical energy of its rotation can be transformed into electrical energy. The electrical energy can be transmitted to a motor that will reverse the process, transforming the electricity back into a useful mechanical energy.

Electricity, then, is not a *source* of energy, but a *form* of energy. It relies on basic energy sources—like falling water or heat from the consumption of various fuels like coal, oil, gas, and uranium—to spin a turbine (Figure 5). The turbine provides the mechanical energy that a generator converts into electricity. The electricity is "shipped" or distributed through transmission lines to homes, schools, hospitals, factories, office buildings, rail systems, and other customers.

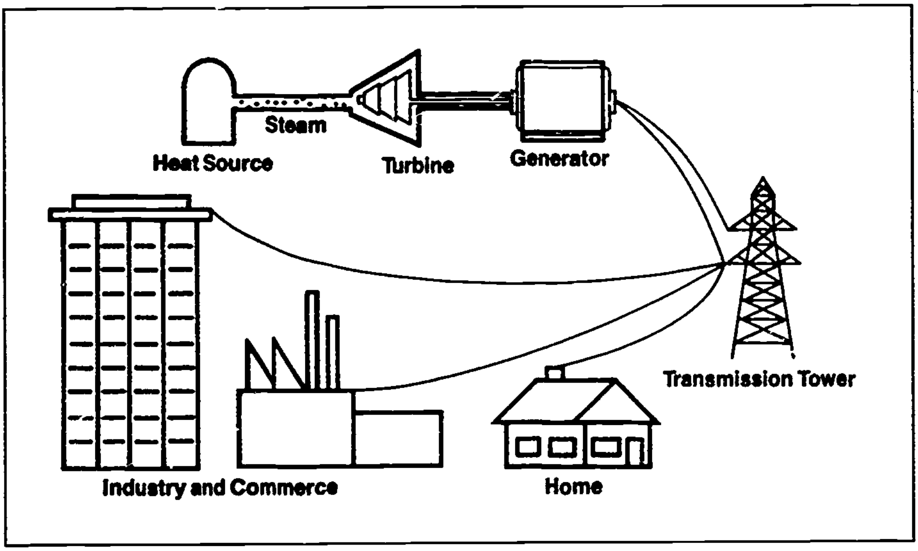


Figure 5. *Electricity: From its source to you.*

Because electricity can easily be shipped considerable distances by transmission lines to big cities, small towns, and farm communities, and because electricity is convenient, economical, and safe for many purposes, the use of electricity has steadily increased. In fact, it has grown far more rapidly in the past few decades than the overall use of energy.

Electricity and the Economy

Over a period of several decades, the development of the U.S. economy has been closely linked to the use of electric power. Electricity demand steadily increased much faster than the national economy—by some 70 to 80 percent—until our energy usage patterns began to change drastically in the early 1970s. Conservation programs and rising energy prices made Americans much more careful about their energy use. Since then, the use of other energy forms has declined, yet the demand for electricity has continued to grow faster than the national economy by some 25 to 50 percent.

Electricity and the Consumer

Approximately one-third of the energy used in the United States goes into the generation of electric power. Of that electricity, about 40 percent is used in industry, about 34 percent in households, and 26 percent in stores and offices. All three segments of our economy have cut back on their use of every other energy form in the past decade, but they have increased their demand for electric power.

Trends in housing have dramatized this steady shift toward electricity. Until 1970, less than 8 percent of U.S. households

Figure 6. The H.B. Robinson Steam Electric Plant near Hartsville, SC, produces electricity from both a nuclear unit (left) and coal-fired unit (right). (Credit: Carolina Power and Light Co.)

rising electrical demand—growing in importance from 4 percent in 1973 to 16.6 percent in 1986—is nuclear energy from uranium (Figure 6).

18

Figure 6. *The H.B. Robinson Steam Electric Plant near Hartsville, SC, produces electricity from both a nuclear unit (left) and coal-fired unit (right). (Credit: Carolina Power and Light Co.)*

rising electrical demand—growing in importance from 4 percent in 1973 to 16.6 percent in 1986—is nuclear energy from uranium (Figure 6).

18

Generating Electricity With the Atom

In concept, a nuclear powerplant operates essentially the same way as a fossil fuel plant, with one basic difference: the source of heat. The reactor of the nuclear plant performs the same function as the burning of fossil fuel in other types of electric plants—it generates heat. The process that produces the heat in a nuclear plant is the fissioning or splitting of uranium atoms. That heat boils water to make the steam that turns the turbine-generator, just as in a fossil fuel plant. The part of the plant where the heat is produced is called the reactor core.

The Fission Process

What is the fission process that produces the heat in nuclear powerplants? It starts with the uranium atom.

Atoms are made up of three major particles (Figure 7):

- Inside the nucleus, which is the center of the atom, there are positively charged *protons*. The number of protons in the nucleus determines to which family or element the atom belongs: all hydrogen atoms have 1 proton, carbon has 6, uranium has 92, etc.

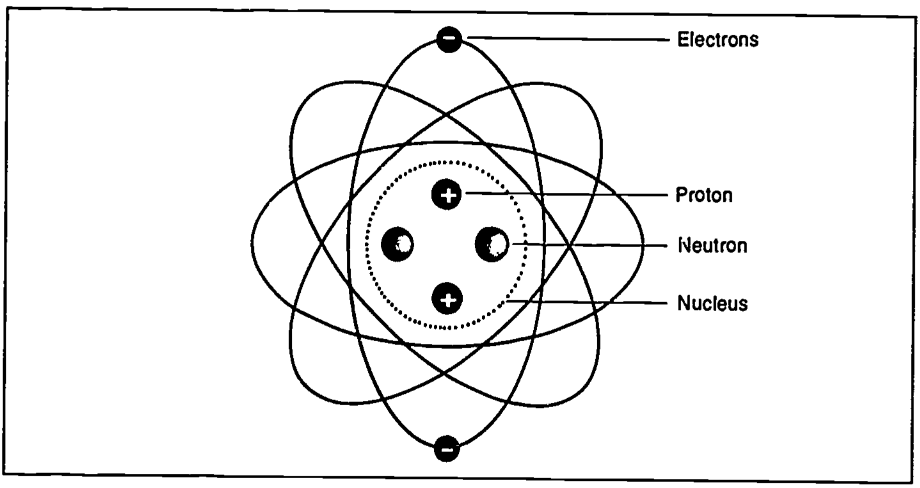


Figure 7. *The components of an atom.*

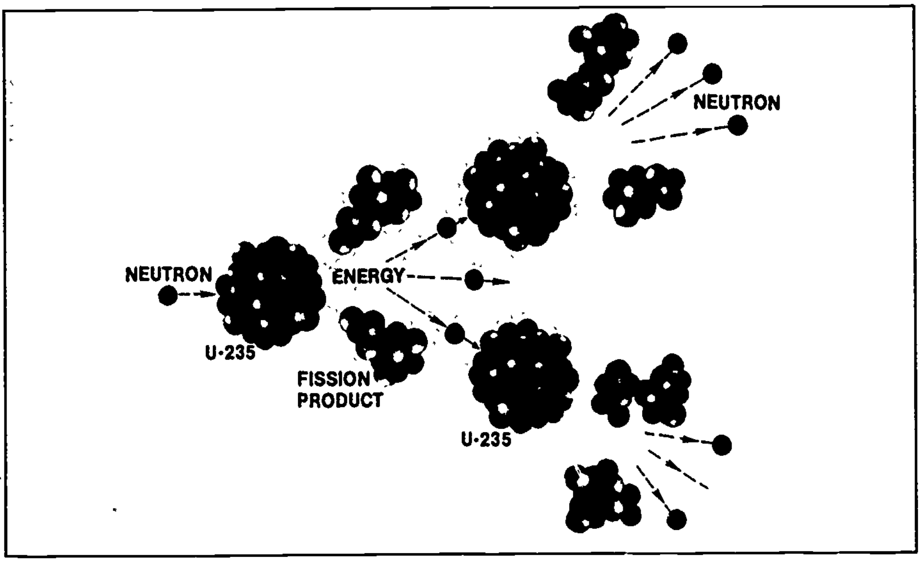


Figure 8. *The fission process.*

- The nucleus also contains uncharged particles known as *neutrons*. The number of neutrons in the nucleus identifies the specific member of the atom's family—or isotope. Different isotopes of the same element are designated by numbers after the element name that describes the total number of protons and neutrons inside the nucleus. The carbon-12 atom, for example, contains six protons (which make it carbon) and six neutrons in the nucleus; the carbon-14 atom has six protons and eight neutrons. Although the isotopes of an element behave the same chemically, they can vary in other properties. Carbon-14, for example, is radioactive, making it a radioisotope.
- Circling around the nucleus of each atom are tiny, negatively charged *electrons*. There are normally the same number of electrons as there are protons in the nucleus; otherwise, the atom has a positive or negative charge and is said to be ionized.

Because the protons have a positive charge, they could be expected to repel each other. However, the particles in the nucleus are held together by an even stronger force that scientists call "nuclear binding energy."

It is possible to overcome that binding energy in some large atoms, such as uranium, causing them to split apart or "fission." The fission process occurs when a free neutron enters the nucleus of a fissionable atom (Figure 8). The nucleus immediately becomes unstable, vibrates, and then splits into two fission fragments that are propelled apart at a high speed. The kinetic energy (energy of motion) of these fragments is transformed into heat as the fission fragments collide with surrounding atoms and molecules.

The process of actually turning mass into energy was anticipated by Professor Albert Einstein in 1905. His formula, $E = mc^2$, predicts that a small amount of mass (m) can be transformed into a large amount of energy (E), and that the amount of energy can be calculated by multiplying the mass times the square of the speed of light (c^2).

In addition to the fission fragments and heat, a fissioning nucleus also frees two or three additional neutrons. Some of these neutrons can strike other fissionable atoms, which release still other neutrons. These neutrons can, in turn, hit other fissionable atoms and continue the chain reaction. The rate at which these "free" neutrons are emitted is the key to sustaining and controlling a nuclear chain reaction.

Uranium Isotopes

The most common fissionable atom is an isotope of uranium known as uranium-235 (U-235), which is the fuel used in most types of nuclear reactors that are being built today. Although uranium is quite common in nature, about 100 times more common than silver, for example, U-235 is relatively rare.

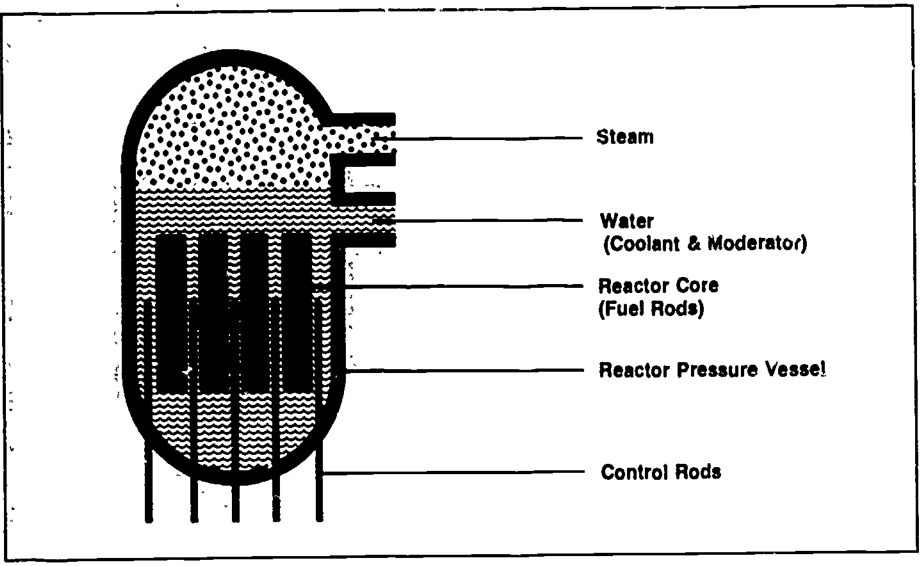


Figure 9. Elements of a water-cooled nuclear reactor.

When uranium is mined, it contains two isotopes: 99.3 percent is the isotope uranium-238 (U-238), and only 0.7 percent is the isotope U-235. Before the uranium can be used as a fuel in a nuclear powerplant, however, the 0.7 percent concentration of U-235 must be enriched to around a 3 percent concentration.

The most common uranium isotope, U-238, is not fissionable under most conditions. Interestingly, though, it is fertile—which means that when it absorbs a neutron, instead of fissioning, it is transformed into an atom that is itself fissionable. As neutrons from other fissions are absorbed by U-238, they cause nuclear reactions that convert U-238 to plutonium-239 (Pu-239), which is fissionable and can be used as fuel the same as U-235. As nuclear reactors operate, they are *using* fuel by burning U-235 and, at the same time, *creating* fuel by transforming otherwise useless U-238 into Pu-239. As plutonium builds up, some of the fissions in a reactor come from the plutonium, when it in turn absorbs another neutron.

- *The fuel.* The nuclear fuel is the heart of the reactor. In most U.S. reactors, the fuel consists of pellets of enriched uranium dioxide encased in 12-foot-long metal tubes, called fuel rods. These fuel rods are bundled to form fuel assemblies.

- *The control rods.* These rods have cross-shaped blades containing materials that absorb neutrons and are used to regulate the rate of the chain reaction. If they are pulled out of the core, the reaction speeds up. If they are inserted, they capture a larger fraction of the free neutrons and the reaction slows. The control rods are interspersed among the fuel assemblies in the core. Boron is a widely used absorber material.

- *The coolant.* A coolant, usually water, is pumped through the reactor to carry away the heat produced by the fissioning of the fuel. This is comparable to the water in the cooling system of a car, which carries away the heat built up in the engine. In large reactors, as much as 330,000 gallons of water flow through the reactor core every minute to carry away the heat. Most U.S. reactors are called light water reactors (LWRs) because they are cooled by ordinary or light water.

- *The moderator.* Neutrons have a better chance of causing an atom to fission if they move considerably slower than their initial speed after being emitted by a fissioning nucleus. The material used to slow the neutrons down is called the moderator. Fortunately for reactor designers, water itself is an excellent moderator, so reactors can be moderated by the same water that serves as a coolant. The moderator is essential to maintain a chain reaction; if water is lost from the core, the chain reaction stops (although the residual heat must still be removed).

Although engineering designs are quite complex, these four elements—the fuel, the control rods, the coolant, and the moderator—are the basic components of a nuclear reactor.

- *The fuel.* The nuclear fuel is the heart of the reactor. In most U.S. reactors, the fuel consists of pellets of enriched uranium dioxide encased in 12-foot-long metal tubes, called fuel rods. These fuel rods are bundled to form fuel assemblies.

- *The control rods.* These rods have cross-shaped blades containing materials that absorb neutrons and are used to regulate the rate of the chain reaction. If they are pulled out of the core, the reaction speeds up. If they are inserted, they capture a larger fraction of the free neutrons and the reaction slows. The control rods are interspersed among the fuel assemblies in the core. Boron is a widely used absorber material.

