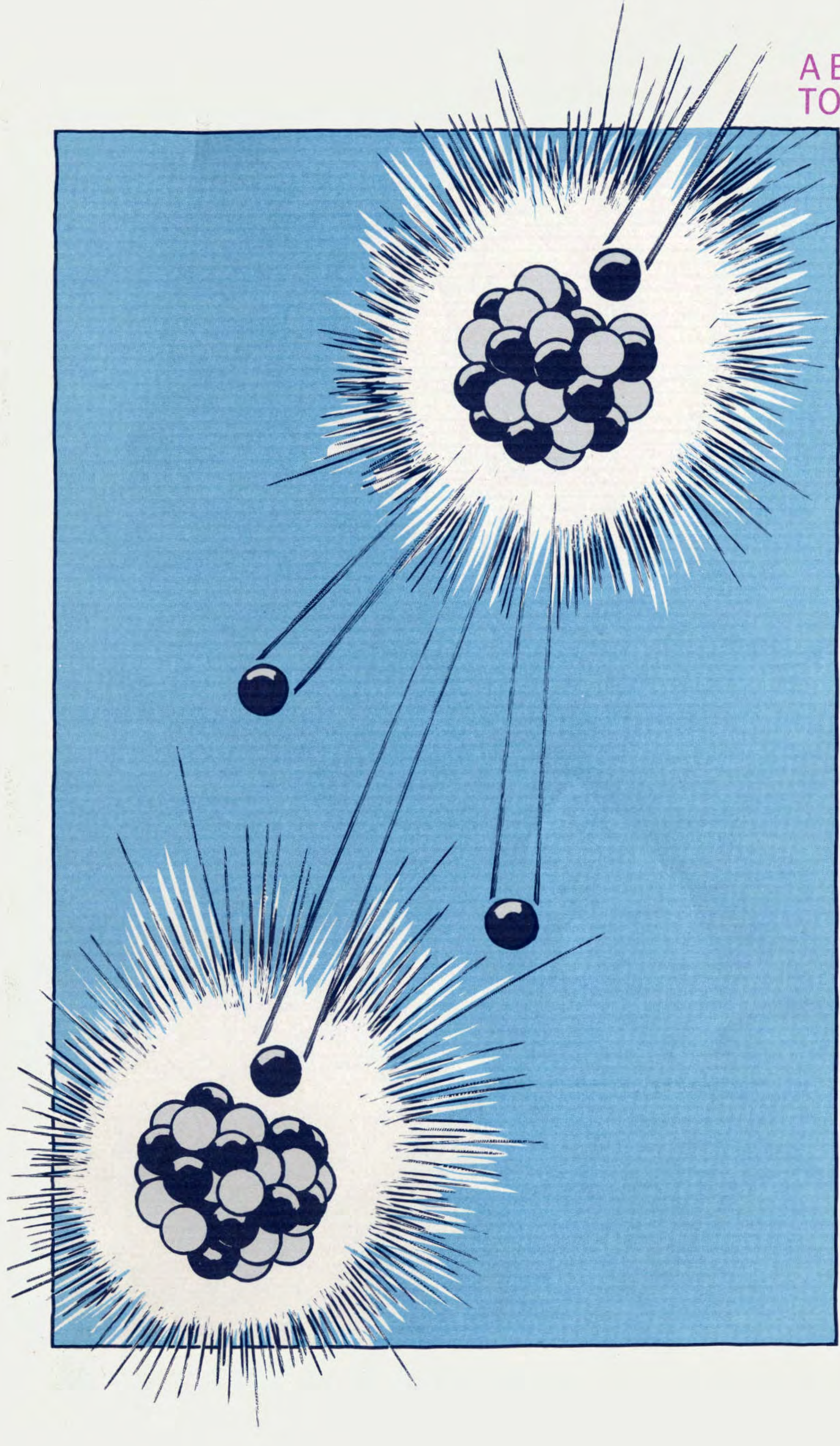
A BASIC GUIDE TO NUCLEAR POWER



Acknowledgements

This booklet came into being with the help of many people. The Northeast Utility Educators Association identified the need for a comprehensive, accessible booklet to answer general inquiries about nuclear power. Barbara Martocci and Greg Wilson performed a long series of heroic tasks in writing and refining the text. Janet White of Edison Electric Institute edited the manuscript and coordinated the publication process. Gayle Monkkonen of SCRIBBLE ably designed the booklet. Bob Soulé drew the illustrations. Anne Wilson ran several evaluations of the booklet's reading level. An extensive panel of reviewers insured the accuracy of information and the quality of presentation. And Suzanne Phelps of Edison Electric Institute, RoseAnne Fogarty of New York State School Boards Association, and Les Ramsey of U.S. Council for Energy Awareness gave especially helpful advice.

This booklet is written for the average sixth grade reader.

A BASIC GUIDE TO **NUCLEAR POWER**

By

Barbara Martocci

Vermont Yankee Nuclear Power Corporation

and

Greg Wilson

Northeast Utilities

What This Book Is About

More than 100 nuclear power plants supply over 17 percent of the electricity used in the United States. This booklet explains how nuclear energy works and how it is used to make electricity. Words defined in the text appear in **boldface** type.

1. ATOMS

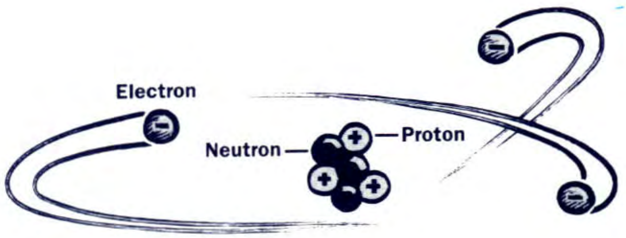


Figure 1. Atom. An atom of lithium has 3 protons and 3 neutrons in the nucleus with 3 electrons orbiting the nucleus.

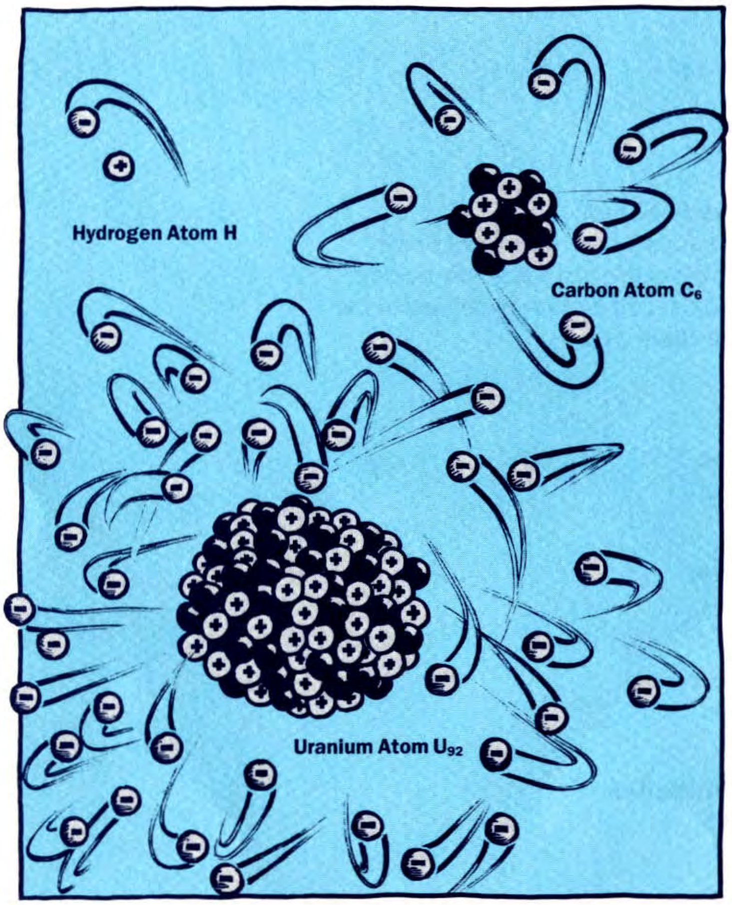


Figure 2. Types of Atoms. The number of protons in the nucleus (the atomic number) determines which element the atom is.

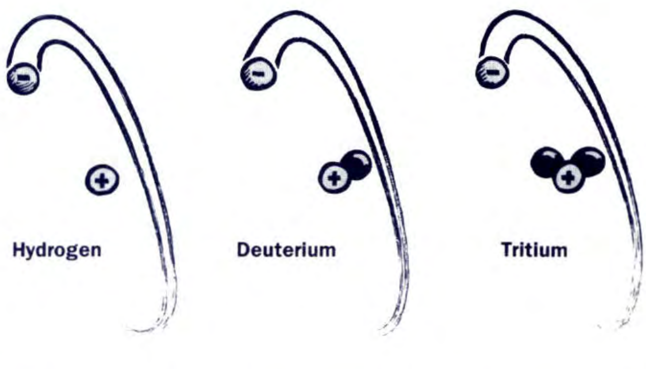


Figure 3. Hydrogen Family. Hydrogen and its two isotopes have different numbers of neutrons in the nucleus.

What is nuclear energy?

Nuclear energy is energy that comes from the nucleus or center of the atom.

What is an atom?

An **atom** is the basic building block of all matter. There are 92 different types of naturally occurring atoms, which are called **elements.** Everything in our world—trees, water, spaceships, people, food—is made of different combinations of these atoms.

What are the parts of an atom?

The center of the atom is called the **nucleus**. (The plural of nucleus is nuclei.) Inside the nucleus are two kinds of particles, the **proton**, with a positive electrical charge, and the **neutron**, which has no electrical charge. Circling around the nucleus are smaller particles with a negative electrical charge called **electrons**. So three kinds of particles make up all atoms—electrons, protons, and neutrons. An electrically neutral atom has the same number of electrons and protons.

How are types of atoms different from each other?

The number of protons in the nucleus determines what kind of element an atom is. Atoms with different numbers of protons are entirely different elements. For example, atoms with only one proton are called hydrogen atoms. Carbon atoms have six protons and oxygen atoms have eight protons. The heaviest naturally occurring atom is uranium with 92 protons. Atoms of the same element always have the same number of protons in the nucleus.

However, atoms of the same element can have different numbers of neutrons in the nucleus. Two atoms of an element that have the same number of protons but a different number of neutrons are called **isotopes** of that element. Isotopes of an element may have different nuclear properties, but the element is still the same. The atoms would behave the same way in chemical reactions.

Where does nuclear energy come from?