- *The coolant.* A coolant, usually water, is pumped through the reactor to carry away the heat produced by the fissioning of the fuel. This is comparable to the water in the cooling system of a car, which carries away the heat built up in the engine. In large reactors, as much as 330,000 gallons of water flow through the reactor core every minute to carry away the heat. Most U.S. reactors are called light water reactors (LWRs) because they are cooled by ordinary or light water.

- *The moderator.* Neutrons have a better chance of causing an atom to fission if they move considerably slower than their initial speed after being emitted by a fissioning nucleus. The material used to slow the neutrons down is called the moderator. Fortunately for reactor designers, water itself is an excellent moderator, so reactors can be moderated by the same water that serves as a coolant. The moderator is essential to maintain a chain reaction; if water is lost from the core, the chain reaction stops (although the residual heat must still be removed).

Although engineering designs are quite complex, these four elements—the fuel, the control rods, the coolant, and the moderator—are the basic components of a nuclear reactor.

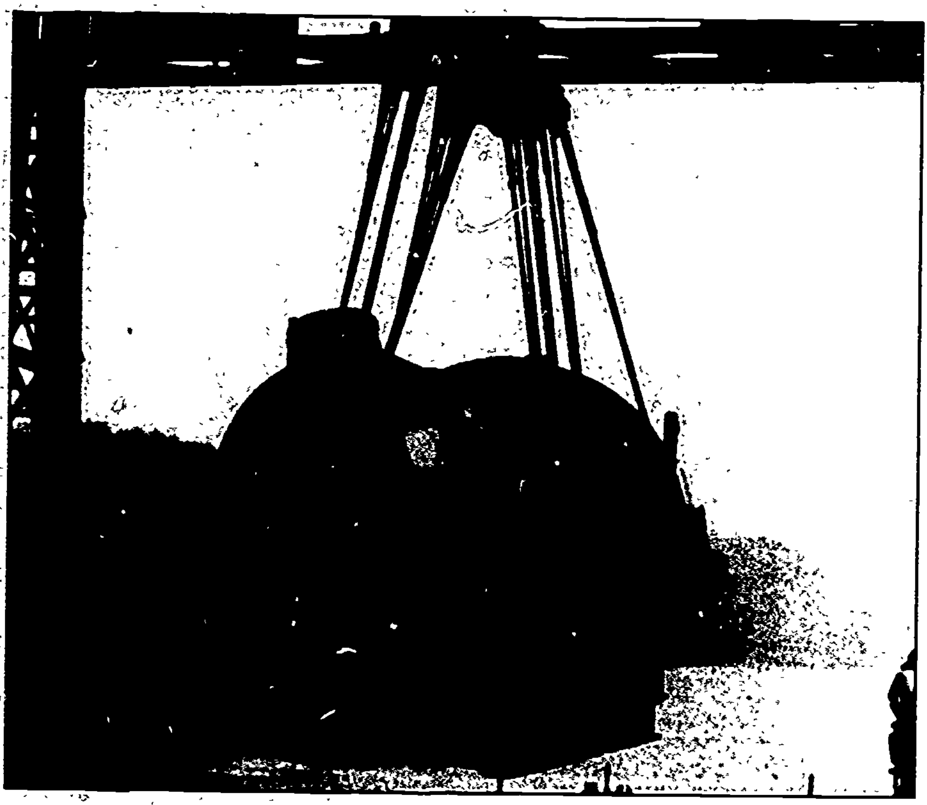


Figure 11. A 500-ton steam generator positioned on a barge for shipment to Arkansas Power and Light's nuclear powerplant outside Little Rock. The barge trip covered 1,065 miles and took about 2 weeks. (Credit: Combustion Engineering)

When the control rods are withdrawn, the uranium fuel begins to fission and release extra neutrons, the neutrons are slowed by the moderator so that they will continue the chain reaction, and the heat is carried away by the coolant.

The Nuclear Powerplant

The reactor is the one unique element that distinguishes a nuclear powcrplant from other powerplants. The rest of the buildings and equipment are similar to other electric powerplants.

Summarizing the process:

- Heat from the fission process turns water into steam;
- The steam flows into the turbine and turns a shaft to spin the generator and generate electricity, losing some of its heat and pressure in the process (Figure 11);
- The steam then moves to the condenser, where water flowing through cooling pipes cools it and condenses it back into water. This water, called "condensate," is preheated to make use of a bit more of the heat in the low-pressure steam and is fed back into the reactor to begin the cycle once again.

The water flowing through the cooling pipes, totally separate from the condensate, is handled differently. Cooling water is necessary for all electric powerplants that make steam from a heat source, not just for nuclear plants. For that reason, electric plants of many kinds are typically located near a river, lake, or other body of water. The cooling water for the plant is pumped from the body of water through pipes to the plant, where it cools the steam. In the process of cooling the steam, the temperature of the cooling water itself rises. To dissipate this leftover heat in the cooling water, many electric powerplants pump the water through a cooling tower or a specially built pond. Later, the water is fed back into its original source. The cooling water does not come into contact with the nuclear reactor or with radioactive materials.

Nuclear Powerplant Safety

In decisions to license, build, and operate nuclear powerplants, the subject of safety is of major importance. Operators of nuclear powerplants must demonstrate to the Nuclear Regulatory Commission (NRC)—the independent Federal agency responsible for licensing and regulating civilian

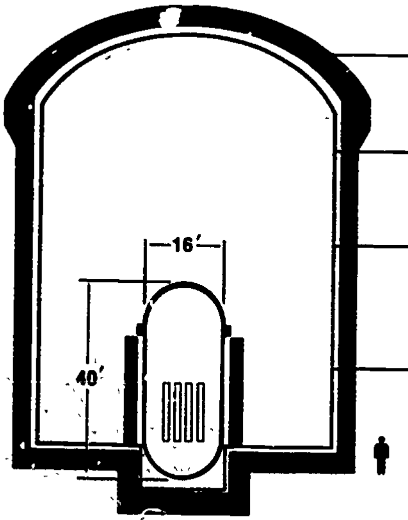


Figure 12. *Cross-section of a pressurized water reactor (PWR) containment building. Safety features in this specialized type of light water reactor are shown above. The containment building has an outer shell of 3 feet of reinforced concrete, with a 3/4-inch steel liner. An emergency core cooling system (accumulator), a pressure control system (ice condenser), and air circulation systems (ventilation fans) surround the core. Inside the reactor, the fuel is in the form of ceramic uranium pellets sealed in zircaloy tubes. (Credit: Westinghouse Electric Company)*

nuclear facilities—that each plant is designed and constructed with stringent, engineered safety features. Most of these safety features have one overall objective: to prevent or minimize the accidental release of radioactive material from the plant. Additionally, the routine operation of nuclear powerplants must also meet stringent safety requirements.

Because matters of safety are treated so seriously during the design, construction, and operation of a nuclear powerplant in the United States, experts consider it quite unlikely that any radioactive release could occur that would seriously affect public health and safety. Further, nuclear explosions are physically impossible: the uranium fuel with only a 3 percent concentration of fissionable atoms is in a form that cannot explode. While other kinds of equipment failure or operator errors are possible, radioactive materials would almost certainly be contained.

The United States has accumulated over 1,000 reactor-years of operating experience with commercial nuclear powerplants without a single loss of life to a member of the public due to the effects of radiation.

Several barriers to trap and contain radioactive material are designed into every nuclear powerplant (Figure 12). They include:

- *Ceramic fuel pellets*. The uranium dioxide fuel material is pressed into pellets to provide a stable form.
- *Zircaloy fuel rods*. The tubes, or fuel rods, that hold the uranium fuel pellets are made out of a strong alloy of zirconium and tin called "zircaloy." They prevent the solid and gaseous fission products from spreading through the reactor system.
- *Containment building*. As a final measure of protection, the entire reactor is surrounded by a massive concrete and steel "containment building." It has the single purpose of preventing radioactive materials from reaching the environment in the event that piping systems inside should leak or break. The concrete in the containment building is typically about 3 feet thick, lined with 3/4-inch steel (Figure 14). The containment building is designed to protect the reactor from being damaged by the direct hit of a large aircraft or tornado winds up to 300 mph.

In addition to these physical barriers, nuclear powerplants are designed and built with several safety systems and backup safety systems. These systems are to protect against malfunctions, mistakes, and potential accidents. For example, the most extensively studied accident is called a "loss-of-coolant accident." If the reactor core is not constantly cooled by water, its tremendous rate of heat generation could melt parts of the core. Even after the control rods shut the reactor down, there is still "decay heat" that requires cooling. To protect against a loss of

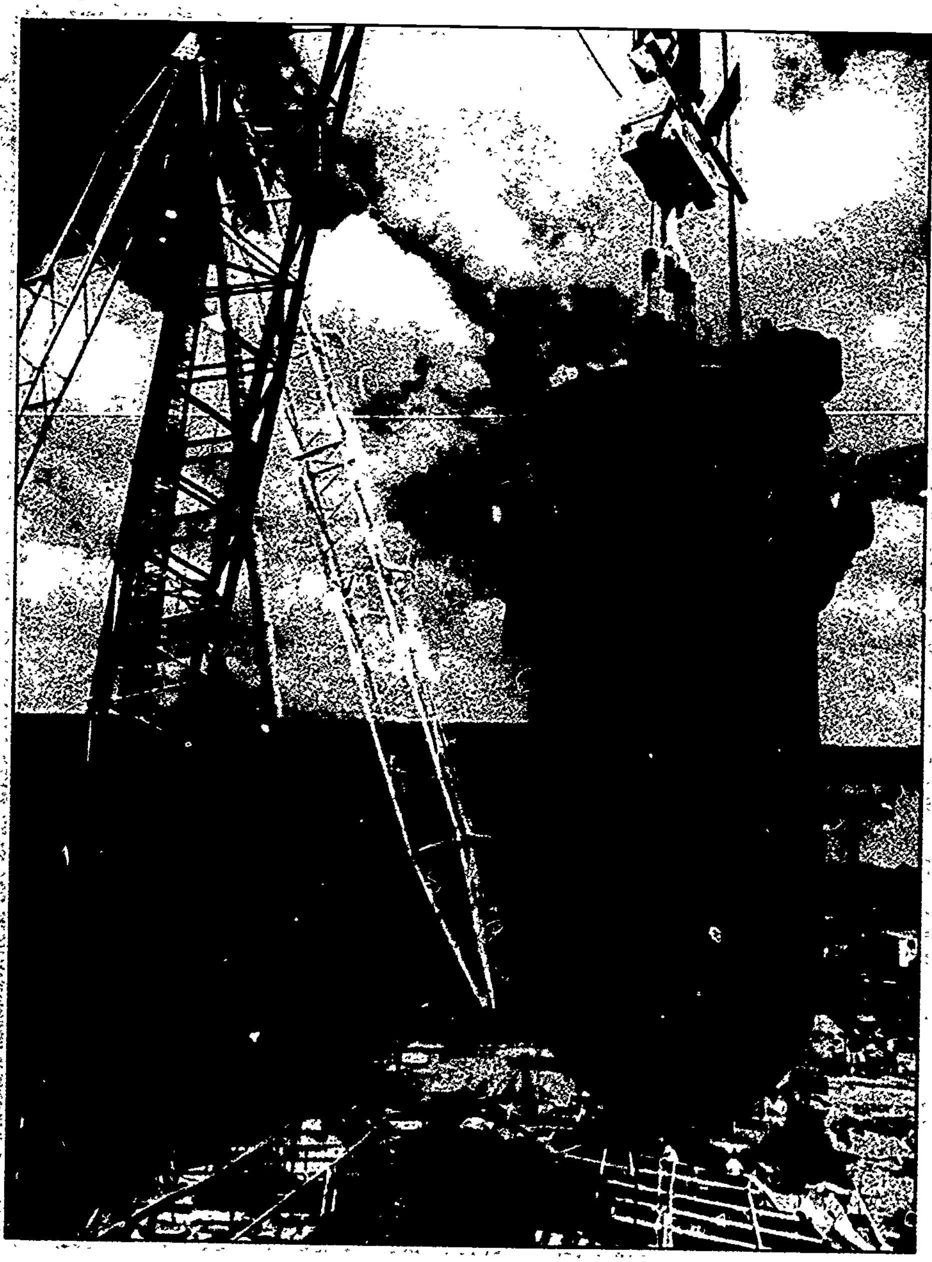


Figure 13. *The reactor vessel for Unit 1 of the Shearon Harris Nuclear Powerplant in North Carolina being hoisted into the containment building in April 1980. (Credit: Carolina Power and Light)*

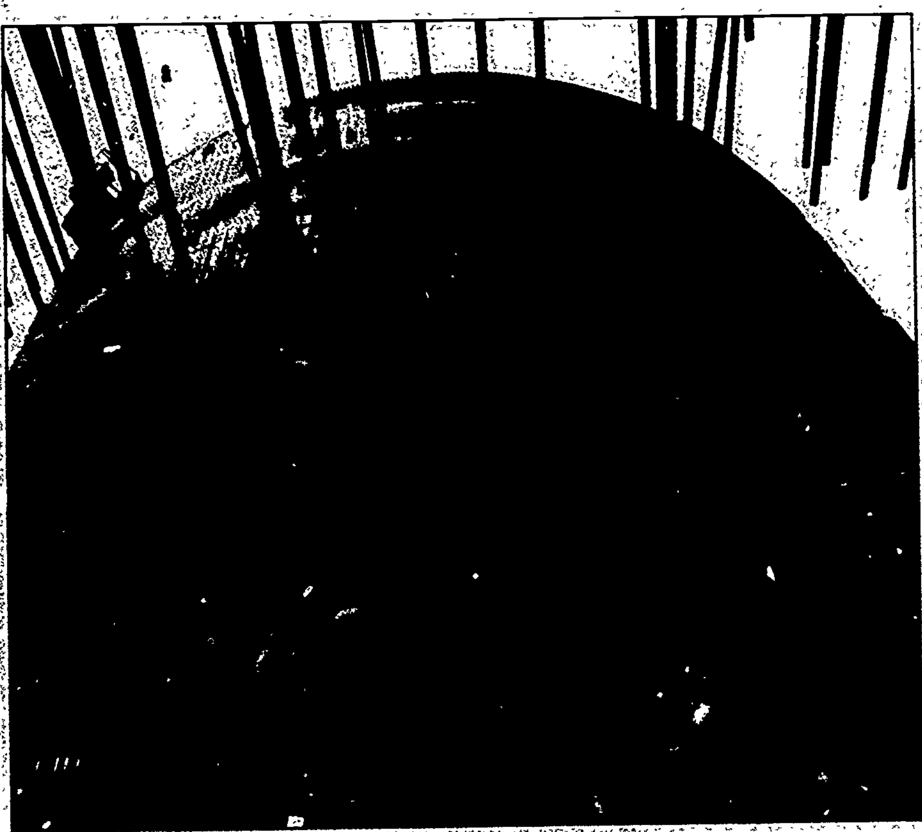


Figure 14. *Workers install reinforcement steel on the containment liner of Unit 1 of Shearon Harris Nuclear Powerplant near New Hill, NC. (Credit: Carolina Power and Light).*

of coolant, nuclear plants contain several backup systems that can be called on to cool the core if the primary cooling system should stop functioning.

With over 80 commercial nuclear plants licensed to operate in the United States, some for more than 17 years, there has never been an accident that has released a significant amount of radioactive materials to the environment. Recent scientific studies confirm that record, even for the 1979 Three Mile Island accident. (On March 28, 1979, the Three Mile Island Nuclear Powerplant near Harrisburg, PA, suffered a loss-of-coolant accident in its Unit 2 reactor. Although the accident was the most serious in U.S. commercial reactor history, there were no deaths, injuries, or large releases of radiation.) That accident provided a considerable amount of information about the adequacy of nuclear power safety systems. Although the backup cooling systems worked as designed and no radiation escaped through the reactor containment building (a small amount was released from a nearby auxiliary building), the accident pinpointed that improvements were needed in operator training and in information displays in the control rooms. New Federal regulations and improved training, monitoring, and management practices by the nuclear industry and utilities help to prevent a recurrence of the type of accident that occurred at Three Mile Island.

Further safety precautions are taken in the immediate vicinity of all licensed nuclear plants. For example, no homes are permitted within the boundaries of the site of the plant, which typically covers several hundred acres. Access to the site is also controlled. These security measures are to protect individuals from exposure to radiation or radioactive materials and to keep unauthorized persons outside the area.

Besides restricted public access to the site, public health is protected by programs that check for radiation releases. At the site boundary and beyond, monitoring and surveillance instruments are set up to measure whether any airborne radioactive materials are being released from the plant in the form of dusts, fumes, or gases. These ongoing monitoring programs ensure that indications of radiation levels remain within the public health standards and that corrective actions would be taken before the safety of the public is jeopardized.

Licensing, Building, and Operating a Nuclear Powerplant

Only after receiving both a construction permit and an operating license from the NRC can a nuclear powerplant be built and brought into service in the United States. To issue these licenses, the NRC conducts detailed technical reviews of utility applications to verify that:

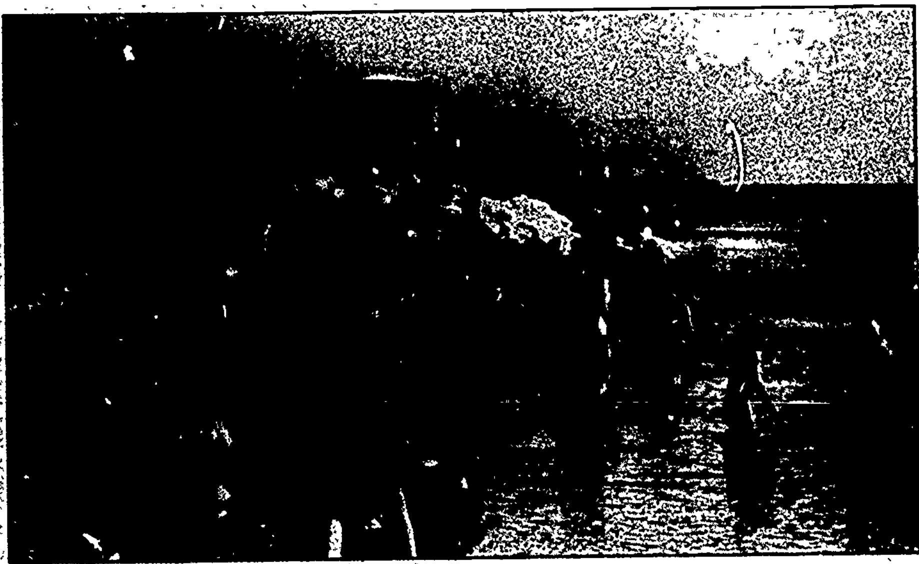


Figure 15. *Zion Nuclear Power Station is on Lake Michigan. (Credit: Commonwealth Edison Company)*

- Constructing and operating the plant will not present undue risk to public health and safety;
- Licensing the plant will not be harmful to national defense and security;
- The utility is technically qualified to design, construct, and operate the proposed facility; and
- The project complies with the National Environmental Policy Act.

The complete licensing and construction of a nuclear powerplant requires a lengthy series of licenses and permits from Federal, State, and local Government agencies. These permits and licenses determine where the plant can be located, whether the power is needed, and how excavation and construction will be carried out. They also ensure the protection of land, air, water, and local plant and animal life from pollution (Figure 15).

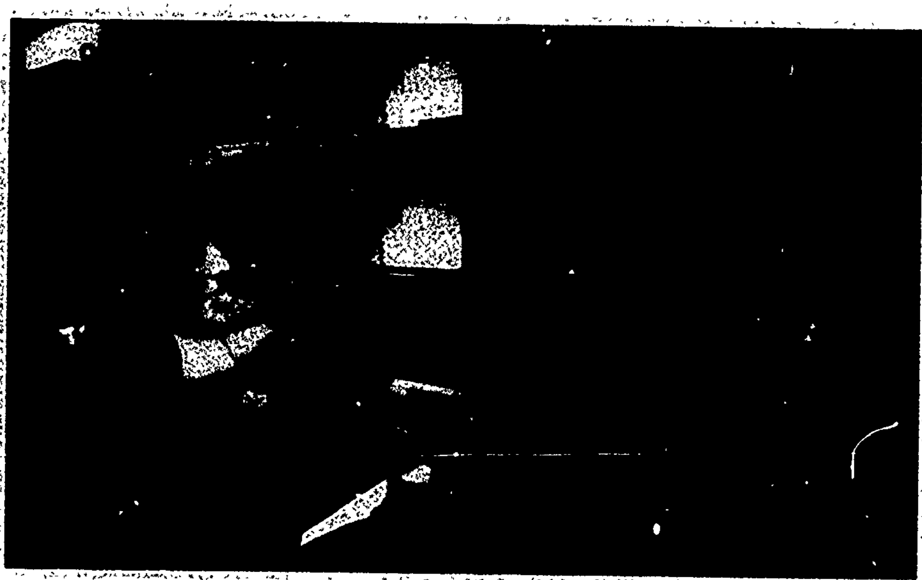


Figure 16. A technician takes a reading from the environmental monitoring system at the Crystal River Nuclear Plant in Florida. (Credit: Florida Power and Light)

Notices about legislation, regulations, and rules that affect nuclear powerplants are published in a Government document called the *Federal Register*. These notices describe the type of action that is proposed and the Government agency responsible for the action. Notices invite members of the public to comment, and they identify a contact who will provide additional information upon request. Copies of the *Federal Register* can usually be found in local libraries.

Utilities provide the NRC with extensive environmental and safety information as part of their license applications. They also are required to submit annual reports about the operation of the plants and special reports on occurrences out of the ordinary (Figure 16). These studies and reports are available for reading in the NRC's public document rooms in Washington, DC, and other locations across the country, including at least one public document room in the area of every nuclear plant.

At important milestones in the planning of new nuclear powerplants, there are opportunities for every member of the public to voice his views, raise questions, and even become a full participant as an "intervenor" in the proceedings. As an intervenor, one is provided copies of all reports and applications and has the right to testify and question the Government and industry witnesses before the Atomic Safety and Licensing Board, which conducts the hearings. Building a nuclear powerplant requires a large number of specialists and skilled laborers. A project construction team includes nuclear engineers (specially trained to design and build the plant); civil, mechanical, and electrical engineers; boilermakers; welders; pipefitters; carpenters; and others. At the peak of construction activity more than 2,500 workers are typically employed, and high standards of quality are required.

Nuclear powerplants are designed and built to operate for at least 40 years. After the plant begins operating, more than 200 workers handle its everyday operation and maintenance. These workers include operators and supervisors, mechanical maintenance crews, instrument technicians, electricians, laborers, experts in radiation protection called "health physicists," and a security guard force. When the plant shuts down about once a year for refueling and major maintenance, this work force may be supplemented for about 2 months with up to 500 workers.

The nuclear plant operators, working shifts to provide around-the-clock coverage, are responsible for the safe operation of the plant. To qualify as a nuclear plant operator, a person must go through extensive training and pass a detailed written examination. Those who qualify are issued a license by the NRC. The qualification process is much like the rigorous training one would undergo to become an airplane pilot. In addition to the initial training and examination, periodic retesting ensures that operators maintain a high level of proficiency.

Nuclear powerplants that are being built today are considerably larger than those constructed in the early days of nuclear development. Electricity-generating stations are rated by the amount of electricity they can generate at their peak levels—usually expressed in terms of the kilowatt, which is 1,000 watts. The early demonstration plants were rated between 200,000 and 300,000 kilowatts. Most nuclear power units that have been completed in the past few years have a capacity of about 1 million kilowatts, and there is often more than one unit on a single plant site. A typical 1-million kilowatt powerplant will generate ample electricity to meet the commercial and residential needs of a city of greater than 300,000 people.

Nuclear Power and Radiation

Nuclear powerplants are permitted by license to release to the atmosphere small amounts of radioactive materials, which are virtually undetectable beyond the reactor site boundaries by even the most sensitive instruments. These small quantities are relatively insignificant when compared to the natural radiation that has always been a part of the Earth's environment.

Natural radiation comes in the form of cosmic rays from the Sun and from naturally radioactive elements like potassium, radon, radium, and uranium that are scattered throughout our soil, building materials, food, and even our air and water (Table 1). The average American receives about 100 millirem—a standard unit of radiation measurement—each year from naturally occurring radiation. In addition, adult Americans receive about 90 millirem a year from medical and dental x rays and from other medical procedures.

TABLE 1. *Typical sources of radiation exposure in the United States*

Source of radiation	Average radiation exposure per person (millirem per year)
Medical x rays	77
Cosmic rays from the sun (depending on altitude)	28
Terrestrial	26
Naturally radioactive elements in air, water, and food	46
Medicines with radioisotopes	13.6
Fallout from weapon tests	4.5
Naturally radioactive elements in building materials	3.5
Dental x rays	1.4
Luminous clocks	0.5
Airline travel	0.5
Nuclear powerplants and associated activities	0.1

Source: "The Effects on Populations of Exposure to Low Levels of Ionizing Radiation," Committee on the Biological Effects of Ionizing Radiation, National Academy of Sciences, Washington, DC, 1980, and NCRP Report No. 77, National Council on Radiation Protection and Measurements, Bethesda, MD, 1984.

Current Federal standards recommend that workers in the nuclear industry be exposed to no more than 5,000 millirem above background levels in any year. For the general public, the recommended limit is 25 millirem a year above background levels. The radiation that a person would receive should be kept as low as possible with no single source of manmade radiation accounting for the total dose an individual receives.

Workers in nuclear plants wear monitors such as pocket dosimeters and badges that record radiation exposure. These devices are regularly checked to ensure that exposure is kept to a minimum. Protective measures, such as special clothing and respirators, reduce worker's exposure to radioactive materials. In addition, shorter working hours decrease the length of time a worker will be exposed.

The biological effects of very high doses of radiation are well known. A dose of 100,000 millirem can cause severe radiation sickness, while a whole-body dose of 500,000 millirem or more is usually fatal. The effects of smaller doses of radiation become more difficult to measure as the amount of exposure decreases. Internationally, radiation dose limits have been specified by the International Commission on Radiation Protection, while in the United States, recommendations for industry are made by the National Council on Radiation Protection. The most significant reports on low-level radiation have come from the National Academy of Sciences' Advisory Committee on the Biological Effects of Ionizing Radiation. These scientific groups assist the Environmental Protection Agency in setting the stringent standards within which the NRC regulates nuclear plants.

Types of Nuclear Reactors

Just as there are different approaches to designing and building airplanes and automobiles, engineers have developed different types of nuclear powerplants. Several types are used in the United States: boiling water reactors (BWRs), pressurized water reactors (PWRs), and high temperature gas-cooled reactors (HTGRs). PWRs and BWRs are generically called light water reactors (LWRs). The electricity-generating process is essentially the same for all of them; the principal differences lie inside the reactor that produces the heat.

Boiling Water Reactors (BWRs)

About 38 of the nuclear plants in operation in the United States are BWRs (Figure 17). In a BWR, the water that is heated by the core turns directly to steam in the reactor vessel, and the same steam is used to power the turbine-generator.

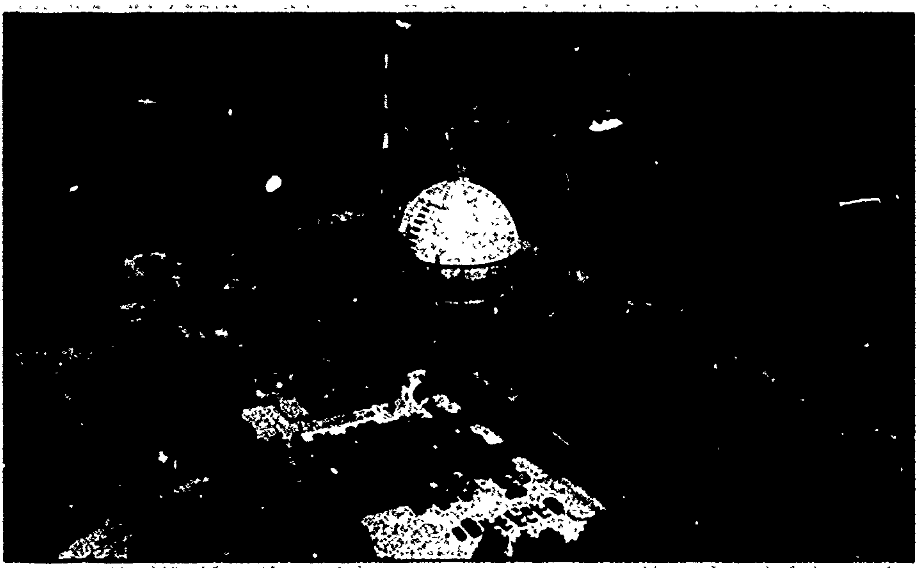


Figure 17. Big Rock Point Nuclear Powerplant, a boiling water reactor plant in Michigan. (Credit: Consumers Power Company)

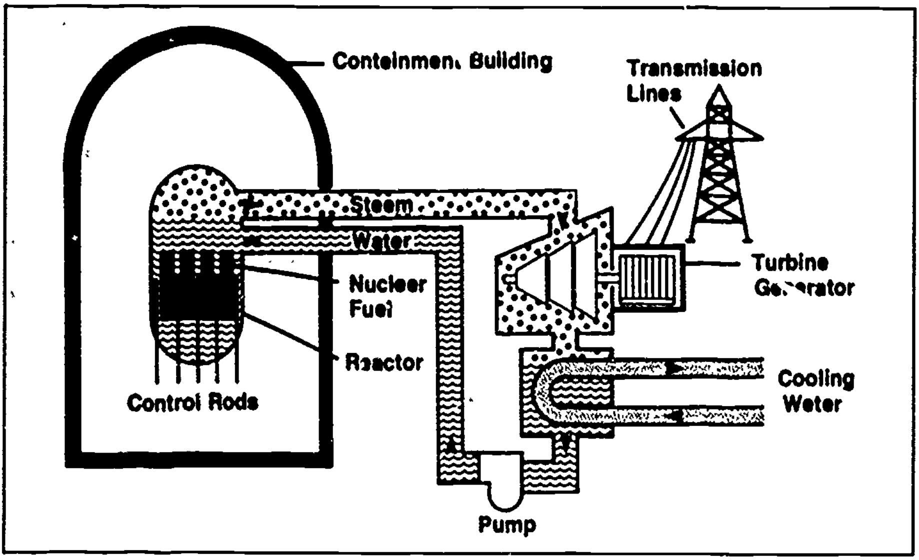


Figure 18. *Boiling water reactor.*

The water in a BWR is piped around and through the reactor core and is transformed into steam as it flows up between the elements of the nuclear fuel. The steam leaves the reactor through a pipe at the top, turns the turbine-generator, is condensed back to water, and is pumped back into the reactor vessel, beginning the process again (Figure 18).