Protons and neutrons in an atom's nucleus are held together by energy. The energy inside the nucleus is very strong. It is this energy that is released in a nuclear reactor when atoms are split or fissioned. (A **reactor** is the system of equipment that contains and controls a fission reaction. *See Figures 10 and 11.*)

II. FISSION

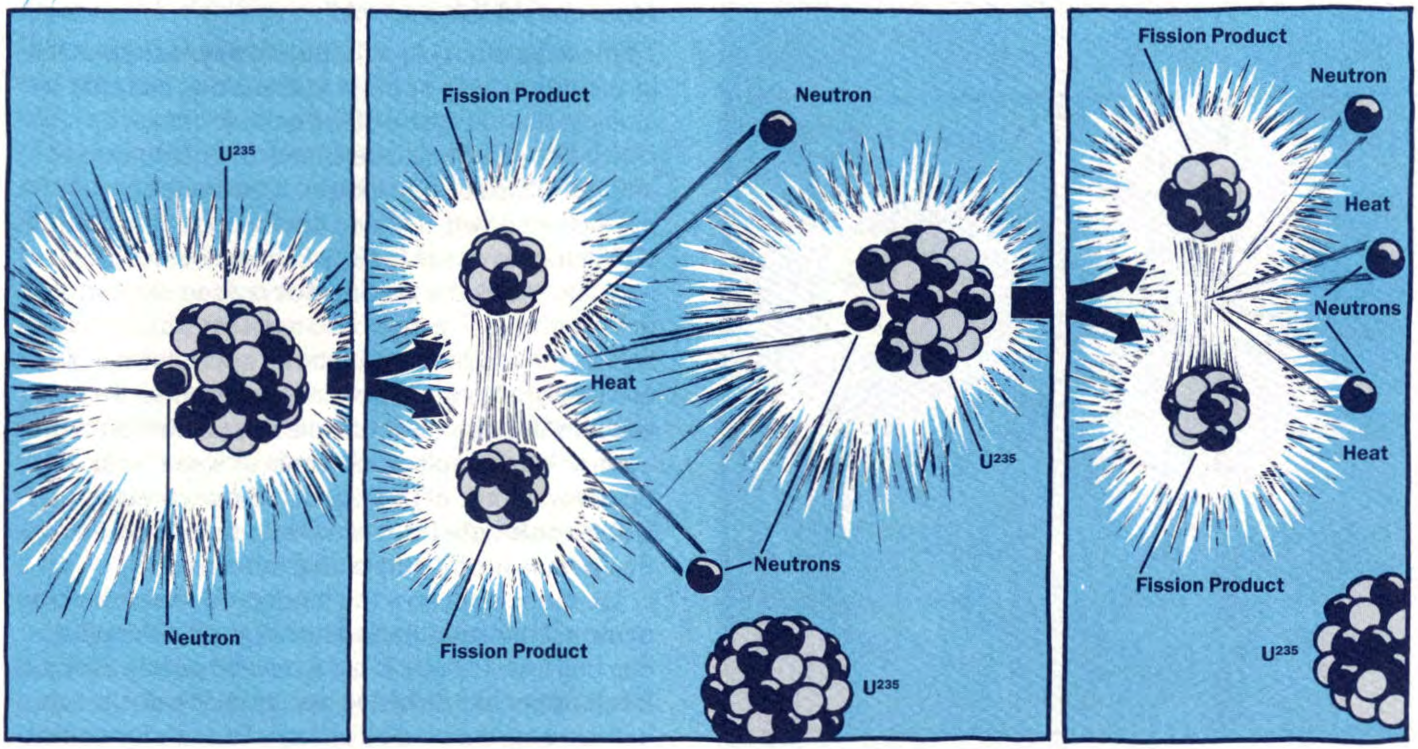


Figure 4. Fission Overview. Neutrons strike uranium 235 atoms causing the atoms to fission.

What is fission?

Fission means to split atoms into smaller parts. Only a very few elements will fission. When an atom splits, two smaller atoms, called **fission products**, are formed. A lot of energy is released, and so are two or three neutrons from the nucleus.

What kinds of atoms are used for fission?

A nuclear reactor needs fuel that will fission. Reactors use two uranium isotopes, **uranium 235** (U235) and **uranium 238** (U238). The numbers represent the number of protons and neutrons in the nucleus. Because they are both uranium, they both have the same number of protons (92). U238 has three neutrons more than U235.

Uranium 235 atoms can fission. They are known as **fissionable atoms**, meaning atoms that will split. Uranium 238 atoms very rarely fission. Instead, they go through a series of changes, called **transformations**. Through these transformations U238 can become an isotope of another element that will fission. An isotope that must go through this change to become fissionable is called a **fertile isotope**.

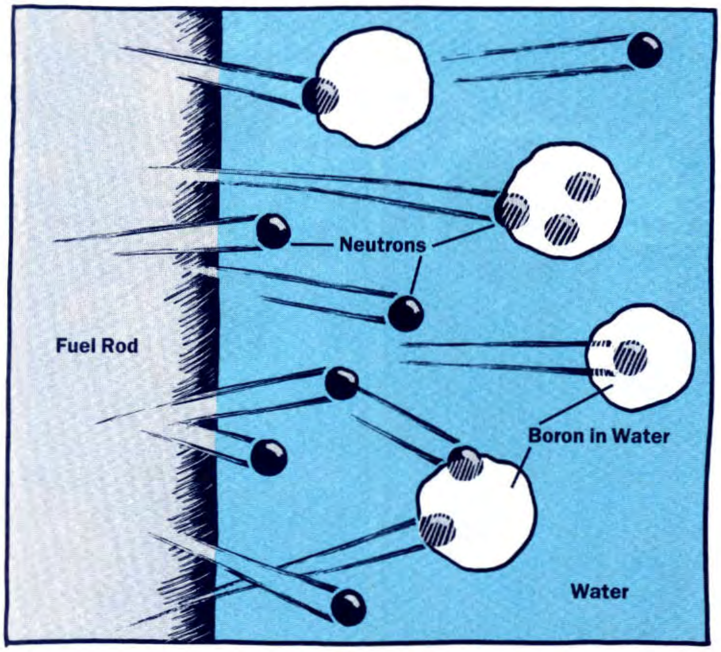


Figure 5. Neutron Absorption. Boron atoms in the water will absorb some of the neutrons released by fission.

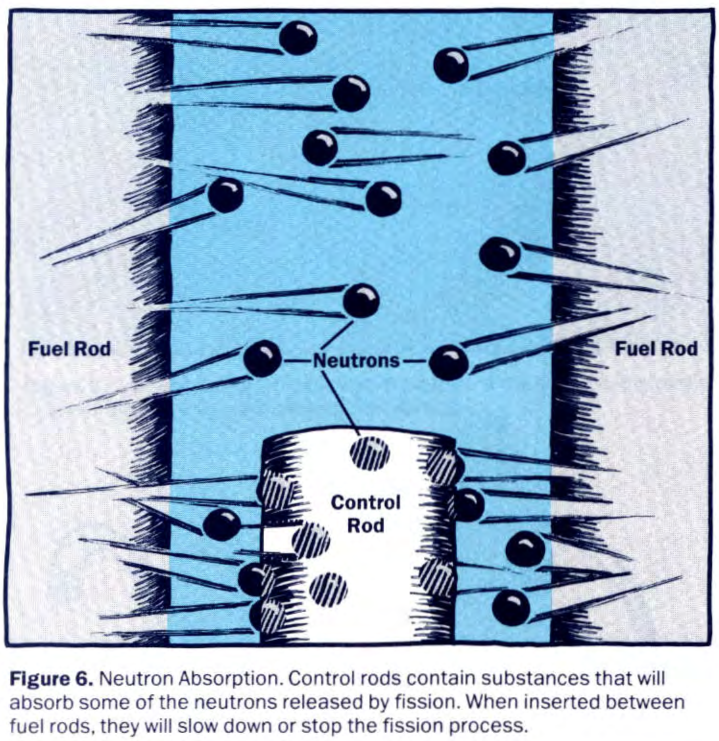


Figure 6. Neutron Absorption. Control rods contain substances that will absorb some of the neutrons released by fission. When inserted between fuel rods, they will slow down or stop the fission process.

How does fission work?

To make an atom of U235 fission, the nucleus is hit by a neutron from another nucleus that has split already. But the speed of the neutron must be slowed down after it is released in order to cause another U235 atom to fission. If the neutron were not slowed down, it would not interact with another U235 atom to cause fission. In a nuclear reactor, a substance called a **moderator** is used to slow down neutrons. In most U.S. reactors, purified water acts as the moderator. Neutrons travel through the moderator. The neutrons slow down when they hit water molecules. (A molecule is a combination of atoms. For example, a molecule of water is made up of two atoms of hydrogen and one of oxygen—H_20. A **molecule** is the smallest unit of a substance that retains the identity of that substance.)

To understand how the moderator slows down a neutron, think about the game of pool. When the cue ball (white ball) is hit, it travels quickly until it hits another ball. When it hits another ball, the cue ball gives up some of its energy. This energy makes the second ball move and slows the cue ball down. The cue ball slows down because it gave up some of its energy. In the same way, a neutron will slow down when it hits a water molecule, because it gives up some of its energy.

So what actually happens to cause fission?

A neutron, slowed down by the moderator, hits the nucleus of a U235 atom. The neutron is absorbed by the fissionable nucleus. The extra neutron makes the nucleus bigger and unstable. The nucleus splits into two parts. These parts are actually two new atoms (fission products).

Each atom that fissions releases two or three neutrons. Moving freely, these neutrons strike other uranium 235 (fissionable) atoms. Because two or three neutrons are released from each atom of U235 that is split, it is possible that two or three more U235 atoms will be split. So one splitting atom could cause two or three more atoms to split, which could cause four to six more atoms to split, which could cause eight to twelve more atoms to split, and so forth. The continuous splitting of U235 atoms is known as a **chain reaction.**

The energy released during fission is given off in the form of heat. A lot of heat is produced. To make this heat into useful energy, the chain reaction must be controlled.

How is the chain reaction controlled?

In a reactor, the chain reaction of fissioning nuclei is controlled by capturing some of the neutrons before they cause other U235 atoms to fission. Substances used to capture neutrons are called **neutron absorbers** or "**poisons**." One common neutron absorber is boron.

The neutrons are absorbed in two ways. One: Boron can be added directly to the moderator (water) to absorb the neutrons. Two: **Control rods**, steel rods containing boron, can slow the reaction. Control rods are moved into various places in the reactor. They absorb some neutrons before the neutrons reach other U235 atoms. Because the chain reaction is controlled, the reactor can produce a specific amount of heat energy. This heat energy can be used to heat water, which in turn creates steam.

It is important to note that the chain reaction also is controlled by the fuel itself. The fuel used in nuclear power plants is very different from the fuel used for nuclear bombs. Fuel for bombs must contain much more U235 than U238. Because the amount of U235 is much less concentrated in power plant fuel, it is physically impossible for a nuclear power plant reactor to explode like an atomic bomb.

CHERNOBYL

Chernobyl is a nuclear power station located in the USSR about 60 miles north of Kiev. At this nuclear power station, there are four 1000 megawatt RBMK-1000 reactors. This type of reactor uses graphite (a carbon substance) as the moderator instead of water to slow down neutrons so that fission can occur. In the RBMK-1000, water rising through pressure tubes inserted in the graphite picks up heat from the fission process and boils to become steam. This steam is then used to drive a turbine-generator to produce electricity. (*See figure below*). (In the United States, water is used to moderate (slow down) the neutrons and remove heat to produce steam. *See Figure 9, page 6.*)

On April 26, 1986, during an inadequately planned experiment, Chernobyl's power rapidly spiraled out of control. Power levels reached 100 times full power in 4 seconds. Because of this rapid increase there was a steam explosion and graphite fire which destroyed the reactor. A large amount of radioactivity was released to the environment because there was no containment building around the reactor.

A number of major design flaws of the Soviet RBMK reactor have been identified since the accident. In addition to these problems that were built into the reactor, operators who were conducting the experiment had turned off all automatic safety systems and had failed to follow operating procedures. Both design flaws and human error appear to be the main causes of the accident.

(In the U.S., operators are not allowed to shut off emergency systems without shutting down the plant. The moderator (water) cannot burn. Large reinforced containment buildings are in place to prevent release of radioactivity to the environment even during an accident.)

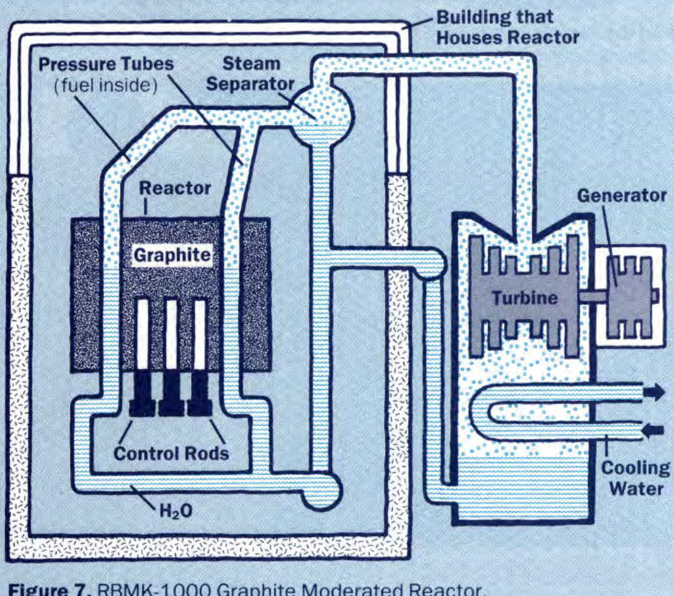


Figure 7. RBMK-1000 Graphite Moderated Reactor.

III. HEAT PRODUCTION

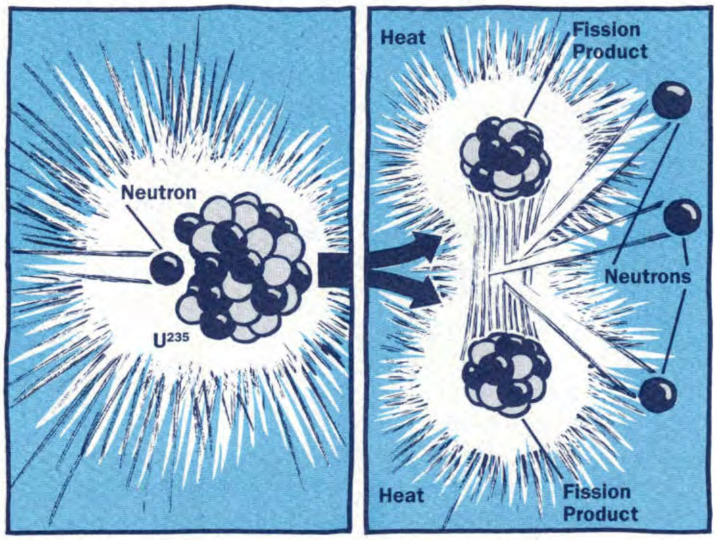
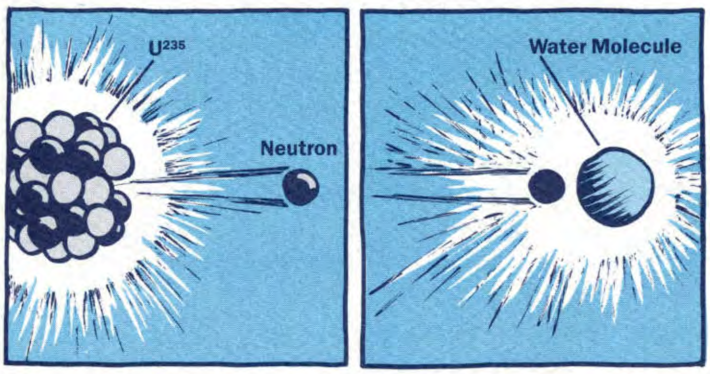
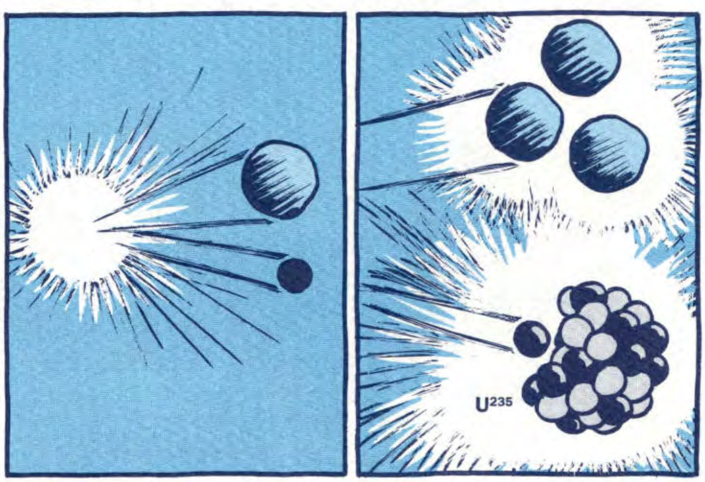


Figure 8. Heat Released During Fission.



1 A fast neutron is released from a fissioning atom.

2 Neutron collides with water molecule.



3 Collision speeds up water molecule and slows down neutron.

4 Slowed neutron can be absorbed by an atom of uranium 235 continuing the chain reaction. Sped up water molecule hits other water molecules. The friction generates heat.

Figure 9. Pool Table Effect.

Where does the heat energy come from?

When atoms fission, heat is released. Neutrons also are released. The neutrons collide with water molecules and with each other. These collisions produce friction. Friction causes heat. The heat from friction and from fission is absorbed by the water molecules. Remember, this is happening to trillions of atoms per second, so a lot of heat is created.

The water molecules that are absorbing the heat energy are the same ones that are slowing the neutrons down. Therefore, the water in the reactor has two purposes. First, it is the moderator to slow the neutrons down to let fission take place. Second, water absorbs the heat energy from the fissioning atoms. The heat is used to produce steam.

There is a third purpose for this water: It cools the fuel. Once fuel has been used in the reactor, it continues to produce some heat even after fission stops taking place. This happens because the left-over fission products give off heat. Therefore, the fuel must always be covered with water to prevent it from overheating and melting. Several separate water supplies are always available to make sure the fuel is covered and thus kept cool.

How is the heat used?

The heat is used to produce steam. The steam is used to turn a turbine-generator which produces electricity. (*See Figure 14.*)

There are two basic kinds of reactors used in the U.S. to produce electricity. One is a boiling water reactor (BWR). The other is a pressurized water reactor (PWR). Both also are known as light water reactors (LWR). (**Light water** is like regular tap water, but it must be highly purified to be used in a reactor.)

In a **BWR**, the water that absorbs the heat from the nuclear reaction boils and turns to steam. The steam is sent directly to turn the turbine-generator, which produces electricity.

In a **PWR**, the water absorbing the heat does not boil because it is kept under high pressure, like air in a tire. Instead, it becomes **"superheated" water.** The superheated water is sent through tubes in a steam generator. There, the tubes in which the water travels are surrounded with cooler water. The cooler water flows over the hot tubes and boils to steam. The steam turns a turbine-generator to produce electricity. The two sources of water remain separated from each other. Only the heat is transferred.

What happens to the steam?

After the steam is used to spin the turbine-generator and produce electricity, it is sent to the condenser to be changed back into water. The **condenser** is an enclosed box with tubes of cool water running through it. This cooling water, which comes from lakes, rivers or oceans, is always separate from the reactor water. As the steam flows over these condenser tubes, it is cooled and condenses back into water. Then the water is pumped to either the reactor or the steam generator to become steam again. In neither a BWR nor a PWR does radioactive water from the reactor come into contact with the outside environment. It is separated from the cooling water by the tubes of the condenser.

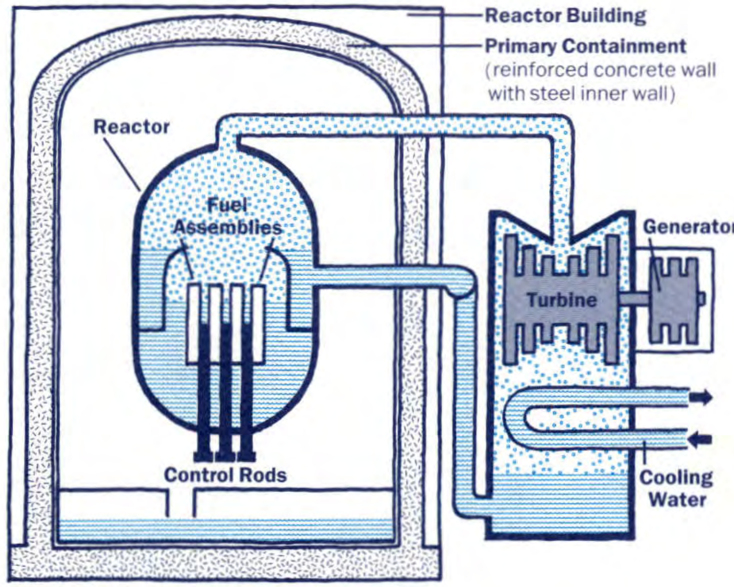


Figure 10. Boiling Water Reactor.

COOLING TOWERS

Figure 13. Cooling Towers.

Cooling water is used in a nuclear power plant to condense the steam back into water. Some plants built on an ocean or river simply can pump in large amounts of water to cool the steam. This cooling water then is pumped back out to the ocean or river. The water is somewhat warmer than when it entered the plant. Other plants must use the cooling water over and over. The heat that is added to it must be discharged. Cooling towers are used to transfer the heat in the cooling water to the air.

In a cooling tower, the water is pumped up into the tower. It is allowed to fall down inside the tower. Air comes in from the sides of the tower and passes by the falling water. As the air passes the water, it picks up some of the heat and also evaporates some of the water. This heat and evaporated water flow out the top of the tower in the form of a fine cloud-like mist. The cooled water is collected at the bottom of the tower and pumped back into the plant for reuse.

Cooling towers are used in many places other than nuclear power plants, for example, coal plants, oil plants, and even some universities and manufacturing firms.

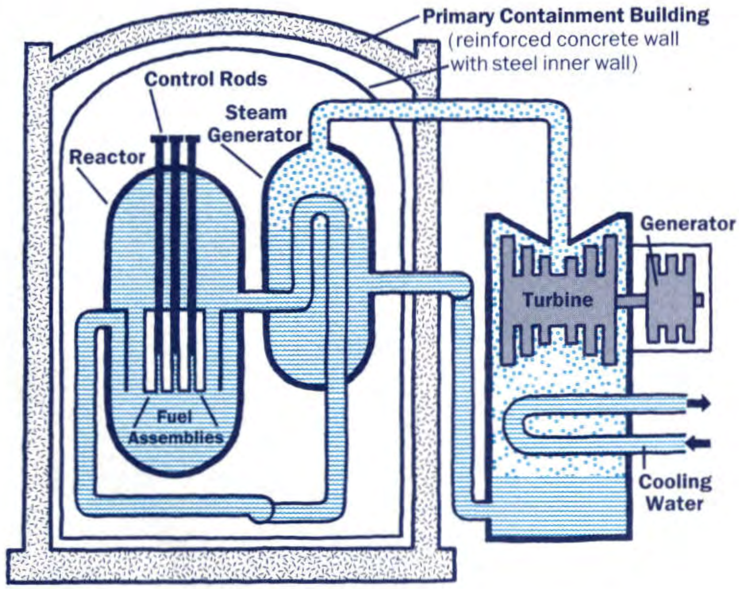


Figure 11. Pressurized Water Reactor.

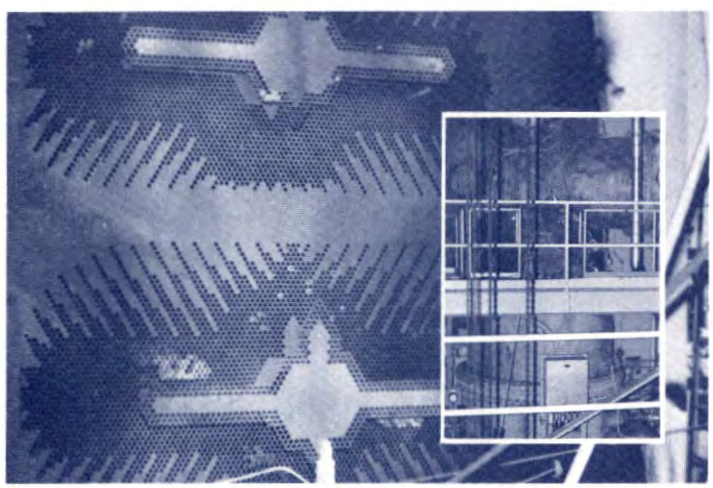


Figure 12. Condenser Tube Plate. This structure is located inside the condenser box and supports the tubes that carry cooling water. Inset shows the outside of the condenser. It sits below the turbine and is built to fit between the supports for the turbine deck above.