Normally, water turns to steam at a temperature of 212° Fahrenheit (100° Celsius). But at such a low temperature, steam—like a boiling tea kettle—contains too little energy to be used in a turbine-generator. To raise the temperature and the energy content, the water in a BWR is kept at a pressure of 1,000 pounds per square inch (psi), instead of the normal atmospheric pressure of about 15 psi. Because of this added pressure, the water does not boil and turn to steam until it reaches a temperature of about 545° Fahrenheit (285° Celsius). This higher temperature adds to the energy value of the steam in turning the turbine.

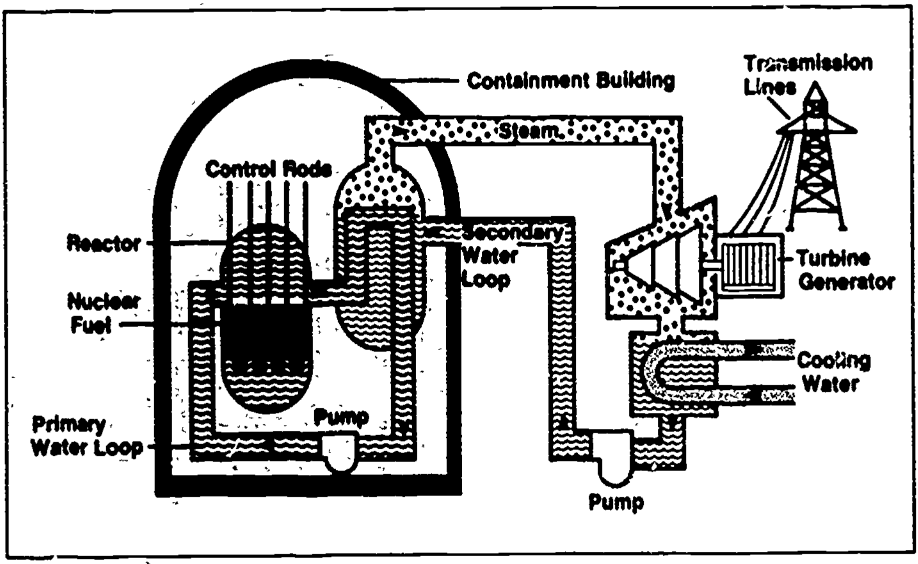


Figure 19. *Pressurized water reactor.*

Pressurized Water Reactors (PWRs)

In a PWR, the water passing through the core is kept under sufficient pressure so that it does not turn to steam at all—it remains liquid (Figure 19). Steam to drive the turbine is generated in a separate piece of equipment.

The PWR system is known as a double-loop system because it involves two separate circuits of water—or loops—that never physically mix with each other. One is called a "primary loop"; the other is called a "secondary loop." The water that flows through the reactor, known as the primary loop, is pressurized to about 2,250 psi. The water is heated to about 600° Fahrenheit (315° Celsius) without boiling and leaves the reactor as a liquid. It is pumped through tubes in the steam generator. After transferring its heat to the secondary loop, the highly pressurized water in the primary loop is pumped back to the core to be reheated and continue with the process.

The secondary loop water circulates around the tubes in the steam generator, picking up or "exchanging" heat from the primary loop. This heat exchange turns the secondary water into steam, which flows toward the turbine at a temperature of about 500° Fahrenheit (260° Celsius). About 69 of the nuclear powerplants operating in the United States are PWRs (Figure 20).

High Temperature Gas-Cooled Reactors (HTGRs)

HTGRs are also double-loop systems (Figure 21). The principal difference is that the coolant in the primary loop—which flows through the core to carry away the heat—is not water, but a gas.

The gas used in HTGRs is helium, which is circulated through pipes in the primary loop by huge blowers. The gas, kept under a pressure of several hundred pounds per square inch, can achieve much higher temperatures than water. In some designs, the gas can be heated to as much as 1,400° Fahrenheit (760° Celsius). As a result, the steam produced from the water in the secondary loop, which powers the turbines, can have temperatures as high as 1,000° Fahrenheit (538° Celsius). This higher temperature leads to improved thermal efficiency; that is, more electric power is generated for the same amount of heat from the fuel.

Another major difference between gas-cooled reactors and water-cooled reactors is the moderator. As was explained previously in the description of reactor core elements, in water-cooled reactors the water serves as a moderator to slow neutrons and increase the likelihood of atoms fissioning. Gas, however, is not a satisfactory moderator because it is so much less dense. Therefore, another material must be included in the core.

Figure 20. *Point Beach Nuclear Plant at Two Creeks, WI. The plant has two 497-megawatt pressurized-water reactors (PWRs). Unit 1 began operation in 1970, Unit 2 in 1972. (Credit: Wisconsin Electric Power Company)*

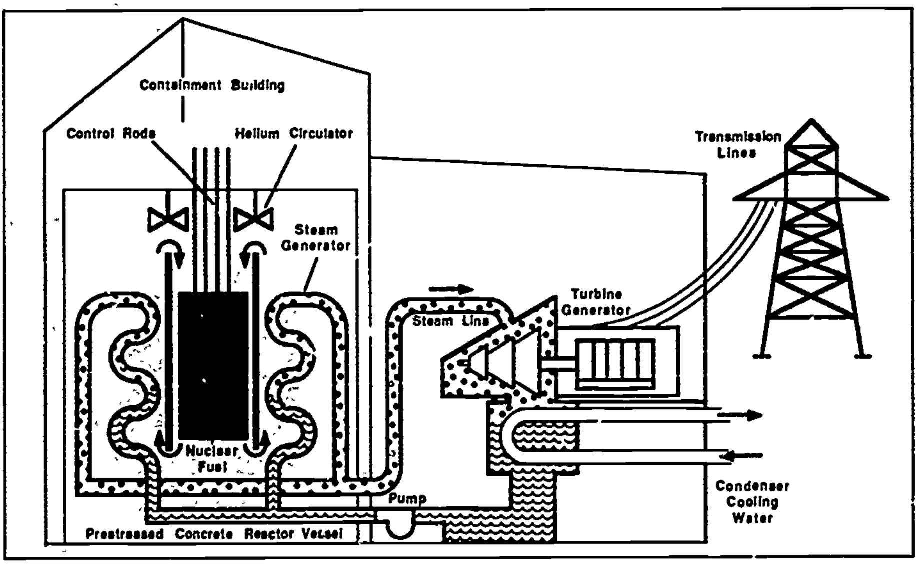


Figure 21. *High temperature gas-cooled reactor.*

Figure 22. Fort St. Vrain in Colorado is the first commercial high temperature gas-cooled reactor to be built in the United States. It is also the first to use a prestressed concrete pressure vessel. (Credit: Public Service of Colorado)

The moderator in gas-cooled reactors is graphite, which can withstand the high temperatures of these systems. The fuel, uranium carbide particles, is distributed throughout the graphite in the core of an HTGR.

In the United States, one gas-cooled reactor, Peach Bottom 1, operated as a demonstration plant in Pennsylvania for seven years. A commercial HTGR, Fort St. Vrain, has been operating in Colorado since 1979 (Figure 22).

Breeder Reactors

Scientists and engineers have been working for over three decades on breeder reactor technology. Breeder reactors greatly increase the energy extracted from uranium by converting that finite energy resource into a virtually inexhaustible energy supply.

All nuclear powerplants produce new fuel material while they are operating—extra neutrons, produced by fission, are absorbed by U-238 atoms, which are then transformed into fissionable plutonium (Figure 23). Some reactors are designed to do this so efficiently that they actually produce more fuel than they consume and are called "breeder" reactors.

Breeder reactors are able to multiply the amount of energy available from uranium resources. By using the U-238, which exists in great quantities as an otherwise useless leftover from the uranium enrichment process, a breeder reactor can get 60 times as much usable energy from natural uranium as today's nuclear powerplants.

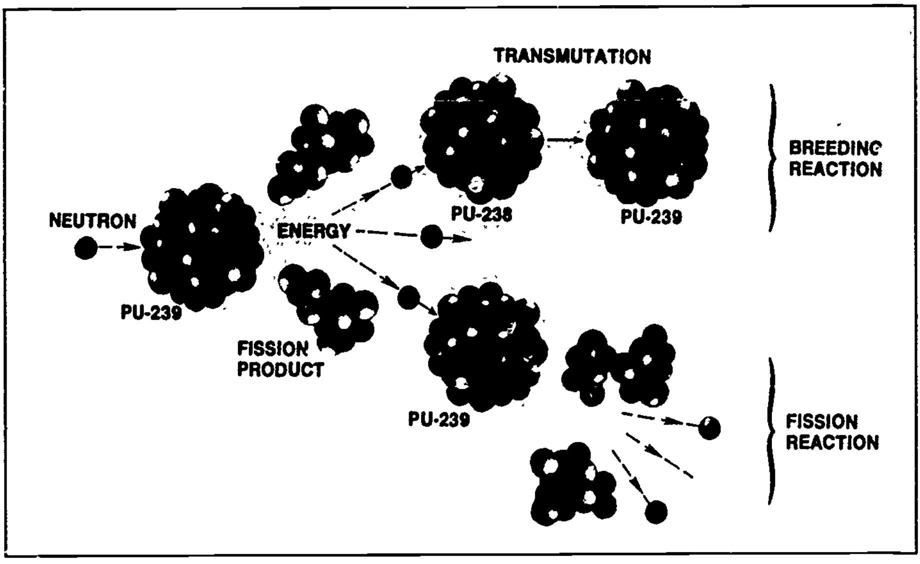


Figure 23. *The breeding process.*

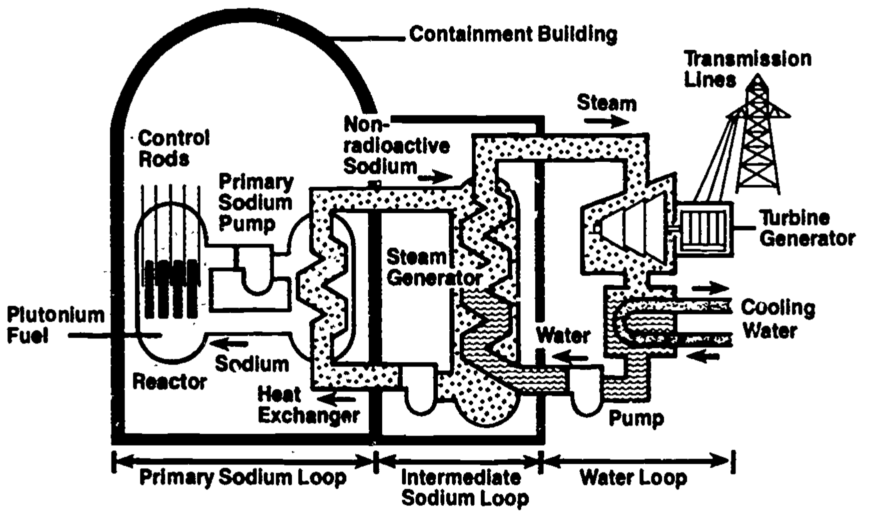


Figure 24. *Liquid metal fast breeder reactor.*

Several reactor types have the potential for breeding. The one that has been developed most thoroughly through experimental reactors and actual operating plants is cooled by circulating a liquid metal (sodium) through it. It is called the liquid metal fast breeder reactor, or LMFBR (Figure 24).

Several experimental breeder reactors have operated in the United States. In fact, the Experimental Breeder Reactor-I (EBR-I) produced the world's first electricity generated by nuclear power in Idaho in 1951. Its successor, the Experimental Breeder Reactor-II (EBR-II), is still operating as a test reactor after almost 23 years, testing advanced reactor fuels and materials (Figure 25). A developmental commercial LMFBR, the Enrico Fermi Atomic Power Plant, operated in Michigan in the 1960s. Fuel failure caused the plant to be shut down temporarily in 1966. After repairs, the plant resumed operations. High fuel cycle costs caused the plant to shut down in 1972, but not

Figure 25. *The Experimental Breeder Reactor-II, located at Idaho Falls, Idaho, has been in operation since 1963. (Credit: U.S. Department of Energy)*

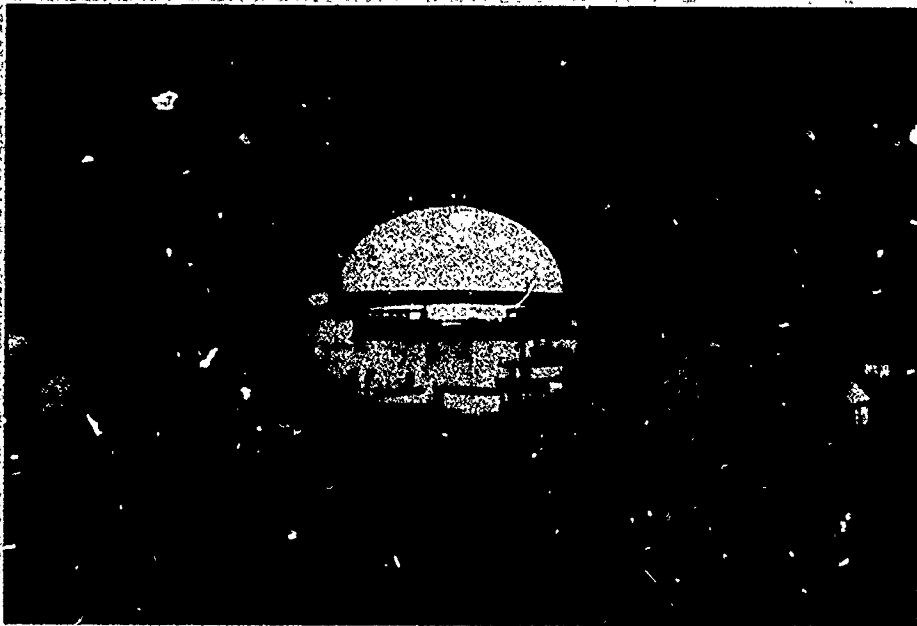


Figure 26. The Fast Flux Test Facility is designed specifically for the testing of breeder fuel and components. It began operation in February 1980. (Credit: U.S. Department of Energy)

before its operation had helped to train personnel from France, the Soviet Union, and Japan, who were later to develop fast reactor programs in their own countries. In 1980, the Fast Flux Test Facility (FFTF)—a 400,000-kilowatt (thermal), sodium-cooled, fast neutron flux reactor designed for irradiation testing of fuels and materials for the LMFBR program—began operating at the DOE Hanford Engineering Development Laboratory (HEDL) site near Richland, Washington (Figure 26).

France, the Soviet Union, West Germany, and Great Britain each have commercially operating breeder reactors. Several commercial-size breeders are being planned in the near future in France, the Soviet Union, West Germany, and Japan. The French "Super Phenix" breeder began operation in April 1986. Before the Super Phenix began operation, the largest breeder was the 600,000-kilowatt Beloyarsk plant in the Soviet Union.

Advanced Reactors

Research programs are now underway to develop advanced reactor designs that will be suited to future energy needs. Efforts are focused on reactor designs that can be factory built as small, modular units, according to a standardized design and passive safety systems features.

Small, modular reactors will allow utilities to match load growth by installing a single unit, which can be supplemented with additional units to meet additional power demands. Factory fabrication should reduce construction costs, while use of standardized designs will reduce the time and costs involved in licensing. Passive safety systems are integral to the new plant designs. For example, excessive heat can be more easily removed from the reactor core, thus reducing reliance on complex mechanisms and operator control.

Nuclear Fuel: Mining to Reactor

Unlike fossil fuels, which can be burned in a powerplant in virtually the same form that they exist underground, uranium must go through a series of complex changes to become an efficient fuel for the generation of electricity. By the time it reaches the reactor, the uranium fuel has been mined, chemically processed, isotopically enriched, and fabricated into fuel pellets, and—in the process—has been transformed from a salt to a powder to a gas and, finally, to a dense ceramic.

Mining and Milling

Uranium is a fairly abundant element. It exists throughout much of the Earth's crust and is even found in the world's oceans. The largest deposits of uranium ore that have been discovered so far are in the western United States, Australia, Canada, South Africa, and several other countries in Africa and South America (Figure 27).

Uranium in nature, however, is quite dilute, combined in smaller proportions with other elements to make up such minerals as pitchblende and carnotite. Natural uranium exists in an oxide form

Figure 27. *Uranium ore is being carted from the Schwarzwalder underground mine in Golden, Colorado. (Credit: Cotter Corporation)*

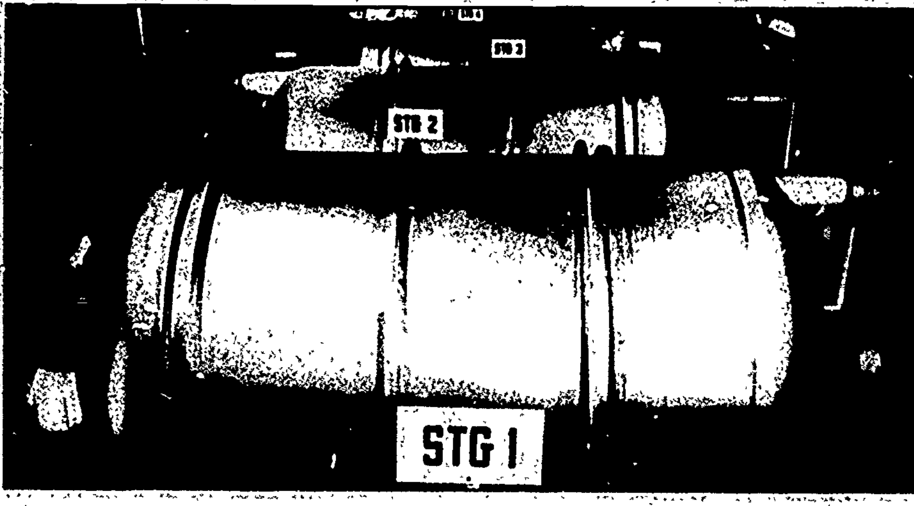


Figure 28. In a gaseous diffusion enrichment plant, uranium in the form of uranium hexafluoride gas is passed in stages through many porous barriers. More than 1,200 stages are needed to produce uranium enriched to 3.0 percent U-235. (Credit: U.S. Department of Energy)

material, called "yellowcake," is then combined with fluorine gas to be transformed into uranium hexafluoride gas (UF^6). In this form, it is ready for enriching.

Enrichment and Fuel Fabrication

In the process of extracting the few pounds of uranium oxide that were present in the original ton of ore, impurities that would interfere with the fission process are chemically removed. But the uranium contains the natural proportion of isotopes: 99.3 percent is nonfissionable U-238 and only about 0.7 percent is the U-235 that can be used as fuel. Because a light water reactor (LWR) requires that its uranium fuel contain about 3.0 percent U-235, the refined uranium must be enriched in its fissionable isotope.

Large uranium enrichment plants owned by the U.S. Government make use of the fact that a U-233 atom is about 1 percent heavier than a U-235 atom because it contains three more neutrons (Figure 28).

To enrich uranium, the gaseous form (UF^6) is piped into a gaseous diffusion plant and pumped through barriers that have microscopically small holes, less than 1-millionth of a centimeter in

After the uranium is enriched, it is chemically converted back into uranium oxide to be processed into fuel. The powdery oxide is compressed into small, cylindrical pellets and loaded and sealed into metal tubes to form the fuel rods. Detailed inspection follows every step of this fuel fabrication process (Figure 29).

These fuel rods, about 12 feet long, are grouped together in bundles known as fuel assemblies. The fuel rods are carefully spaced in the assemblies to allow coolant to flow between them. The fuel assemblies are grouped together to make up the core of the reactor (Figure 30). The nuclear fuel fissions and generates heat in the reactor, just as burning coal or oil generates heat in a boiler.

Figure 30. *Loading the fuel at the McGuire Nuclear Station in North Carolina. (Credit: Duke Power Company)*

Nuclear Fuel: Reactor to Waste Disposal

All operations involving radioactive materials—including nuclear powerplants, hospitals, research centers, and industrial processes—create radioactive wastes that must be handled and disposed of safely. Because these wastes vary from slightly to intensely radioactive, they are handled in different ways depending on their level of radioactivity, their form, and other factors.

Handling Spent Fuel

A 1-million kilowatt nuclear powerplant typically contains about 100 tons of uranium fuel. Each year, about one-third of the fuel—roughly 33 tons, or 60 of its fuel bundles—are removed and replaced. The used fuel is called "spent fuel."

Figure 31. *Technicians use an underwater periscope to inspect fuel assemblies in the spent fuel pool. (Credit: Wisconsin Electric Power Company)*

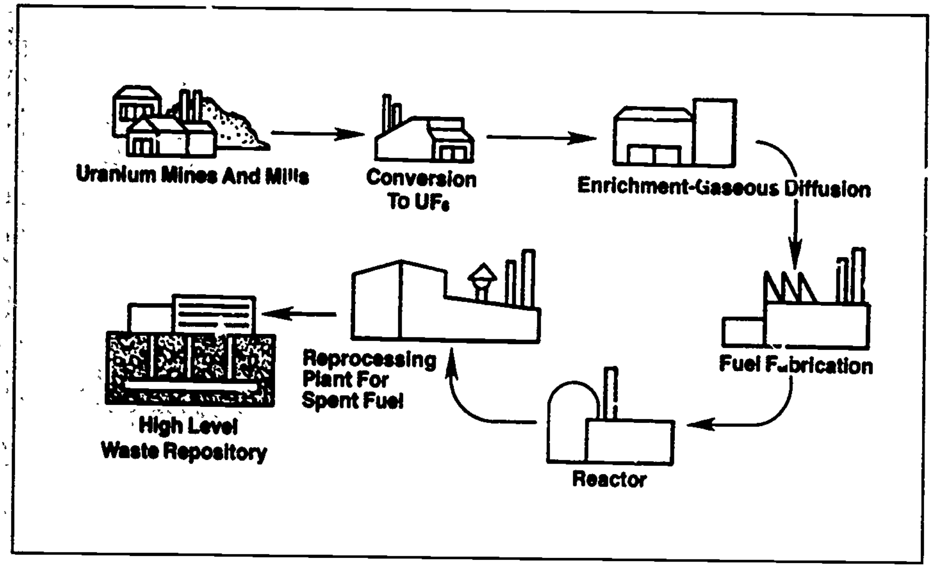


Figure 32. *The nuclear fuel cycle.*

As the spent fuel rods leave the plant, they are physically similar to the new fuel rods that were originally installed. They are still composed largely of U-238, more than 94 percent by weight. The primary difference is that the U-235 that released its energy in the reactor created radioactive fission products and other long-lived radioisotopes. Although they represent a small proportion of the spent fuel, only 3.5 percent, they continue to generate heat and release radiation long after the fuel is removed from the reactor.

Most spent fuel from nuclear powerplants is stored in 40-foot-deep pools of water at the reactor site (Figure 31). The water cools the fuel rods to keep them from overheating, and it serves as an effective shield to protect workers from the radiation.

The level of radiation begins declining immediately, and within 10 years it has decayed by some 90 percent. Nevertheless, some fission products remain radioactive for many years. However, storage of the spent fuel in pools near the reactors is

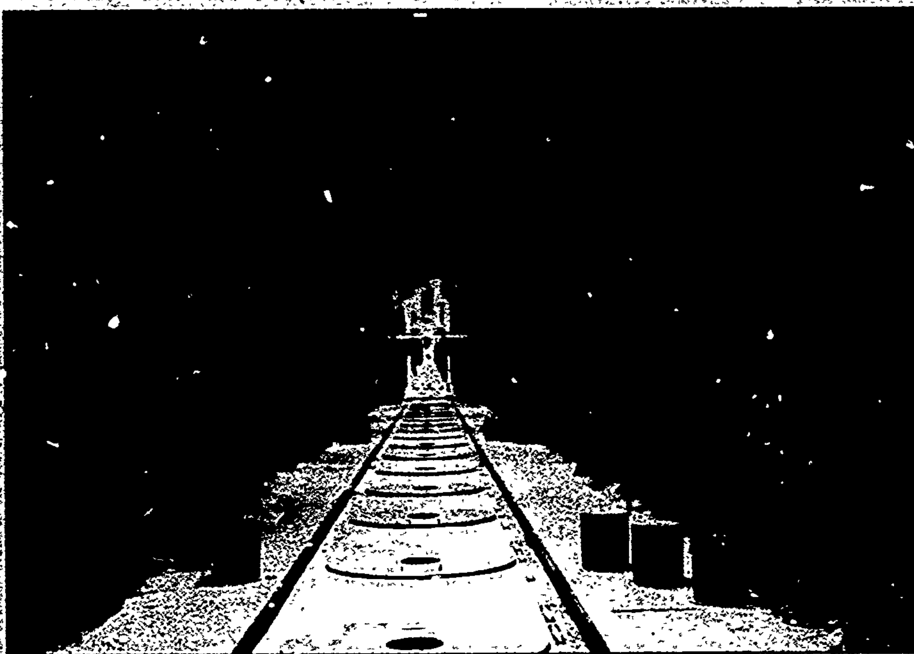


Figure 33. *The Climax Spent Fuel Storage Test was conducted to evaluate the effects of storing spent reactor fuel in a volcanic tuff rock formation 1,400 feet below the surface of the Nevada Test Site. (Credit: U.S. Department of Energy)*

only a temporary measure by design. Recognizing that a permanent waste repository was necessary, Congress passed the Nuclear Waste Policy Act of 1982 to establish a National policy for the safe storage and disposal of high-level radioactive waste.

Repackaging and Disposing of High-Level Waste

Spent fuel contains a relatively high level of radioactivity and after being released by a utility for disposal is designated "high-level waste." The Nuclear Waste Policy Act of 1982 identified mined geologic repositories as the technique for the disposal of high-level radioactive waste. The goal of safe waste disposal is to ensure that essentially no radioactive waste material ever reaches man or the environment. The barriers that are designed to prevent the radioactive material from reaching the environment include the solid form of the material, the storage containers, the packing material in and around the containers, and the physical protection provided by the permanent repository deep underground (Figure 33).

Current plans for the disposal of spent nuclear fuel include the use of a monitored retrievable storage (MRS) facility. The MRS is to be a centrally located receiving and handling facility that will coordinate the scheduling, transporting, and packaging of high-level waste for permanent disposal. If Congress authorizes the construction of the MRS facility, the spent fuel will be removed from the storage pools and transported to the MRS facility before shipment to the licensed geologic repository.

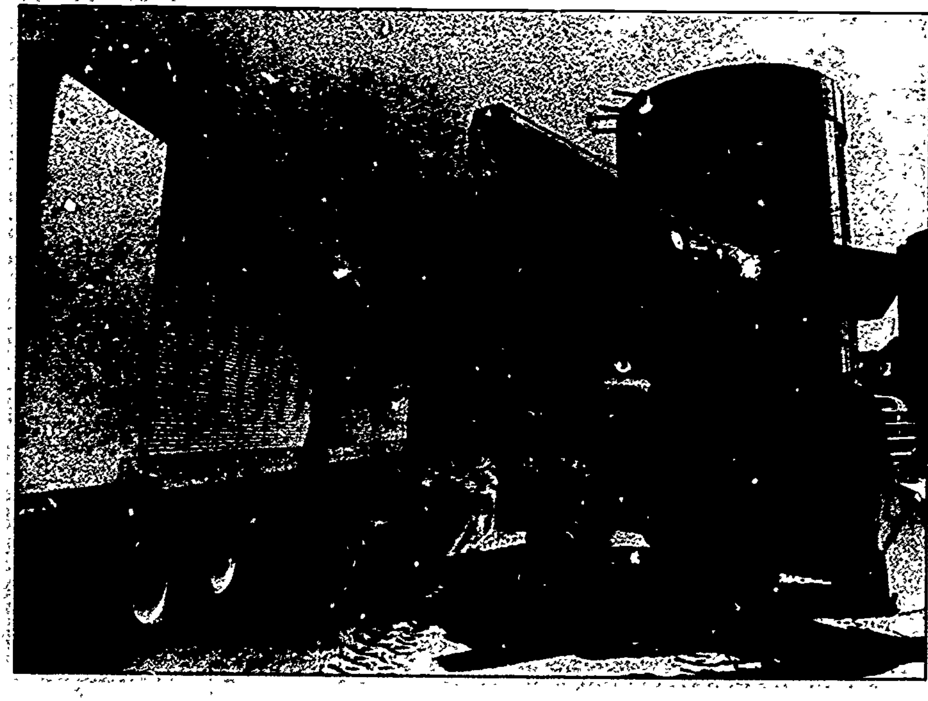


Figure 34. A 55-gallon drum of solid low-level waste is loaded by crane into a trailer for shipment to a low-level waste disposal site. (Credit: Atomic Industrial Forum, Inc.)

At the MRS facility, the fuel assemblies will be disassembled and packed closely together before being sealed inside a cylindrical steel container. This disassembly and packaging will reduce by almost half the space required for the disposal of spent fuel. This reduction in volume will also reduce the number of shipments of fuel to a repository.

The Nuclear Waste Policy Act of 1982 provides for a procedure and timetable for the site selection, construction, and operation of high-level, geologic waste repositories, the first one to be operable around the turn of the century. In addition to this strong commitment to permanent geologic disposal, the act provides for a system of fees paid by utilities to fund waste disposal; a strong voice for States in the choice of siting; a limited, temporary Federal storage program to alleviate near-term storage problems at powerplants; and a study of the MRS as an interim step toward permanent disposal.