IV. ELECTRICAL GENERATION

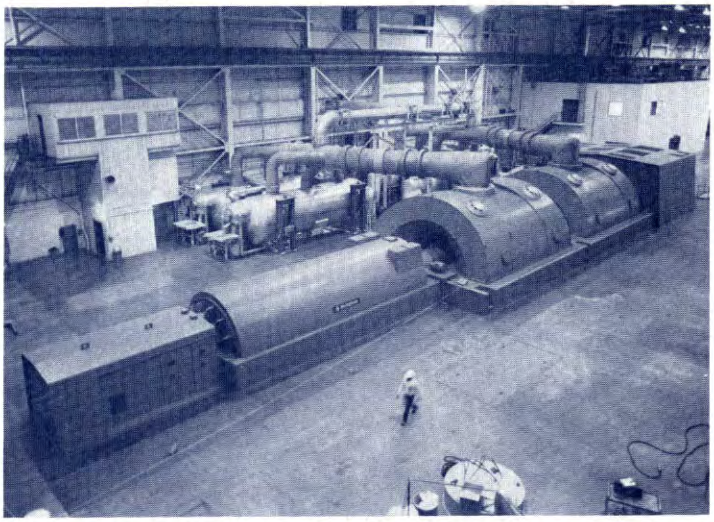


Figure 14. Turbine-Generator System. An exciter, a generator, two low-pressure turbines, and a high pressure turbine are shown on the turbine deck in the power plant (looking from left to right). The exciter supplies the magnetic field to the rotor. The rotor spins to produce electricity.

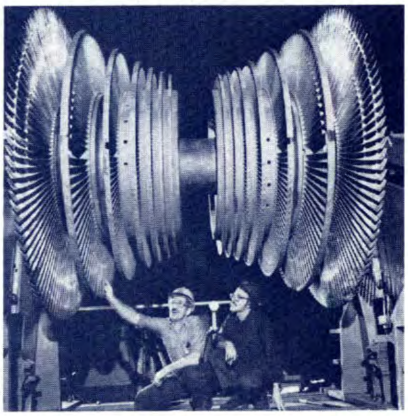


Figure 15. Low Pressure Turbine. Fan-like blades capture steam energy and rotate, spinning the rotor in the generator.

Figure 16. Generator. You can see the coils of wire inside the generator. The rotor is removed so that workers can examine the coils.

In a commercial power plant, electricity is made by spinning a magnet inside a coil of wire. The equipment that does this job is called a turbine-generator. The motion causes electrons in the wire to move. (Remember, electrons are part of every atom and have a negative electrical charge.) The constant flow of electrons through a wire is an **electric current**.

What is a turbine?

A **turbine** is the device that makes the magnet spin. On one end of the turbine shaft is a set of blades, like those on a windmill. On the other end, inside the generator, is the magnet. The steam from the boiler hits the turbine blades. The blades turn and make the shaft spin. This causes the magnet on the other end to spin as well.

What is a generator?

A **generator** is the device that produces electric current. Inside the generator is a coil of wire surrounding a magnet that is spun by the turbine.

As the magnet spins, electrons in the wire are pushed along. As each electron pushes the electron next to it, an electric current flows through the wire, out of the generator, and into the transmission lines leading from the power plant.

What happens to the electricity after it is generated?

The electric current made in the generator flows out to a transformer, located outside the turbine building. This **step-up transformer** increases the push behind the electrons (known as **voltage**). At high voltage, electrical energy can travel long distances. The electricity then leaves the step-up transformer through transmission lines. When the electricity reaches its destination, it passes through a substation where **step-down transformers** lower the voltage. From there the electricity is distributed to homes, schools, and businesses.

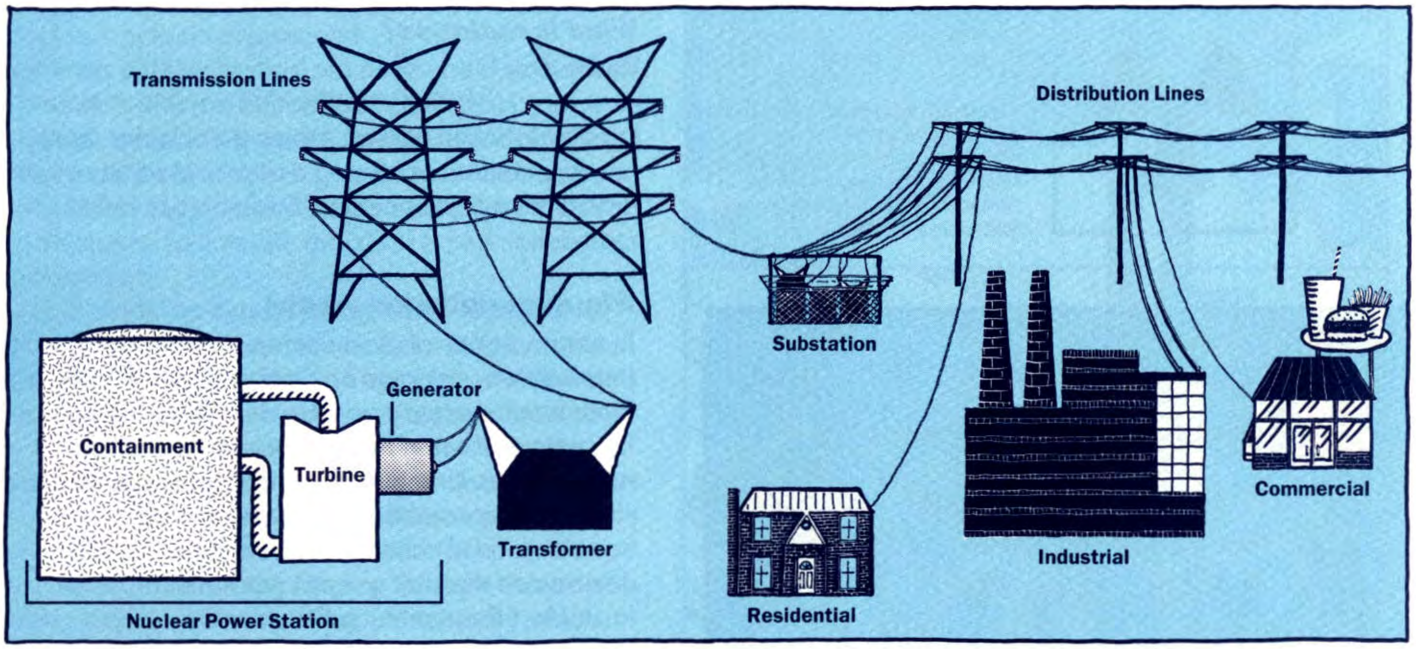


Figure 17. Producing and Distributing Electricity.

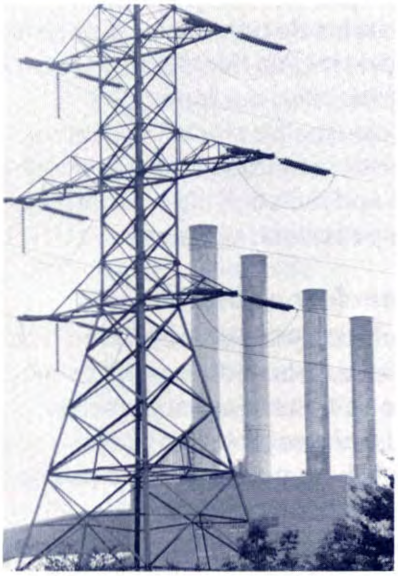


Figure 18. Transmission Lines. Strong, tall towers support high voltage transmission lines from the power plant to the substation.

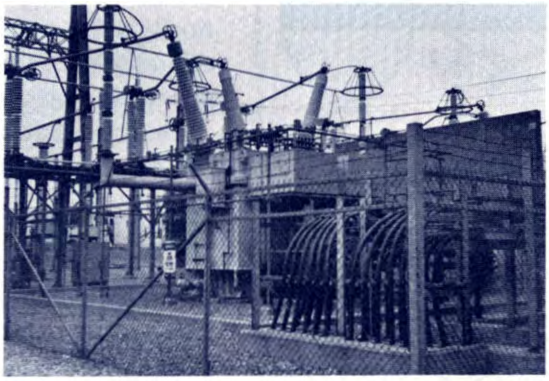


Figure 19. Step-Down Transformer. At the substation, the voltage is decreased by the step-down transformer before the electricity is sent to the consumer.

Figure 20. Distribution Poles. Wooden poles support distribution lines that bring electricity at lower voltage from the substation to houses and businesses.

V. RADIATION

The fission process in nuclear power plants produces energy in two forms: heat and radiation.

Figure 21. International Radiation Symbol. This sign is used to mark places (such as containers of nuclear waste or certain areas in power plants) where radioactive materials are found.

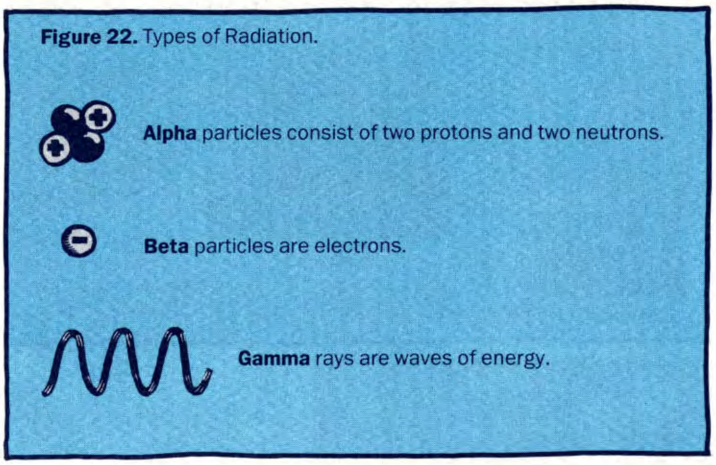


Figure 22. Types of Radiation.

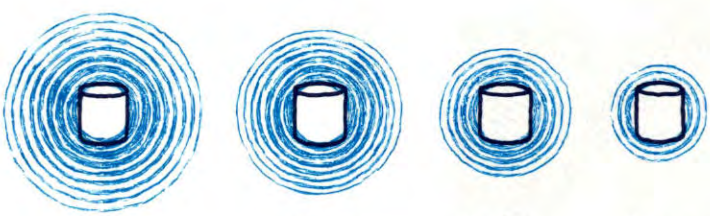


Figure 23. Radioactive Decay of Iodine 131. The circles around the container show that the iodine decays and the amount of radiation decreases as each half-life passes. As it decays, the iodine changes to different elements; so, the number of iodine atoms will get smaller. But the amount of material in the container remains the same.

What is radiation?

Radiation is energy in the form of moving particles or waves. Heat, light, and motion are other, more familiar forms of energy. Atoms that change from one type to another during fission and other natural processes release energy. This energy is called radiation.

Why does radiation occur?

In nature, atoms of most elements are stable; that is, they will never change on their own. Some outside force must change them. Atoms of some elements, however, are naturally unstable and are called **radioactive.** Uranium, for example, is a radioactive element. The combination of the number of neutrons and the number of protons in the nucleus determines whether or not a particular atom is unstable. (Remember, protons and neutrons are the parts of the nucleus.) Unstable elements eventually will become stable. But in order to become stable, an atom must get rid of excess energy within its nucleus. To do this, atoms **decay**; that is, they give off radiation. (Decaying means that the atoms are giving off energy, not that they are rotting.)

Fission products, the smaller atoms left after an atom undergoes fission, are radioactive. They continue to give off heat and radiation after fission has stopped because they continue to decay.