Handling and Disposing of Low-Level Waste

Every organization that uses or produces radioactive materials generates some waste that is slightly radioactive, called "low-level waste." Industrial users that manufacture radiopharmaceuticals, smoke alarms, emergency exit signs, luminous watch dials, and other consumer goods produce low-level waste consisting of machinery parts, plastics, and organic solvents. Most of this waste requires little or no shielding and no cooling and may be handled by direct contact.

About half of the total low-level waste generated today is from nuclear powerplants. This includes used resins from chemical ion-exchange processes, filters and filter sludges, lubricating oils and greases, and detergent wastes from laundry operations and from decontaminating personnel and equipment. Most of this waste is processed and packaged for disposal at a specially designed waste facility.

volume-reduction techniques. At the present time, nearly 2.5 million cubic yards of low-level waste has been shipped to the three commercial sites for disposal. Costs have risen as well, especially for transporting the waste as much as 3,000 miles to accommodate current volume ceilings at the existing disposal sites.

When Congress enacted the Low-Level Radioactive Waste Policy Act of 1980 and subsequent amendments, it set in motion major changes in the National low-level waste disposal program:

- As of January 1, 1993, each State will be responsible for providing its own disposal facilities for low-level waste. That includes all 50 States and the District of Columbia.
- The most efficient method would be through regional compacts, which would provide a central disposal facility for several neighboring States. Congress must endorse the creation of each compact in advance and renew the approval every five years.
- After January 1, 1993, any State can refuse to accept low-level waste from other States that are not members of its regional compact. Essentially, this means that a State must enter into a regional agreement, establish its own disposal facility, or stop generating low-level waste.

Vital services like electricity supply, medical diagnosis and treatment, and advances made possible in research centers across the country depend on adequate low-level waste disposal capacity in the coming decades.

Transporting Radioactive Materials

Each year in the United States, some 500 billion shipments of commodities are made by truck, rail. barge, airplane, or other means. Of these, about 1 in 5,000 contains material classified as hazardous. They include caustics and acids, toxic materials like pesticides and poisons, explosives and flammables like gasoline and propane, corrosives, compressed gases, and radioactive materials.

Radioactive materials account for only about 2 percent of all hazardous materials shipped. Half of these are radionuclides used in the practice of nuclear medicine. The rest are mostly radioisotopes used in industrial radiography, consumer products, and some industrial and scientific instrumentation. Radioactive materials involved in the operation of the Nation's nuclear powerplants account for only a fourth of a percent of all shipments of hazardous materials (Table 3).

TABLE 3. Annual Shipments of Nuclear Materials in the United States

Type of Material	Shipments per year	Percent of Total Shipments	Percent of Curies
Pharmaceutical and other medical sources, mainly radioisotopes used for diagnosis and treatment	1,730,000	62.2	34.3
Exempt amount or limited radioactivity level materials (including smoke detectors, luminous signs, or watches)	519,000	18.6	0.2
Industrial radiation sources, (including gauges to measure thickness of paper, portable x-ray devices)	213,300	7.6	63.1
Wastes from all industrial, powerplant, and medical sources	181,000	6.5	1.5
Nuclear materials used in the fuel cycle (including uranium, fuels from fabrication plants, and a small amount of interplant spent fuel)	114,000	4.1	0.7
Research and development uses (including commercial and academic studies)	17,100	0.6	0.1
Other unspecified uses	7,500	0.3	0.1
TOTAL	2,781,950		

Source: Javitz, H.S., et al. SAND84-7174, TTC-0534; reprinted in "The Transportation of Nuclear Materials," Sandia National Laboratories, 1984.

TABLE 4. *Five-year total of hazardous materials incident reports* in the United States by classification*

Classification	No. of Reports	Percent of Total
Explosives	47	0.13
Flammable compressed gas	688	1.91
Nonflammable compressed gas	633	1.76
Combustible liquid	2,639	7.34
Flammable liquid	15,076	41.95
Flammable solid	258	0.72
Organic Peroxide	205	0.57
Oxidizing material	924	2.57
Poisons, Class A	19	0.05
Poisons, Class B	1,504	4.18
Etiological Agents	7	0.01
Radioactive material	130	0.36
Corrosive material	12,914	35.93
Miscellaneous and unknown	894	2.49
TOTAL	45,650	

*The figures in this table refer to accidents that are reported to the U.S. Department of Transportation from the period 1/81 through 1/85. Some events of each type fail to be reported.

Source: Information Systems Group, U.S. Department of Transportation.

The safety record of shipping radioactive materials is well established. Only half a percent of all accidents in the shipment of hazardous materials involves radioactive materials (Table 4). Most of the accidents involve small packages of low-level waste that contain little radioactivity. No deaths or serious injuries have ever been attributed to the radioactive nature of any materials involved in a transportation accident.

Radioactive materials are subject to the same transportation hazards as any other freight. However, radioactive matrials have special regulations that govern their shipment. These regulations and procedures are shaped by two considerations: first, the methods for shipping radioactive materials from one location to another should minimize the chance that an accident will occur; and second, the radioactive materials should be packaged in such a way that no significant radiation will be released even if

Figure 35. *A large spent fuel rail cask. (Credit: U.S. Department of Energy)*

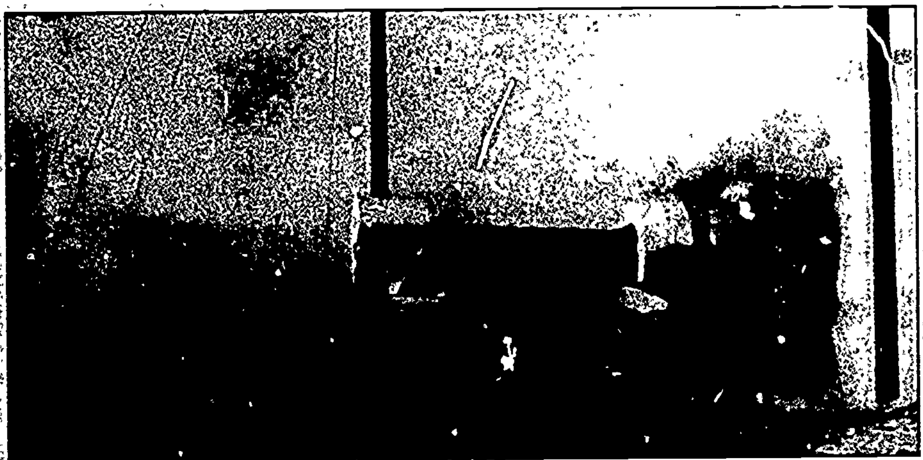


Figure 38. To test the durability of a 22-ton container used to transport spent nuclear fuel, technicians at the U.S. Department of Energy's Sandia Laboratories in New Mexico mounted the cask on the bed of an expendable tractor-trailer. The rig was then loaded onto the lab's rocket sled and slammed into a 10-foot thick concrete wall at 60 mph. Although the truck was totally demolished, the container suffered only a slight dent at one end, but no part of the cask cracked open. A high-speed camera recorded the moment of impact and scattering wreckage immediately following. (Credit: Sandia Laboratories)

an accident should occur. Traditionally, the primary safety factor is the shipping container itself, which is designed to contain its radioactive contents in the event of an accident.

Spent Fuel Shipments

All fuel assemblies in the reactor are replaced over a 3-year period. At this point, the used or "spent fuel" assemblies are highly radioactive. They are removed to storage pools of water at the reactor site where they are held for a time to allow their radioactivity to decay and their heat to diminish before shipment. After a period of several years, the spent fuel assemblies will be packaged and then shipped in specially designed protective shipping containers to a temporary site for storage until a permanent disposal facility is available.

Each nuclear powerplant annually produces the equivalent of approximately 25 truckloads or 10 railcars of spent fuel (Figure 35). Since 1964, over 4,000 spent fuel assemblies have been shipped from reactor sites to other locations, including two reprocessing plants. Today, however, there are no operational reprocessing plants or permanent disposal sites for commercial spent fuel, so such shipments are not routinely taking place.

The shipping containers for spent fuel are rigorously designed, manufactured, tested, and licensed for use (Figure 36). In one cask design, the fuel assemblies are sealed into a water-filled stainless steel cylinder with walls 1/2-inch thick, clad with 4 inches of heavy metal shielding, enclosed by a shell of steel plate 1-1/2 inches thick, surrounded by 5 inches of water, and encircled by a corrugated stainless steel outer jacket. The overall package measures 5 feet by 17 feet and weighs 70 tons.

The shipping cask is required by the Nuclear Regulatory Commission (NRC) to withstand a series of hypothetical accident conditions:

- a 30-foot fall onto a flat, hard surface (as if the cask dropped from an overpass onto a concrete highway);
- a 40-inch drop onto a metal pin 6 inches in diameter (as if the cask hit a sharp corner of a bridge abutment);
- a 30-minute exposure to a temperature of 1,475° Fahrenheit (800° Celsius) (as if a tank of gasoline ruptured in an accident and a fire ensued); and
- complete immersion in 3 feet of water for 8 hours (as if the cask rolled off into a creek along the highway).

The container must undergo these destructive forces in sequence with no breach of containment and with no significant reduction in shielding.

Road experiments designed to confirm the integrity of the spent fuel cask have been carried out, and in all cases, the safety requirements have been met or exceeded.

Transporting High- and Low-Level Wastes

Commercial spent fuel rods containing high-level waste will be transported from nuclear powerplants to a monitored retrievable storage facility (see pages 49-51) or to a permanent geologic repository, once these facilities are operational. A commercial nuclear reactor also generates from 10 to 45 truckloads of low-level waste each year. Low-level waste contains small amounts of radioactive materials that generally do not require shielding during transportation. Most often this waste is shipped by truck in compacted solid form in sealed drums.

Shipping Procedures and Regulatory Responsibilities

The U.S. Department of Transportation (DOT) has general authority for regulating the transportation of hazardous materials, including radioactive materials. Its regulations include:

- packaging, marking, and labeling of materials;
- carrying shipping papers and displaying placards;
- establishing the way in which materials are carried and personnel are trained; and
- loading, unloading, handling, and storage of materials.

The NRC is responsible for licensing and regulating all commercial users and handlers of radioactive materials, including waste shippers and carriers.

Shipping procedures are designed to ensure that radioactive materials are transported safely and carefully. In shipping low-level waste, for example, truck drivers must be familiar with the basic mechanical operation of the equipment, must meet driving performance requirements, and are responsible for truck inspection and maintenance of vehicle logs. DOT also requires that appropriate warning placards be placed on the truck to designate specific quantities and types of radioactive materials such as high-level waste.

Shipments of spent fuel require further precautions. For example, appropriate State and local authorities are notified of the shipments. In addition, the NRC and DOE have physical protection requirements in place to provide security for the shipments, and a communication center remains in touch with the transport vehicle and monitors its progress.

The Economics of Nuclear Power

Do nuclear electric plants cost more than other types of powerplants, or do they save money for the electricity consumer? Surprisingly, the answer to both questions can be yes.

Just as you may spend more money for a car that gets better gas mileage, saving you money over the life of the car, utilities spend more to construct nuclear plants because the fuel costs are so much lower than for plants that burn coal. Because of the considerable difference in fuel costs, nuclear plants have resulted in a savings to consumers in many parts of the country, particularly in areas like the northeast that do not have coal mines nearby.

The cost of electricity from a generating plant is made up of three parts:

- the cost of fuel (coal, oil, gas, or nuclear) and the disposal of the residue (ash or nuclear waste);
- operation and maintenance costs (largely salaries, plus tools, equipment, replacements, repairs, and scrubbers); and
- powerplant capital cost (cost of design, engineering, and construction, including factory equipment, tools, interest on the capital, etc.).

Actual generating costs depend on several factors that can vary considerably: the location of the plant, the fuel choice, environmental protection equipment, and the length of time that it takes to build the plant. One of the most important cost factors is the time frame over which the plant was built. Although interest and inflation rates of the past few years have been brought down, costs can be increased significantly by long construction periods, making new electric power stations much more expensive than those built a few years earlier.

Capital costs for electricity-generating plants are expressed in terms of *dollars per kilowatt of installed capacity*. For example, if a 1,000 kilowatt plant cost $500,000, we would describe its capital costs as $500 per kilowatt. When we evaluate nuclear energy only on the basis of its capital costs, it has always been comparatively expensive. To illustrate: the average cost of a nuclear powerplant that entered service in the late 1960s was about $350 per kilowatt. The average cost for coal plants during that period was about $120 per kilowatt.

Over the past two decades, the cost of building new powerplants has increased dramatically. Current projections for nuclear plants entering service at the end of the 1980s are $3,000 per kilowatt, and coal plants will cost about $1,600. That means that a 1-million kilowatt nuclear plant would cost about $3 billion, and a coal plant of the same size would cost about $1.6 billion.

Nuclear plants, however, begin saving money after they go into service because of their lower fuel costs. While every utility system is a unique case, one of the most useful comparisons of nuclear and fossil costs can be seen in the Commonwealth Edison electric system in the Chicago area. That utility has eight large nuclear units and six large coal units of roughly the same size and dates of construction. In 1985, the electricity from the nuclear units cost nearly 25 percent less to produce than electricity from the coal units. The principal difference between them was the cost of the fuel. The fuel amounted to 64 percent of the total cost of coal-generated electricity, but only 21 percent of the cost of nuclear power.

The differences are not necessarily this dramatic in all parts of the country. However, in a 1986 DOE study of 86 powerplants, both nuclear and coal powerplants showed comparable total generation costs. Nationwide, these nuclear plants generated electricity at a cost of 3.2 cents per kilowatt-hour in 1984; for coal plants, the cost was 3.1 cents. Even though oil-fired plants are much less expensive to build than either nuclear or coal plants, the costs of the fuel itself make their electricity costs considerably higher.

Estimated costs of electricity from new powerplants in the future continue to show that both nuclear and coal will generate electricity at reasonable and comparable costs, and at a much lower cost than the alternative fuels such as oil. These projections depend on several unknowns—the future inflation rate, interest costs, regulatory processes, pollution control equipment, fuel costs, and demand for power.

It is important to remember that the low cost of generating electricity from coal and nuclear plants is due to favorable economic conditions during the construction and operation of the plants. Under conditions of high interest, high inflation, rising fuel costs, and lengthy regulatory processes, electricity from any new electric plant—whether nuclear or coal—will no doubt be more expensive than from older plants. This means that every new generating unit, nuclear or coal, tends to raise the cost of electricity to consumers.

Utilities, electricity ratepayers, and bond holders have an enormous investment in the nuclear powerplants that are now operating or being built. The steadily rising capital costs of electric plants are adding new pressures to electric utilities: instead of paying $100-$350 million for a 1-million kilowatt electric plant, as they did in the mid-1960s, utilities must now commit upwards of $3 billion. The pressures associated with raising that much capital, paying the carrying charges, and seeking increases in electric rates to pay for these costs have steered utilities away from a "build-and-grow" philosophy. Instead, they are encouraging energy efficiency and conservation programs to slow down the rate at which they must build new central station generating plants.