What forms does nuclear radiation take?

This energy most commonly takes three forms. The forms are alpha particles, beta particles, and gamma rays. **Alpha particles** are the heaviest particles released. They consist of two protons and two neutrons (just like a helium nucleus). **Beta particles** are electrons. **Gamma rays** are waves of energy. These waves are similar to the energy waves called x-rays.

How is radioactive decay measured?

Not all radioactive atoms give off energy at the same rate. The time it takes for one-half of the nuclei in a sample to change into different atoms is called **half-life**. During each following half-life, half of the unstable atoms that remain each time will change. (*See Figure 23.* Remember, unstable atoms change into stable atoms by giving off radiation.) Some radioactive elements have half-lives of thousands of years. Others have half-lives of hours or minutes or even tiny fractions of a second.

Where are radioactive atoms found?

In nature, unstable atoms are found in small amounts in many different things. Air, water and certain kinds of rocks and soils contain naturally radioactive elements. As a result, radiation is part of the environment.

In some places natural background radiation is more concentrated than usual. For example, some rock formations contain small amounts of uranium. Over thousands of years, some of the uranium has decayed into **radon**, a radioactive gas. Through cracks in the foundations, radon gas can seep into homes that have been built over these rocks. This may result in high levels of radon in the house. In a few places, groundwater flowing through these rocks can pick up radon. When that water comes out of the faucet, radon trapped in the water is released to the air. This also adds to the amount of radon inside a house. Radon gives off alpha particles. If people eat or breathe substances that give off alpha particles, health problems can occur.

Sealing the cracks in cellar walls and floors prevents radon from seeping into homes. The amount of radon inside can be reduced by allowing more air to flow through homes. The amount of radon in groundwater can be reduced by allowing radon gas to escape from water wells.

How is radiation measured?

There are several different instruments which detect and measure radiation. The most familiar instrument is a **geiger counter**. It measures the number of atoms decaying per minute. Because radiation can affect living cells, scientists use geiger counters and other tools to find out how much radiation is present.

Figure 24. Natural Background Radiation. Exposure to radiation occurs just by living on the earth. The radioactive elements in the soil, water, air, from the sun and from outer space all expose people to small amounts of radiation.

Figure 25. Radiation Protection.

Figure 26. Radiation Protection. In Figure 25, the boy's hat keeps his head and neck from overexposure to the sun's ultraviolet radiation. (UV rays cause sunburn and may contribute to skin cancer.) In Figure 26, an x-ray bib protects the woman's body from exposure to radiation when the dentist x-rays her teeth.

Figure 27. Radiation Monitor. This instrument indicates the presence of radioactivity and measures the number of atoms decaying per minute.

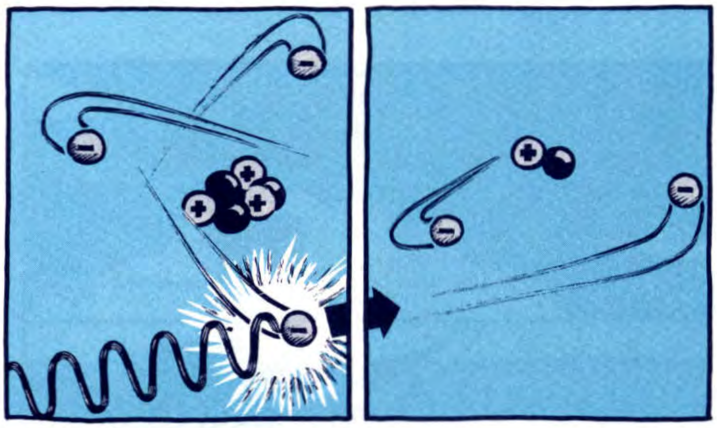


Figure 28. Ionization. Atoms become ions by losing an electron (shown on the left) or by gaining an electron (shown on the right).

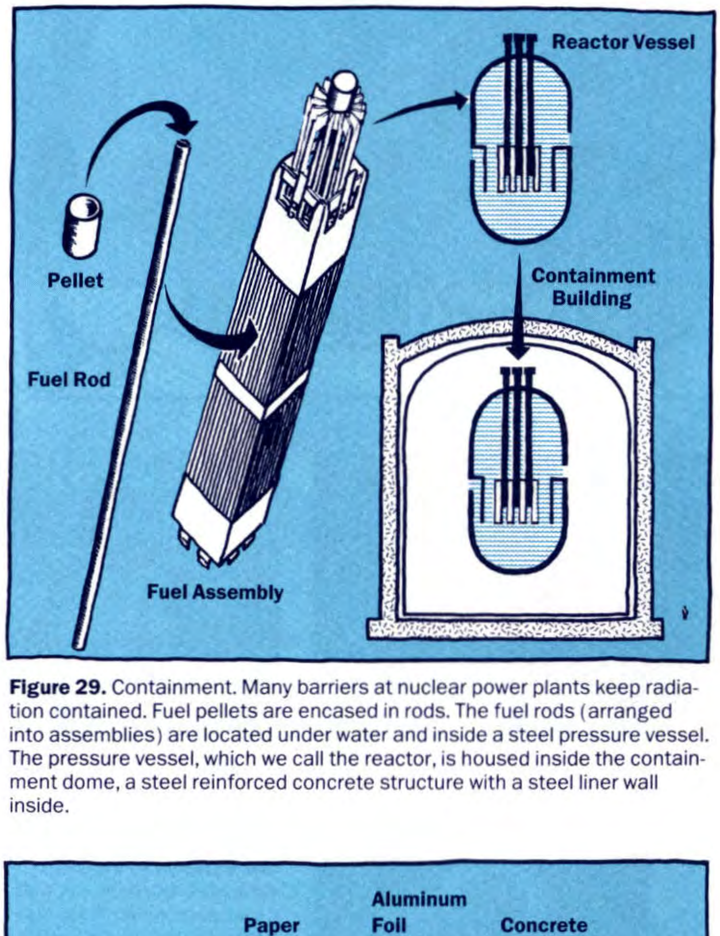


Figure 29. Containment. Many barriers at nuclear power plants keep radiation contained. Fuel pellets are encased in rods. The fuel rods (arranged into assemblies) are located under water and inside a steel pressure vessel. The pressure vessel, which we call the reactor, is housed inside the containment dome, a steel reinforced concrete structure with a steel liner wall inside.

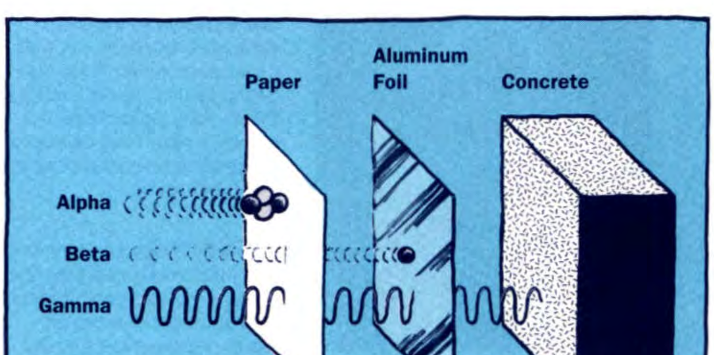


Figure 30. Layers of Shielding.

How does radiation affect living things?

All living things are made of cells. (A **cell** is the smallest unit of living matter that is able to perform basic life functions.) All types of radiation can affect the cells exposed to it. Radiation can change the structure of a cell by changing the number of electrons in the atoms of the cell. Radiation hits an atom and removes or adds electrons. The change in number gives the atom an electrical charge. The charge is positive (+) if the atom now has more protons than electrons. The charge is negative (−) if the atom has more electrons than protons. An atom with an electrical charge is called an **ion.** Radiation that changes a cell in this way is called **ionizing radiation**.

Changing the atoms in a cell can damage the cell. The amount of radiation to which the cell is exposed determines the effect on the cell. Usually, the cell can repair itself with little or no effect. The cell also can become changed (abnormal). The reproduction of abnormal cells can be unhealthy. (It can lead to some forms of cancer.) Sometimes the cell is destroyed.

Some cells are more sensitive to radiation than others. Fast growing cells—for instance, reproductive cells—are most likely to be damaged by radiation. It should be noted here that cancer cells also are fast growing, and large doses of radiation can be used to destroy these abnormal cancer cells.

What is done at nuclear plants to protect the environment from too much radiation?

Nuclear plants put up barriers to keep radioactivity out of the environment. Radioactivity from the fuel travels through the walls of the fuel rod, then through the moderator, then through the steel walls of the reactor vessel. Each of these barriers stops some of the radioactivity. The final barrier, the **containment** building, is made of thick concrete and prevents radioactivity from reaching the outside environment. *(See Figure 29.)* These barriers are called **shielding**.

Different types of radiation require different amounts of shielding. Alpha particles can be stopped by a sheet of paper or by the outer layer of skin. Beta particles can be stopped by thin sheets of metal or the first few layers of human skin. Gamma rays require thick layers of a dense material, such as concrete, lead or water to stop them.

Why is shielding needed?

If a substance that gives off alpha particles is taken into the body by eating or breathing, the alpha particles can cause cell damage. Overexposure to beta particles can cause skin burns or can damage unprotected eye tissue. Gamma rays can pass through an unshielded human body possibly causing cell damage.

How are the effects of radiation on living things measured?

The unit used to determine the health effect on the body is the **REM** (Roentgen Equivalent Man). The REM is a very large unit. Normally, radiation is measured in much smaller units called **millirem**. (The prefix "milli-" means 1/1000.)

You probably are familiar with the ton which is a large unit of measure. It can be broken down into 2000 smaller units called pounds. (1 ton = 2000 pounds.) In the same way, one REM can be divided into 1000 smaller units. (1 REM = 1000 millirem.)

Natural background radiation is present in the environment all the time. People are exposed to about 100 millirem of it per year. *Figure 33* shows how much radiation a person receives from selected natural sources. Radiation from human activities and sources adds to this amount. On the average, a person receives about 200 millirem total per year.

From *Figure 33*, we see that nuclear power plants add a very small amount of radiation to the environment. The many types and layers of shielding built inside and around the reactor make sure that radiation levels are kept very low. (*See Figure 29.*)

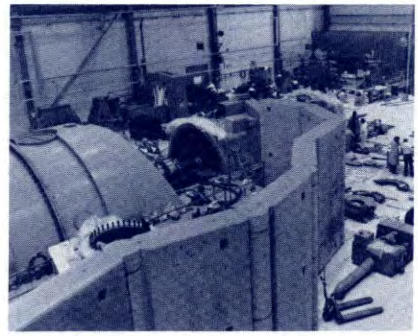


Figure 31. Shielding. This concrete wall around a BWR turbine reduces radiation exposure to surrounding areas.