Even with more effectively managed growth in electric demand, more generating plants will probably be required in most areas of the country. Why? There are many important reasons. The country's population continues to grow. Old powerplants need to be replaced. The economy—which is extremely dependent on energy—continues to expand, even if not as rapidly as in the past. And, many energy users are continuing to shift from direct oil use to other substitutes, including electricity. This will extend the need for new powerplants that generate electricity at a cost competitive with other available fuel sources.

Nuclear Electricity in Other Countries

In September 1956, two nuclear electric plants, Calder Hall 1 and 2, in Northern England began operation, becoming the world's first commercial nuclear generating station. Because of its dependence on imported oil, England turned to nuclear power earlier than other countries. The wisdom of this decision was dramatized when the Suez Canal crisis erupted only weeks after Calder Hall had started up. England presently has about 33 gas-cooled nuclear powerplants in operation, generating over 19.3 percent of that country's electricity in 1985.

Today, most industrialized nations are pursuing the nuclear power option, as are some of the smaller, lesser developed nations. The reasons for these national directions are numerous and vary from country to country. Some have perceived the need to lessen the impact of any future oil embargo and have recognized the cost advantages of nuclear power. Still others, being net oil exporters, developed nuclear power to use domestically, leaving their oil available for export. Other nations with small alternative energy source reserves chose to develop nuclear power to improve their energy security. In some cases the relative cost of nuclear versus fossil did not matter when compared to the desire for national energy security. This has led to the current situation in which the United States is now about 12th in the world in regard to the percentage of electrical energy generated by nuclear power.

At the end of 1985, the 271 nuclear plants operating outside the United States provided more than 15 percent of the world's electricity (Table 5). More than 317 other nuclear plants are under construction or being planned, which would bring the total nuclear generating capacity in other countries to some 452 million kilowatts—equal to the entire U.S. electrical capacity as recently as 1973.

TABLE 5. *Nuclear powerplants outside the United States*

Reactor Status	Megawatts	Reactors
In Operation	166,917	271
Under Construction	111,397	134
On Order	8,820	9
Planned	165,509	174
TOTAL	452,643	588

Nuclear generating capacity outside the United States in 1985

Country	Net. Megawatts	Percent of Capacity (1)	Percent of Generation (2)
Argentina	944	7.6	12.8
Belgium	5,148	36.7	59.8
Brazil	626	1.5	1.2
Bulgaria	1,760	12.3	31.6
Canada	9,373	10.6	12.0
Czechoslovakia	1,900	na	14.6
England	7,222	11.6	19.3
Finland	2,260	22.1	38.2
France	33,878	43.1	64.8
Germany, Democratic Republic of (East)	1,830	na	12.0
Germany, Federal Republic of (West)	16,112	17.5	30.0
Hungary	880	na	5.0
India	1,330	3.0	2.0
Italy	1,273	2.3	3.6
Japan	23,665	17.0	27.0
Korea, Republic of (South)	2,865	na	17.8
Netherlands, The	505	3.5	8.0
Pakistan	125	na	0.2
South Africa, Republic of	1,046	4.4	4.0
Spain	5,690	14.0	22.0
Sweden	9,525	23.7	42.0
Switzerland	2,885	19.0	34.3
Taiwan	4,928	32.2	52.4
Union of Soviet Socialist Republics	28,348	9.0	11.0
Yugoslavia	632	3.5	5.5

NOTES: (1) percentage of the countries' total generating capacity made up of nuclear power.
(2) percentage of the countries' total electricity actually generated by nuclear powerplants.

72

Throughout the 1970s, France conducted the world's most aggressive nuclear development program. France was relying on imported oil for more than 65 percent of its energy needs when oil prices quadrupled in the early 1970s. France turned to its one abundant energy resource, uranium, and developed a policy of "tout nucleaire," or "all nuclear," vowing that no more coal- or oil-fired electric plants would be built. By the end of the decade, France was operating 22 nuclear powerplants and bringing new ones into service at an average of one every two months (Figure 37). France's nuclear program is the second largest in the world after the United States and is first in percentage of electricity needs satisfied by nuclear reactors. Nuclear energy was providing more than 64 percent of France's electricity in 1985.

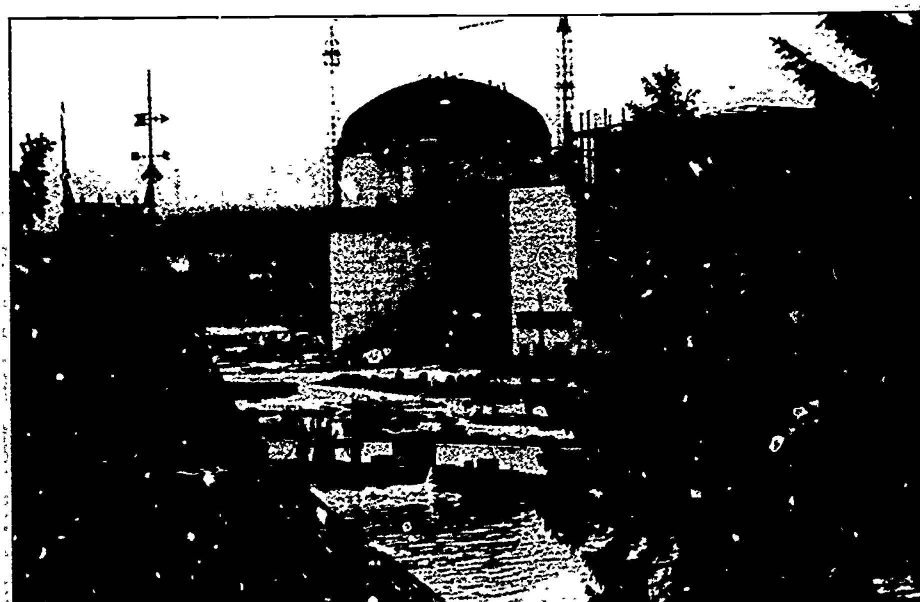


Figure 37. *France and Belgium share equally the power generated by the Tihange-1 Nuclear Powerplant. Shown here during construction, the 870,000-kilowatt facility has been operating since 1975. Tihange is a pressurized water reactor whose major components were manufactured in Europe. (Credit: Atomic Industrial Forum, Inc.)*

Currently, the Soviet Union is operating 50 nuclear electric plants and providing some 28 million kilowatts of capacity. The Soviet Union generated 11 percent of its electricity from nuclear power in 1985, with 25 percent projected for 1990.

Japan, which brought its first nuclear powerplant into service in 1966, now operates 33. It provided 24 million kilowatts of capacity, or about 27 percent of the Nation's total electricity generated in 1985. One of its plants, Fukushima, is one of the largest nuclear generating facilities in the world, with six reactors representing a total of 4.7 million kilowatts. By 1990, Japan expects to have increased its nuclear power program to 34 million kilowatts (Figure 38).

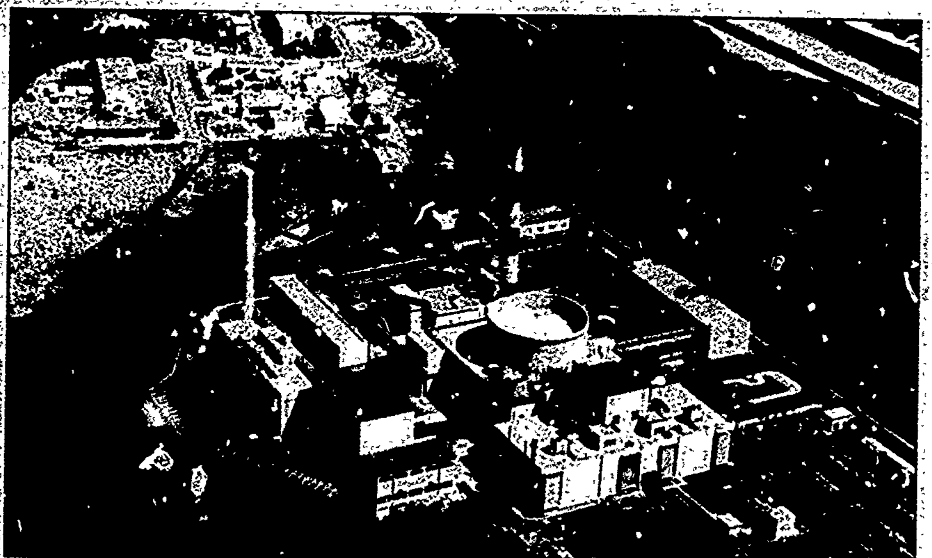


Figure 38. *The 100,000-kilowatt reactor, Joyo, near Mito, Japan, is a liquid metal fast breeder reactor (LMFBR), which achieved criticality in 1977. Other facilities planned for the Japanese LMFBR program are the 280,000-kilowatt Monju prototype demonstration plant and a 1,500,000-kilowatt commercial plant. (Credit: U.S. Department of Energy)*

Conclusion

Electricity generated by nuc! ›ar energy has grown from a small experimental scale only 30 years ago to its current position as a significant component of the energy supply of the Uniteu States and most of the industrialized world. Because of the increasing costs of oil and natural gas, experts generally agree that nuclear energy and coal are now the only two energy sources that are available economically for large new electric powerplants.

The future of nuclear power in the United States will depend largely on economic factors and energy policies yet to be determined. If the demand for electricity continues to increase as projected as a result c^f economic growth, and if we continue to sh'ft from our reliance on imported oil, nuclear energy can provide electric power while preserving our li⁻⁄ited fossil fuel (gas and oil) supply for other, more productive applications. Even the current level of nuclear plant: in operat' n and under construction around the country indicates that, at a minimum, nuclear energy will continue to generate a significant share of our electric power well into the 21st century.

Selected References and Resources

Books

- *The Nuclear Waste Primer: A Handbook for Citizens*, League of Women Voters. Nick Lyons Books, New York, NY. 1985, 175 pp.
- *The Second Nuclear Era: A New Start for Nuclear Power*, Russ Manning (Ed.), Praeger Publishers, New York, NY. 1985, 439 pp.
- *Continuing the Nuclear Dialogue*, Alvin Weinberg. American Nuclear Society, La Grange Park, IL. 1985, 204 pp.
- *Nuclear Power Issues and Choices*, Ford Foundation/Mitre Corporation. Ballinger Publishing Co., Cambridge, MA. 1977, 418 pp.
- *Meeting Our Need for Electric Energy: The Role of Nuclear Power* (DOE/NE-0054), Argonne National Laboratory, U.S. Department of Energy, Washington, DC. 1984, 61 pp., available from the National Technical Information Service, Springfield, VA 22161, NTIS Order No. DE-84-015422, $11.95.*
- *Energy, Economics and the Environment*, Russell Mills and Arun Toke. Prentice-Hall, Inc., Englewood Cliffs, NJ. 1985, 496 pp.
- *A Guidebook to Nuclear Reactors*, Anthony Nero, Jr. University of California Press, Berkeley, CA. 1979, 289 pp.
- *Social and Economic Aspects of Radioactive Waste Disposal: Considerations for Institutional Management*. National Academy Press, Washington, DC. 1984, 175 pp.
- *Understanding Radioactive Waste*, Raymond Murray. Battelle Press, Columbus, OH. 1985, 117 pp.
- *Electricity: Today's Technologies, Tomorrow's Alternatives*. Electric Power Research Institute, Palo Alto, CA. 104 pp.

Reports, Articles, and Pamphlets

- "Annual Report to Congress." Energy Information Administration, U.S. Department of Energy, Washington, DC.
- "Energy—A Special Report." National Geographic. February 1981..
- "Nuclear Reactors Built, Being Built, or Planned." U.S. Office of Scientific and Technical Information, U.S. Department of Energy, available from the National Technical Information Service, Springfield, VA 22161. NTIS Order No. PB-85-90300, $11.50.
- "Energy Resources Available to the United States, 1978 to 2000," Earl T. Hayes. *Science*. January 1979, 233-239 pp.
- "Economics of Nuclear Power," A.D. Rossin and T.A. Rieck. *Science*. August 1978.
- "Report to the President by the Interagency Review Group on Nuclear Waste Management," Directorate of Energy Research, U.S. Department of Energy. March 1979, 149 pp., available from the National Technical Information Service, Springfield, VA 22161. NTIS Order No. TID-29442, $22.95.*
- "Nuclear Energy Economics," U.S. Department of Energy. 1984, 16 pp., available from the Office of Scientific and Technical Information, ATTN: Request Services, P.O. Box 62, Oak Ridge, TN 37831.
- *Mission Plan for the Civilian Radioactive Waste Management Program*, U.S. Department of Energy, available from the Office of Civilian Radioactive Waste Management, Mail Stop RW-40, Washington, DC.
- "Electricity from Nuclear Powerplants," U.S. Department of Energy. 1984, 2 pp., available from the Office of Scientific and Technical Information, ATTN: Request Services, P.O. Box 62, Oak Ridge, TN 37831.

- "The History of Nuclear Energy," U.S. Department of Energy. 1985, 20 pp., available from the Office of Scientific and Technical Information, ATTN: Request Services, P.O. Box 62, Oak Ridge, TN 37831.
- "The Nuclear Fuel Cycle," U.S. Department of Energy. 1984, 4 pp., available from the Office of Scientific and Technical Information, ATTN: Request Services, P O. Box 62, Oak Ridge, TN 37831.
- "Nuclear Power in Space," U.S. Department of Energy. 1986, 27 pp., available from the Office of Scientific and Technical Information, ATTN: Request Services, P.O. Box 62, Oak Ridge, TN 37831.
- "Nuclear Powerplant Safety: Design and Planning," U.S. Department of Energy. 1985, 16 pp., available from the Office of Scientific and Technical Information, ATTN: Request Services, P.O. Box 62, Oak Ridge, TN 37831.
- "Nuclear Powerplant Safety: Operations," U.S. Department of Energy. 1985, 15 pp., available from the Office of Scientific and Technical Information, ATTN: Request Services, P.O. Box 62, Oak Ridge, TN 37831.
- "Understanding Radiation," U.S. Department of Energy. 1986, 17 pp., available from the Office of Scientific and Technical Information, ATTN: Request Services, P.O. Box 62, Oak Ridge, TN 37831.

Films

- *Electricity—The Way It Works* (16mm, color, 16 minutes, 1976). This film explains the generation and transmission of electricity and includes reports on such alternative fuels as coal, hydropower, nuclear energy, the sun, and wind. Available from King Features Entertainment, 235 East 45th Street, New York, NY 10017.

- *Electricity: Instant Energy* (16mm, VHS and Beta videotape, color, 16 minutes, 1982). This film takes its viewers behind the switch to learn where electricity comes from, how it is generated and transmitted, and what our Nation's needs and sources will be in the 21st century. It explains options for producing electricity, ways of conserving energy to ensure a brighter tomorrow, and numerous choices of alternative energy sources Available from King Features Entertainment, 235 East 45th Street, New York, NY 10017.

- *Electricity and the Environment* (16mm, color, 23 minutes, 1984). This film focuses on the utility industry's commitment to the protection of man's environment. This film is an excellent tool for showing how various environmental control systems work in coal and nuclear plants. For high school level and up. Available from The Magic Lantern, 925 Penn Avenue, Pittsburg, PA 15222.