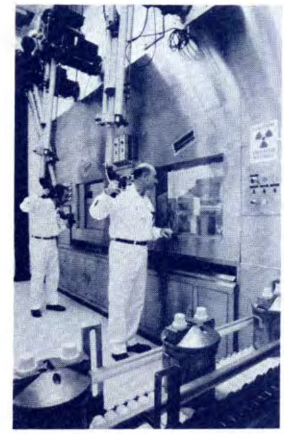
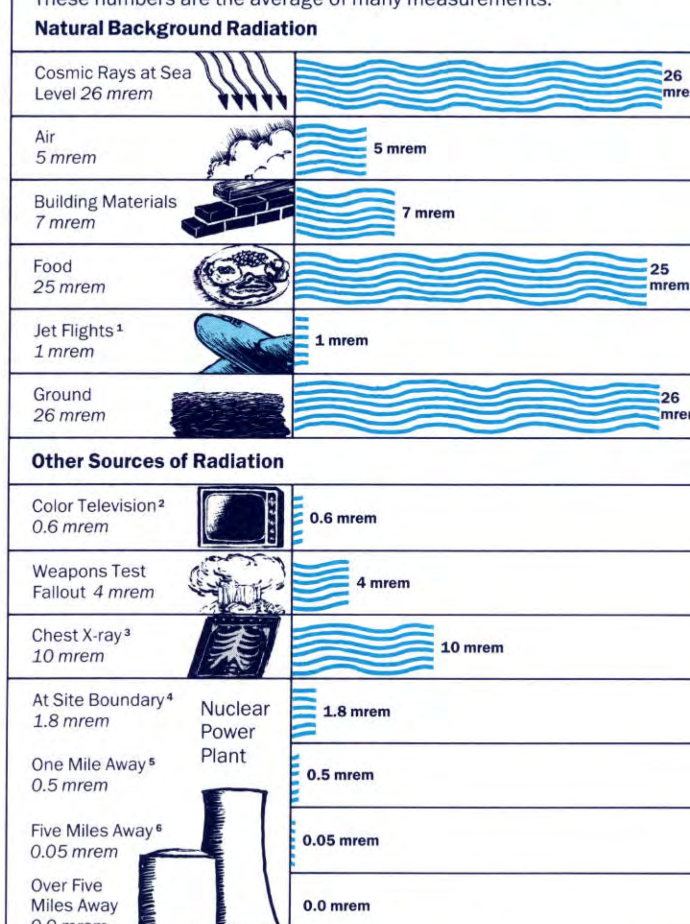


Figure 32. Shielding. Thick glass windows protect workers from radioactive materials in an industrial laboratory.

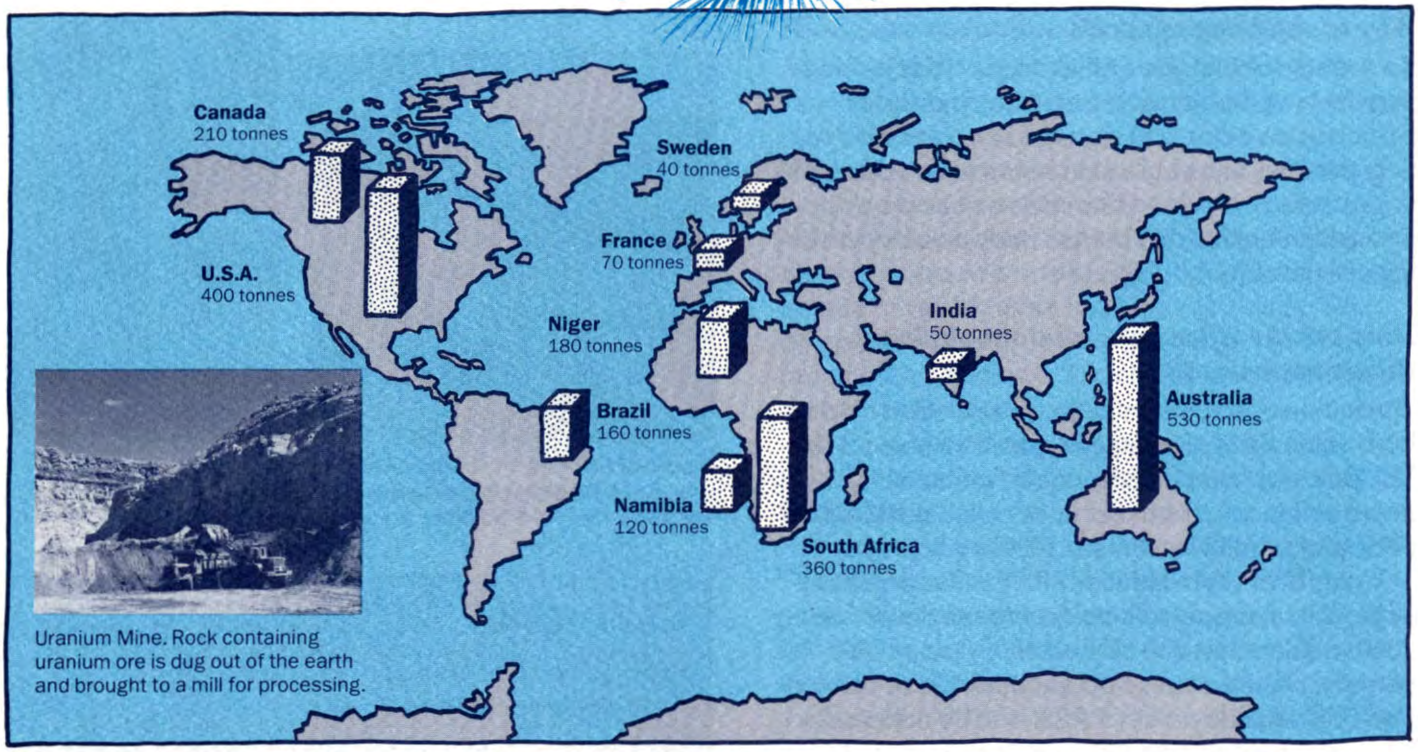
Figure 33. Annual Radiation Exposure. People are exposed to radiation every day. How much radiation they receive differs from place to place. These numbers are the average of many measurements.



(1 mrem = 1 millirem = 0.001 REM)

[1] For every 2500 miles.
[2] 4 hours of viewing per day/year = 1460 hours/year.
[3] Average annual dose to U.S. population from all nuclear medicine is 92 mrem.
[4] 9 hours/day/year = 3285 hours/year.
[5] 24 hours/day/year = 8760 hours/year.
[6] 24 hours/day/year = 8760 hours/year.

VI. FUEL CYCLE



Uranium Mine. Rock containing uranium ore is dug out of the earth and brought to a mill for processing.

Figure 34. World Uranium Resources 1986 (in metric tonnes). These numbers show the amount of uranium in the ground that can be produced for $80 or less per kilogram as of 1986. (One metric tonne = 1,000 kilograms.) Uranium resources in the Soviet Union and China are not shown.

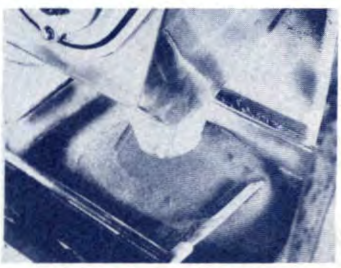


Figure 35. Making the Fuel Rod. This is processed uranium, shown before it is made into fuel pellets.

Figure 36. Fuel pellets are encased in metal tubes.

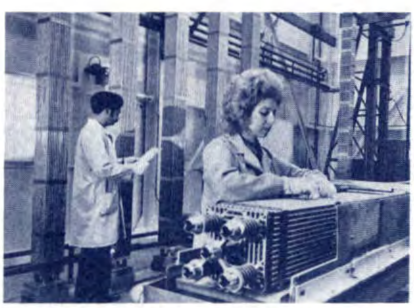


Figure 38. Fuel rods are assembled into a bundle.

Figure 37. Sealed tubes, now called fuel rods, are being inspected.

How is uranium mined and processed?

Uranium is an element that occurs naturally and is found in the ground. It is not manufactured. Uranium ore is usually combined with many other elements in the rock. In this raw form it cannot be used as a fuel. After it is mined, it must be processed. The uranium must be separated from all the other elements, and the fissionable uranium must be concentrated.

In nature most uranium is uranium 238. Only a very small amount is uranium 235. In a reactor, U235 is needed for fission to occur. To be sure there is enough U235 in the fuel, the uranium is put through a process called **enrichment**. This process concentrates U235 atoms within the fuel so that fission can take place in the reactor.

After enrichment, the uranium fuel mixture is formed into **fuel pellets**. The pellets are approximately one-half inch long and as thick as a pencil. These fuel pellets are stacked and sealed inside long metal tubes called **fuel rods**. The rods are grouped together to form a **fuel assembly** or bundle which is 8 to 12 inches square. The fuel assemblies are put into the reactor. Under the proper conditions, fission will occur within the fuel pellets.

How is a reactor refueled?

After three to four years in a reactor, there is still some U235 left in the fuel. But, there are too many fission products around it for the fission process to be efficient. Some of the fuel assemblies are removed from the reactor and replaced with new fuel. This process, called **refueling the reactor**, is done every 12 to 18 months. The fuel assemblies that are removed are called **spent fuel**. All spent fuel is moved underwater to the spent fuel pool using a crane. (Spent fuel is radioactive and must be shielded from the environment.)

During refueling, approximately one-third of the assemblies are removed and placed in the spent fuel pool. The remaining assemblies are rearranged to take the place of the spent assemblies. New fuel is brought in and arranged around the remaining assemblies. By rotating the fuel in this way, fuel assemblies will last three to four years.

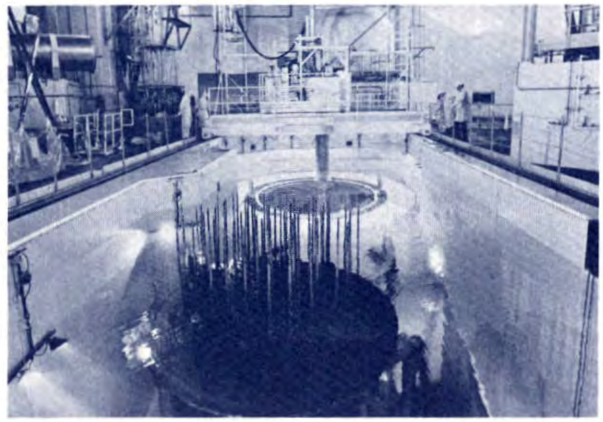


Figure 39. Refueling. The refueling cavity in a PWR is full of water. The reactor head in the foreground has been removed in preparation for moving the fuel.

What is a spent fuel pool?

A **spent fuel pool** is a large pool of water about 40 feet deep. Here spent fuel assemblies are stored. The spent fuel contains most of the fission products that were created in the reactor. These products are highly radioactive and are shielded from the environment by the water in the pool. As the spent fuel sits in the pool, the radioactive materials decay and give off heat. The water absorbs both the heat and the radiation. Currently, there is no central site for permanent disposal of spent fuel. It remains stored in the power plant's spent fuel pool.

After the assemblies have been stored in the pool for several years, much of the radioactivity has decayed. Although still highly radioactive, the assemblies can be removed more safely and transported for permanent disposal.

Spent fuel is considered high level waste. The U235 that is still useful fuel can be separated from the fission products in spent fuel. This technology is called **reprocessing**. But because the nuclear power industry in the United States does not reprocess spent fuel, the entire spent fuel assembly is considered waste.

Figure 40. Lifting the Assembly. The crane used to move new assemblies into the reactor core also is used to move spent fuel from the reactor to the spent fuel pool.

Figure 41. Spent Fuel Storage. Spent fuel assembly is lowered into a rack in the spent fuel pool.

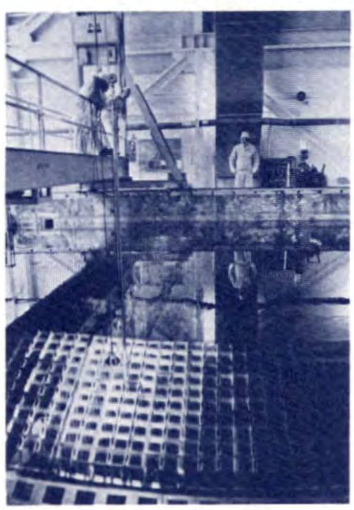


Figure 42. Spent Fuel Pool. Large, deep pool of water holds racks that contain spent fuel assemblies.

VII. NUCLEAR WASTE

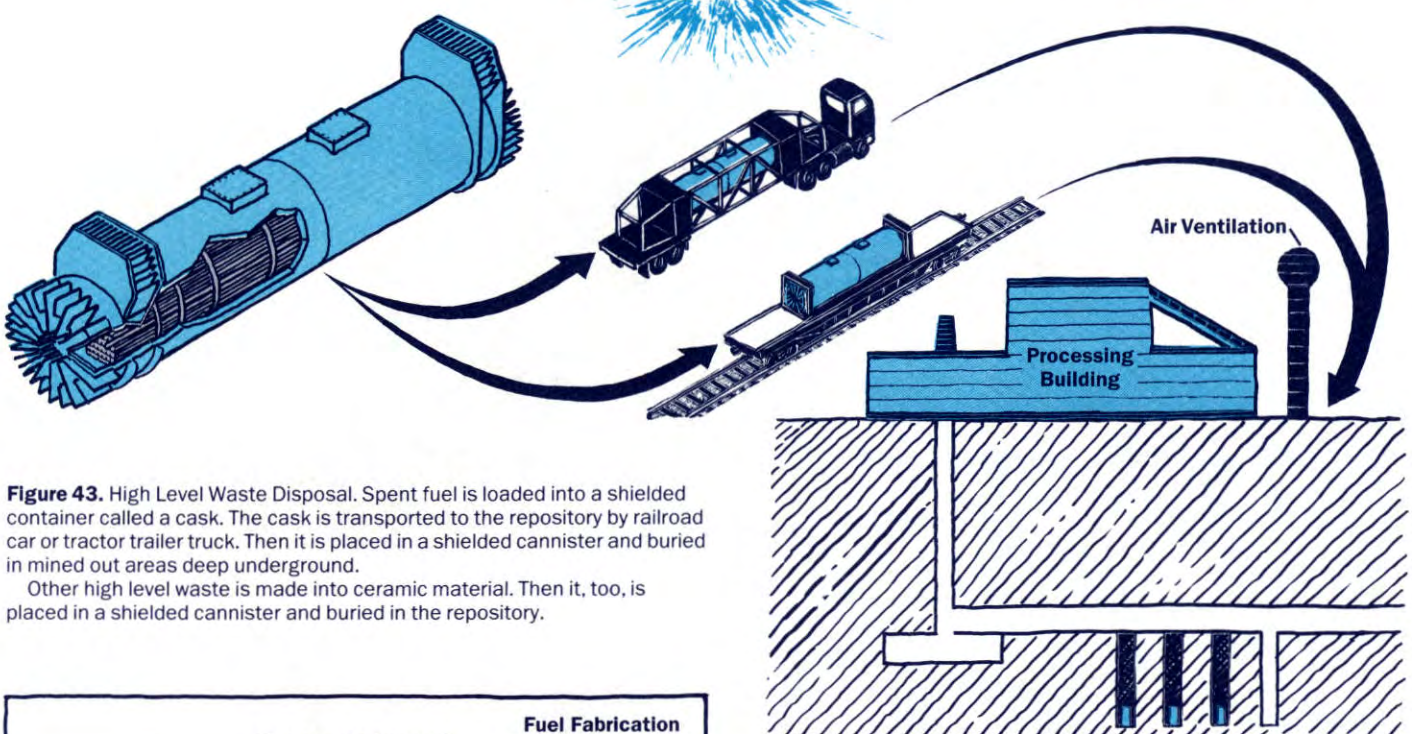


Figure 43. High Level Waste Disposal. Spent fuel is loaded into a shielded container called a cask. The cask is transported to the repository by railroad car or tractor trailer truck. Then it is placed in a shielded cannister and buried in mined out areas deep underground.

Other high level waste is made into ceramic material. Then it, too, is placed in a shielded cannister and buried in the repository.

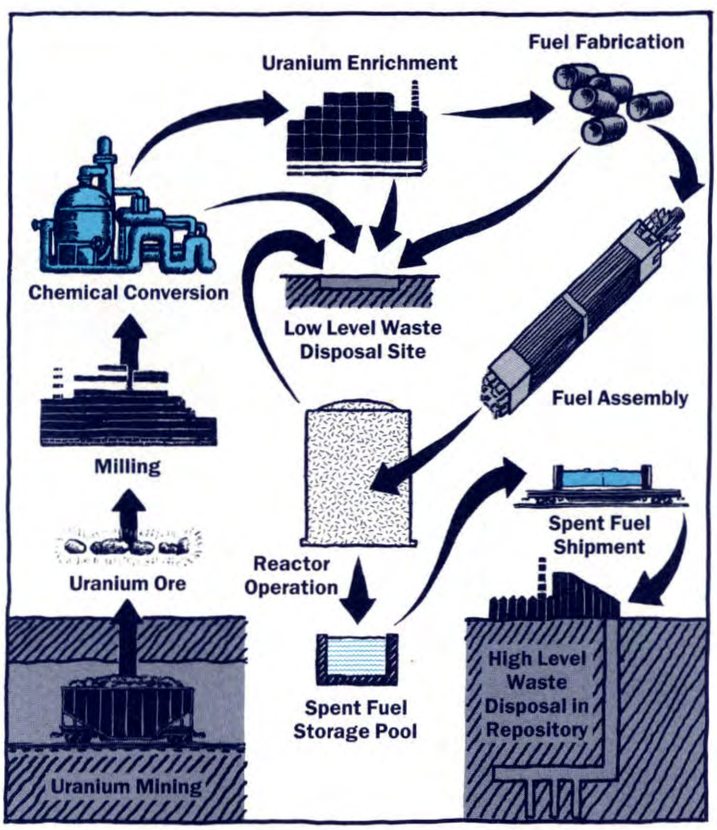


Figure 44. Nuclear Fuel Cycle. Shows where waste is generated in the process of mining, fabricating, and using fuel.

Nuclear waste can be divided into two categories. **High level waste** is composed of spent fuel and material from nuclear weapons production. These wastes are highly radioactive and will not decay to background levels for hundreds of years. **Low level waste** is composed of items that have been contaminated with radioactive materials. Tools and protective clothing are examples of low level waste. These wastes are less radioactive than high level waste and decay to background levels in less time.

What are the plans for permanent high level waste disposal?

In 1982 the Congress of the United States passed the **Nuclear Waste Policy Act**. This Act set up a timetable for final disposal of high level nuclear waste. The Act included a plan to build a high level waste repository at a selected location. A second location will be selected if needed. A **high level waste repository** is a disposal facility which will be built in a rock formation deep in the earth that will not change for thousands of years. (This kind of rock structure is called a **geologically stable formation**.) There, a specially prepared waste package will be buried permanently.

A waste package will be prepared in this way: Spent fuel assemblies will be placed in shielded containers designed to keep radioactivity in and water out. To be sure that water cannot get into the waste package, the package will be buried inside several barriers. The barriers are the rock formation itself plus backfills of other soil and rocks around the waste package. After the repository is filled, it will be sealed and monitored for many years to come.

The amount of space taken up by spent fuel assemblies from all reactors in the United States is very small. For this reason, it is possible that only one repository will be necessary.

High level wastes are transported by rail or truck in heavy, rugged shipping containers called **casks**. Under federal regulations these casks had to be designed to withstand a series of severe tests: crashing at high speed, free falling from 30 feet, burning, and being submerged in water. In each case the containers withstood the test. None of their contents leaked into the environment. These tests show that the containers can be safe even under extraordinary stress.

What is low level waste? How is it disposed of?

Low level waste consists of materials other than spent fuel that have become contaminated or radioactive during their use. These items include protective clothing, rags, cleaning materials, papers, boxes, and tools. In addition to nuclear power plants, low level waste comes from hospitals, research facilities, industries, and universities. Low level waste is placed in wooden boxes, 55 gallon drums or large metal containers. The material in the containers is packed very tightly together or made into a solid and shipped for disposal. Containers normally are shipped by truck to a low level waste disposal site.

The **Low Level Waste Policy Act** passed in 1980 gave each state responsibility for the disposal of its own wastes. Because every state does not need its own disposal site, states were encouraged to form compacts. Each compact has to adopt some form of written agreement among its member states on how to dispose of their low level waste. The agreement has to be approved by Congress. Making this agreement has been a difficult task because most people do not want a low level waste site in "their backyard." Some states have decided to develop a disposal site on their own. These states do not wish to be responsible for any other state's waste. Other states are still working to reach an agreement.

Low Level Waste Disposal

Figure 45. Bags of Low Level Waste.

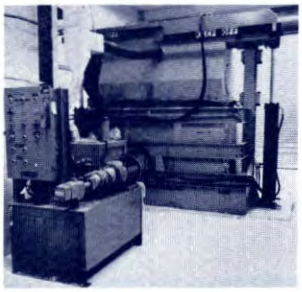


Figure 46. Low Level Waste Compactor. Here low level waste materials are packed very tightly together (compacted) before being shipped for disposal.

Figure 47. Boxes of low level waste ready to be placed on a truck.

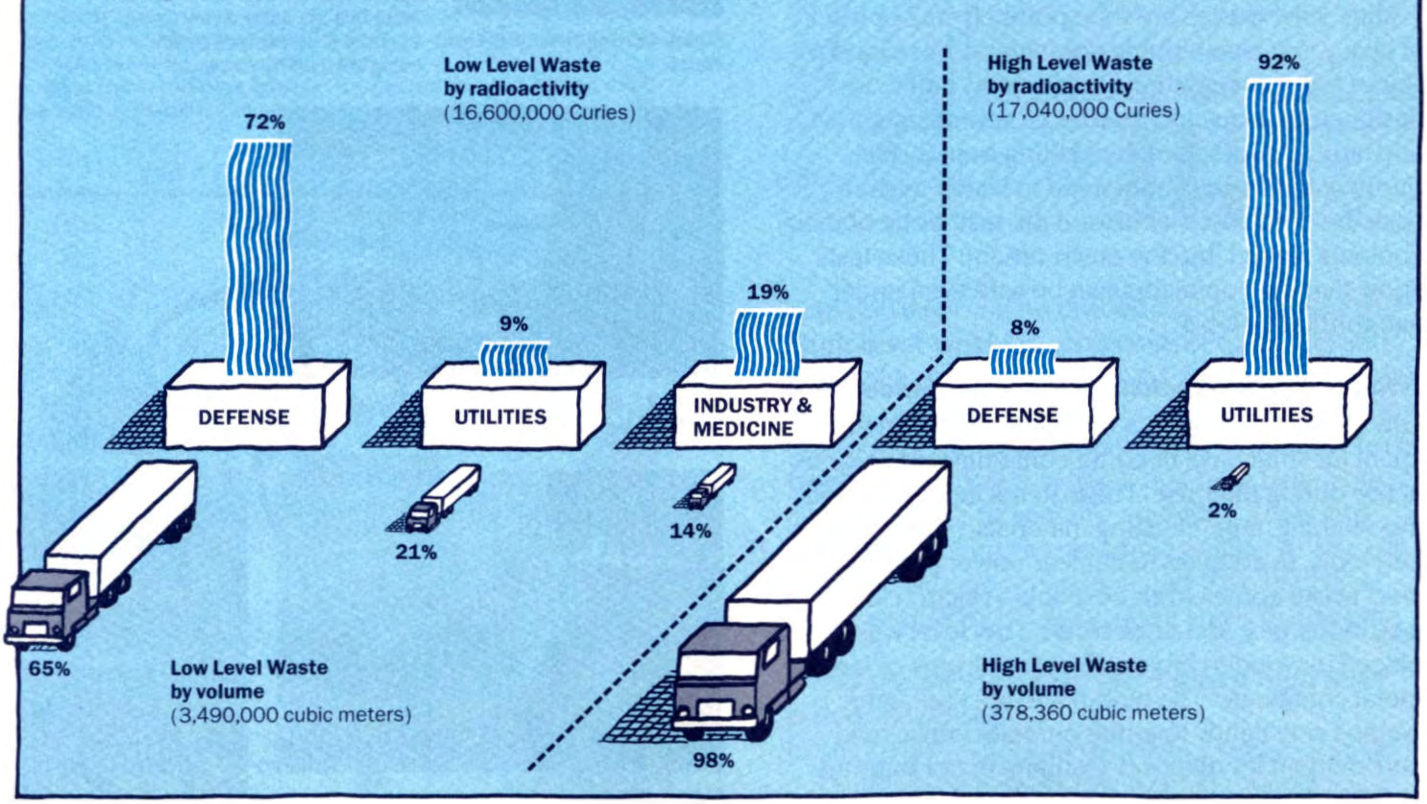
Figure 48. Low Level Waste Shipment. Resins used to filter slightly radioactive water are dried (called **dewatering**) and put into these containers for shipment to a disposal area.