*A $3.00 handling fee must be included for each NTIS order of one or more publications.

- *Electricity: Instant Energy* (16mm, VHS and Beta videotape, color, 16 minutes, 1982). This film takes its viewers behind the switch to learn where electricity comes from, how it is generated and transmitted, and what our Nation's needs and sources will be in the 21st century. It explains options for producing electricity, ways of conserving energy to ensure a brighter tomorrow, and numerous choices of alternative energy sources Available from King Features Entertainment, 235 East 45th Street, New York, NY 10017.

- *Electricity and the Environment* (16mm, color, 23 minutes, 1984). This film focuses on the utility industry's commitment to the protection of man's environment. This film is an excellent tool for showing how various environmental control systems work in coal and nuclear plants. For high school level and up. Available from The Magic Lantern, 925 Penn Avenue, Pittsburg, PA 15222.

*A $3.00 handling fee must be included for each NTIS order of one or more publications.

Glossary

alpha particle—A positively charged particle consisting of two protons and two neutrons. Alpha particles are emitted by certain radioactive materials and can be stopped by a sheet of paper.

atom—The smallest part of an element that has all the properties of that element.

atomic mass—The number of protons and neutrons in the nucleus of an atom.

atomic number—The number of protons (or number of positive charges) in the nucleus of an atom.

background radiation—The natural radioactivity in the environment. Most natural background radiation results from cosmic rays that come from outer space and from radiation from the naturally radioactive elements.

beta particle—A fast-moving electron or positron that is emitted from unstable atoms that are becoming stable. Beta particles can be stopped by aluminum foil.

boiling water reactor—A nuclear reactor in which heat from the fuel rods causes the cooling water to boil. The steam from the boiling water is used to turn the turbine-generator.

boron—A nonmetallic element that occurs in borax and other compounds. Boron is used in nuclear powerplants. Its atomic number is 5 and its atomic weight is 10.811.

breeder reactor—A type of nuclear reactor that makes more new fuel (plutonium-239) than it uses.

BWR—Abbreviation for boiling water reactor.

capital costs—The amount of money invested or required to be invested in an enterprise such as building a powerplant.

chain reaction—A reaction that stimulates its o[illegible]on. In a nuclear chain reaction, some of the neutrons [illegible] by a nucleus that has been split collide with other nuclei, which give off neutrons that collide with more nuclei. The reaction continues to repeat itself.

chemical energy—The energy released when the chemical makeup of materials changes. The energy in coal is released when the coal is burned.

chemical reaction—A process in which one or more materials changes into one or more chemically different materials.

condenser—The equipment that cools steam and turns it back into water.

conservation—Protection or preservation.

construction costs—The amount of money it takes to build something.

construction permit—Permission given by law to build something.

containment building—A structure made of steel-reinforced concrete that houses the nuclear reactor. It is designed to prevent the escape of radioactive material into the environment.

contamination—The act of making some substance impure through the introduction of undesirable elements.

control rods—Devices that are raised and lowered in the reactor core to absorb neutrons and regulate the speed of the chain reaction.

control room—The room in a powerplant where operators monitor and control the operations of the plant. The equipment in the control room informs the operators of what is happening in the reactor and other parts of the plant.

conversion—Changing from one form to another.

coolant—Substance used to remove heat.

coolant/moderator—Substance used to cool the reactor and to slow neutrons. In most nuclear powerplants, water is used for cooling to keep the reactor from getting too hot and to slow neutrons down so they are more likely to cause uranium-235 to fission.

cooling tower—A structure used to remove heat from cooling water in the condenser. The cooling tower prevents thermal pollution of lakes and rivers.

core—The central part of a nuclear reactor that contains the fuel rods, moderator, and control rods. It is in the core that nuclear fission takes place and heat is generated.

cosmic rays—A very powerful stream of energy that comes toward Earth from beyond the Earth's atmosphere.

curie—A unit of measure to describe the intensity of radioactivity in materials. It is based on the radioactivity of one gram of radium and equals 37 billion disintegrations per second.

decay heat—The heat released as radioactive elements spontaneously disintegrate.

decommission—The process of taking a nuclear powerplant out of use and safely disposing of its nuclear reactor after its service life has come to an end.

deuterium—An isotope of hydrogen whose nucleus contains one neutron and one proton and is about twice as heavy as the nucleus of normal hydrogen, which has only a single proton. Deuterium is often referred to as heavy hydrogen.

economics—The science concerned with how we make, use, and distribute goods and services.

economy—A country's or area's system of resources, workers, money, and goods.

efficient—Doing or producing something with the least amount of wasted energy.

electrical energy—A form of energy produced by the flow of electrons, usually through a wire.

electromagnetic wave—A wave that comes from the action of electric and magnetic forces and moves at the speed of light.

electron—The smallest existing particle with a negative electric charge. An electron is one of the three basic types of particles that make up the atom.

element—Any of the 109 substances that cannot be chemically broken down and of which all matter is composed.

energy—The ability to do work; energy is found in the forms of mechanical energy, chemical energy, electrical energy, nuclear energy, heat, and light.

energy conversion—The process of changing one form of energy into another.

energy crisis—A period when the supply of an energy source (such as oil) is limited and prices of the commodity rise.

environmentalists—People who study our surroundings and the effects that certain conditions have on these surroundings.

fission—To divide or split apart; the process of dividing or splitting into parts.

fission products—The atoms formed when uranium is split in a nuclear reactor. Fission products are usually radioactive.

fossil fuel—A natural, burnable substance formed from ancient plant or animal matter. Examples are coal, oil, and natural gas.

84

fuel assembly—A structure composed of about 240 fuel rods, which contain uranium pellets. Fuel for a nuclear powerplant is loaded in the reactor core in the form of fuel assemblies.

fuel costs—The amount of money it takes to get fuel ready to use in a powerplant. These costs include mining, processing, transportation, and storage.

fuel fabrication plant—A plant where uranium fuel is made into a ceramic material called uranium dioxide.

fuel pellets—Small cylindrical units of uranium oxide about ¼ inch in diameter and about ½ inch long that make up the fuel used in a nuclear powerplant.

fuel rods—12- to 14-foot-long rods that hold fuel pellets.

fusion—A combining of atomic nuclei, releasing an enormous amount of energy.

gamma ray—A type of radiation that has high energy and short wave length. Gamma rays can be stopped by lead.

gaseous diffusion plant—A plant where uranium hexafluoride gas is filtered and the percentage of uranium-235 is increased.

Geiger counter—An electronic instrument used to detect and measure radiation.

generator—A machine that makes electricity. It uses mechanical energy to spin a turbine that turns a coil of wire in the presence of a magnetic field. When this happens, an electric current is produced.

half-life—The amount of time needed for half of the atoms in a radioactive material to disintegrate.

high-level waste—Nuclear powerplant waste that is very radioactive.

high temperature gas-cooled reactor—A nuclear reactor cooled with helium.

HTGR—Abbreviation for high temperature gas-cooled reactor.

hydropower—Electric energy produced when the force of falling or moving water is used to spin a generator.

intervenor—A person or a group of people who become involved in a legal proceeding and represent a special point of view.

ionizing radiation—Radiation that has enough energy to remove electrons from the atoms of elements that it passes through, thus forming ions.

isotopes—Atoms of the same element that have the same number of protons, but a different number of neutrons. Isotopes of an element have the same atomic number, but different atomic mass.

kilowatt—1,000 watts; a measure of the rate of electricity generation or use.

kinetic energy—Energy in action.

light-water reactor—The most common type of nuclear reactor in which water is used as the moderator and coolant.

Liquid metal fast breeder reactor—A breeder reactor that is cooled by a circulating liquid metal such as sodium.

LMFBR—Abbreviation for liquid metal fast breeder reactor.

low-level waste—Materials such as laboratory wastes and protective clothing that contain only small amounts of radioactivity, pose few health hazards, and are ususally disposed of by shallow land burial.

Low-Level Waste Policy Act—A Federal law that designates how the Nation's low-level radioactive waste is to be permanently disposed of.

LWR—Abbreviation for light-water reactor.

mechanical energy—Energy spent when force is applied to an object, causing the object to move.

millirem—A unit of radiation dosage equal to one-thousandth of a rem. A member of the public can receive up to 500 millirem per year according to Federal standards. The average American receives 150-200 millirem per year from all sources.

moderator—Substance that slows neutrons down so that they are more likely to cause fission.

molecule—The smallest unit into which a substance can be divided and still keep all its characteristics.

monitored retrievable storage facility—A facility, proposed to Congress, for receiving shipments of spent nuclear fuel from existing nuclear powerplants. At the MRS, the spent fuel would be consolidated and repackaged for shipment to a permanent repository.

MRS—Abbreviation for monitored retrievable storage.

National Environmental Policy Act—A Federal law, passed in 1969, that mandates consideration of the environment in significant Federal actions.

natural radiation—Radiation that is always present in the environment from such sources as cosmic rays, radioactive minerals, building materials, and the human body.

neutron—A particle in the nucleus of all atoms except hydrogen. A neutron is one of the three basic particles that make up the atom

nonrenewable—Not able to be replaced. Fossil fuels are nonrenewable energy sources.

nuclear binding energy—The energy which holds together the particles in the nucleus.

nuclear chain reaction—A nuclear reaction that takes place in the nucleus of an atom and changes the atom into one or two entirely different elements. A chain reaction stimulates its own repetition. For example, if you knock over the first domino in a line of standing dominos, the next one will fall as the first one hits it; then the next one will fall as the second one hits it; and the reaction will continue.

nuclear energy—The energy released when the nucleus of an atom splits or when two nuclei fuse.

nuclear fission—The process of dividing or splitting the nucleus of an atom.

Nuclear Waste Policy Act of 1982—A Federal law that designates how the Nation's high-level nuclear waste is to be permanently disposed of.

nuclear power—Electricity generated by a nuclear reaction.

nucleus—The central part of an atom that contains protons, neutrons, and other particles.

operating costs—The amount of money it takes to keep a powerplant running after it has been built. This includes workers' salaries and the repair and upkeep of the plant.

operating license—Legal permission given to operate something, such as a nuclear powerplant.

plutonium—A radioactive element used in producing nuclear energy. Its atomic number is 94 and its atomic weight is 242.

plutonium-239—An isotope of plutonium with an atomic mass number of 239. Because it readily fissions when hit with slow neutrons, it can be used as fuel in nuclear powerplants.

positron—A positively charged particle having the same mass and magnitude of charge as the electron.

potential energy—The capability to produce energy. Nuclear energy is potential energy; when it fissions, it gives off heat and light.

powerplant—A plant that produces electricity.

pressurized water reactor—A light water reactor in which the cooling water is pressurized to keep it from boiling. Heat from the cooling water is transferred to lower pressure water in a secondary system. The water in the secondary system then boils, producing steam that drives the turbine.

proton—An extremely small particle or bit of matter carrying one positive charge of electricity. A proton is found in the nucleus, and is one of the three particles that make up an atom.

Pu—The symbol for plutonium.

PWR—Abbreviation for pressurized water reactor.

radiation—Fast particles and electromagnetic waves emitted from the center of an atom during radioactive disintegration.

radiation dose—The amount of radiation received during a given amount of time.

radioactive—Giving off radiant energy in the form of particles and rays by the disintegration of atomic nuclei.

radioactive decay—The spontaneous changing of an atom into a different atom or a different state of the same atom.

radioisotopes—Atoms of an element that have the same number of protons and a different number of neutrons that emit ionizing radiation when they decay. Radioactive isotopes are commonly used in science, industry, and medicine.

radioactivity—The property possessed by some elements, such as uranium, of spontaneously emitting alpha or beta particles or gamma rays.

reactor—The part of a nuclear powerplant where fission takes place.

regulate—To change or adjust in order to be in agreement with a standard or rule.

rem—A unit of absorbed dose of ionizing radiation.

renewable—Able to be replaced. The Sun's energy is a renewable energy source.

repository—A storage facility for high-level nuclear waste.

reprocessing plant—The facility where uranium and plutonium are extracted from spent fuel rods to be used again as fuel.

safety systems—Procedures and equipment designed to keep accidents from happening.

secondary system—The non-nuclear part of a powerplant that generates steam and produces electricity.

shielding—Material used to protect people and other living things from ionizing radiation. Lead can act as shielding for gamma rays.

spent fuel—Uranium fuel that has been used and then removed from the reactor.

spent fuel casks—Shipping containers for spent fuel assemblies.

spent fuel pool—A deep pool of water near the reactor where spent fuel from a nuclear powerplant is temporarily stored.

steam generators—Machines that use heat in a powerplant to produce steam to turn turbines.

tailings—The residue separated in the preparation of an ore.

Three Mile Island Nuclear Generating Station—A powerplant near Harrisburg, Pennsylvania where an accident at the Unit 2 reactor on March 28, 1979 seriously damaged the reactor core. There were no deaths or injuries associated with the accident.

TMI—Abbreviation for Three Mile Island Nuclear Generating Station.

turbine—A device consisting of a shaft and many blades that is turned by a gas or liquid. A turbine converts the kinetic energy in a gas or liquid into mechanical energy.

U—The symbol for uranium.

uranium—A heavy, hard, shiny, metallic element that is radioactive. Its atomic number is 92 and its atomic weight is 238.04.

uranium-234—An isotope of uranium with an atomic mass number of 234. It makes up 0.006 percent of naturally occurring uranium in the Earth.

uranium-235—A light isotope of uranium with an atomic mass number of 235. It is capable of undergoing rapid fission, releasing a large amount of atomic energy. For this reason, it is used as fuel in nuclear powerplants. It makes up 0.71 percent of naturally occurring uranium in the Earth.

uranium-238—An isotope of uranium with an atomic mass number of 238. It makes up 99.28 percent of naturally occurring uranium in the Earth.

unstable isotopes—Isotopes that are likely to change.

uranium dioxide—The chemical form of uranium when it is made into fuel pellets.

We invite you to reproduce this document and will be happy to make printing negatives available on a loan basis through the

U.S. Department of Energy
Office of Public Affairs
1000 Independence Avenue, SW
Washington, DC 20585

For additional information about nuclear energy, please contact

U.S. Department of Energy
Assistant Secretary for Nuclear Energy
1000 Independence Avenue, SW
Washington, DC 20585

Single copies of this publication are available through

ENERGY DOE
P. O. Box 62
Oak Ridge, TN 37831

We invite you to reproduce this document and will be happy to make printing negatives available on a loan basis through the

U.S. Department of Energy
Office of Public Affairs
1000 Independence Avenue, SW
Washington, DC 20585

For additional information about nuclear energy, please contact

U.S. Department of Energy
Assistant Secretary for Nuclear Energy
1000 Independence Avenue, SW
Washington, DC 20585

Single copies of this publication are available through

ENERGY DOE
P. O. Box 62
Oak Ridge, TN 37831

U.S. DEPARTMENT OF ENERGY
ASSISTANT SECRETARY FOR NUCLEAR ENERGY
OFFICE OF SUPPORT PROGRAMS
WASHINGTON, DC 20585