Figure 49. Low Level Waste Disposal Site. Waste containers are stacked in specially designed trenches. When full, the trenches are covered with soil and continuously monitored. (See close-up, Figure 50.)

Figure 50. Low Level Waste Disposal Site.

Presently all low level waste goes to one of three sites: Barnwell, South Carolina; Beatty, Nevada; and Richland, Washington. Waste containers are transported to a burial site by truck. There they are placed in a trench that has a leak-proof cap to keep water out. The trench is backfilled and marked and is left undisturbed for the materials to decay. Wells are set in adjoining areas to check groundwater flow to be sure that no radioactivity is escaping from the burial site.

Figure 51. Radioactive Waste (accumulated through 1986). Waste is measured both by radioactivity and volume. Radioactivity means the amount of radiation given off by the waste (measured in Curies). Volume means the amount of space taken up by the waste (measured in cubic meters).



VIII. NUCLEAR POWER TODAY

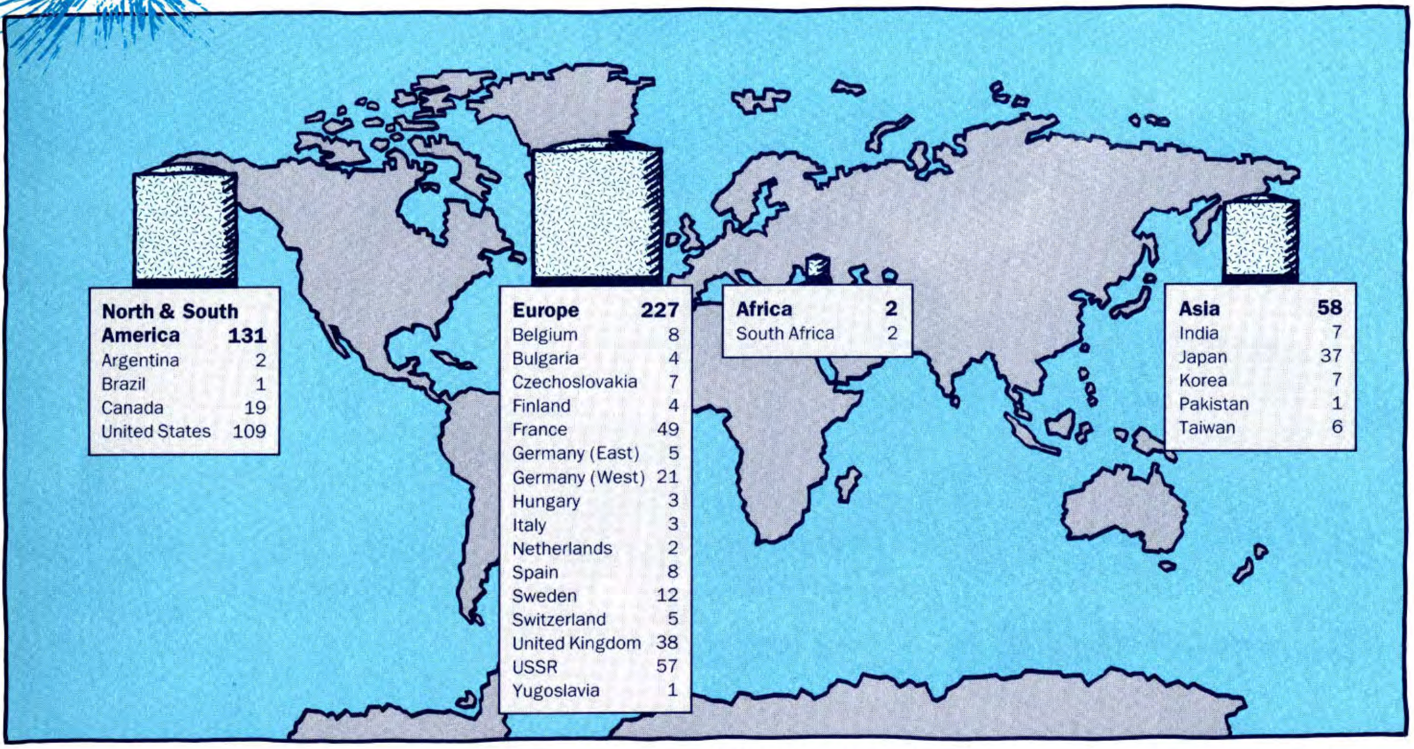


Figure 52. World Map of Nuclear Power Plants (units licensed to operate in 1987). All reactors in the USSR are listed under Europe, although a few are located in Asia.

Today more than 400 nuclear power plants in 26 countries are producing electricity. Worldwide, nuclear power has been an alternative to coal and oil for generating electricity in countries without their own fossil fuels. The use of nuclear power outside the United States continues to grow.

More than 100 nuclear plants now are operating in the United States. Because of a number of social, political and economic concerns, U.S. utilities currently have no plans to build new nuclear plants. Nuclear power plants may again be ordered in the United States if these concerns can be addressed.

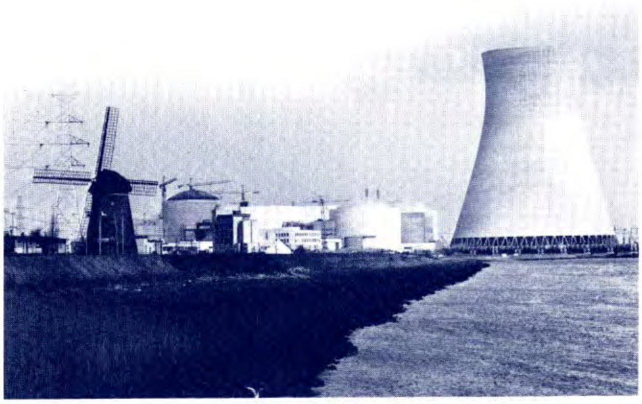


Figure 53. Doël Nuclear Station. A reactor in Belgium stands next to a windmill, one of the oldest energy technologies in Northern Europe.

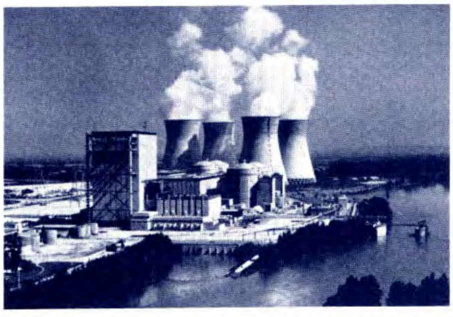


Figure 54. France's Phénix breeder reactor on the Rhône River.

Figure 55. Pickering Generating Station, Ontario. A CANDU (Canadian Deuterium Uranium) reactor fueled by natural uranium rather than by enriched uranium as in U.S. reactors.

IX. CONCLUSION

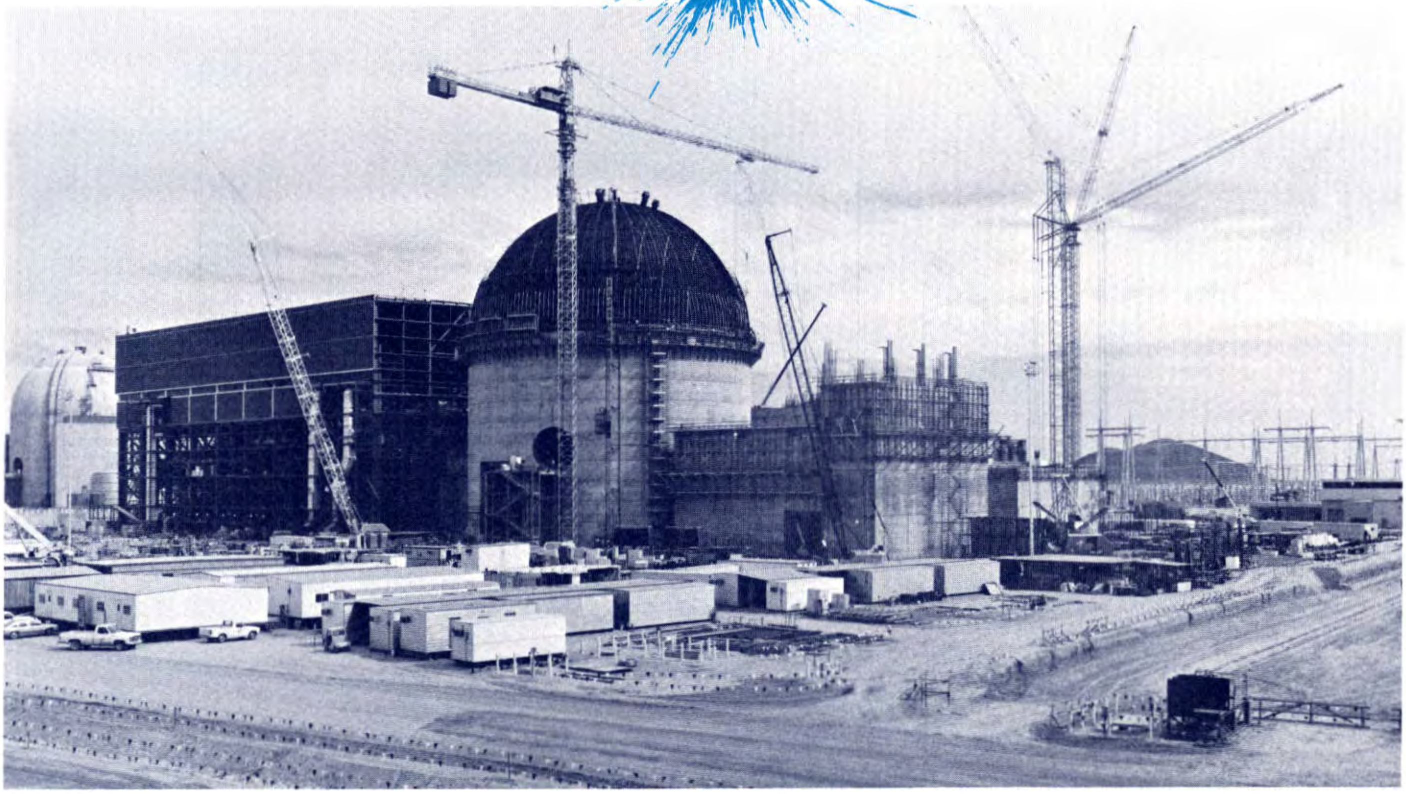


Figure 56.

This book has presented facts supported by scientific technology on nuclear power. There also are other specific issues about which people have questions. Some are social, some are technological, and some are political. The questions include:

a. What are the long-term effects of exposure to low levels of radiation?

b. Where will a repository for high level waste be built?

c. Where will low level waste be disposed of?

d. Can nuclear waste be disposed of safely and kept out of the environment for thousands of years?

e. Can nuclear waste be transported safely?

f. Are further security measures needed to protect against terrorism?

Depending on which group of people you speak to, you can receive very different responses. It is important to know all sides of the nuclear power issue before you make any decisions. We urge you to ask questions and get answers from all sides and then make up your own mind based on the facts. The bibliography on the next page lists a few references with which to begin.

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701 Pennsylvania Avenue, N.W.
Washington D.C. 20004-2696

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