DOE/NE-0074

UNDERSTANDING Radiation

NUCLEAR ENERGY

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

On the cover:
Marie Curie
(1867–1934)

Understanding Radiation

Table of Contents

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

Natural and Man-made Sources of Radiation

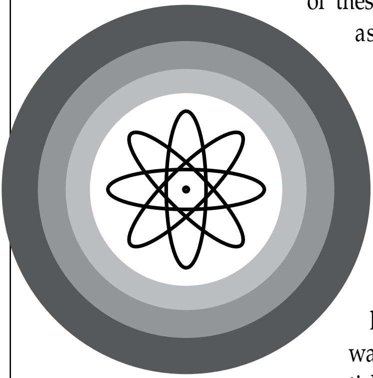
We are constantly exposed to radiation, whether cosmic radiation from outer space or radiation from radioactive elements in the earth's rocks and soil. These sources contribute to the *natural background radiation* that has always been around us. But there are also man-made sources of radiation, such as medical and dental x-rays, household smoke detectors, and materials released from nuclear and coal-fired power plants.

Cosmic radiation from outer space contributes to the level of natural background radiation.

Radiation: The Activity of Atoms

All matter in the universe is made of atoms, and radiation comes from the activity of these tiny particles. Atoms are made up of even smaller particles called *protons*, *neutrons*, and *electrons.* The arrangement of these particles distinguishes one atom from another.

Atoms of different types are known as *elements.* There are over 100 natural and man-made elements. Some of these elements, such as uranium, radium, and thorium, share a very important quality— they are unstable. As they change into more stable forms, they release invisible waves of energy or particles. This is called i*onizing radiation.* Radioactivity is the emitting of this radiation.



Radioactive atoms release an invisible energy called ionizing radiation.

Ionizing Radiation

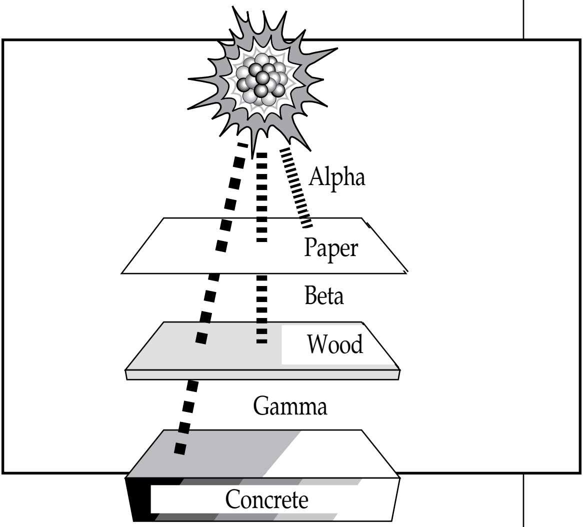
Ionizing radiation is energy that can ionize, or electrically charge, an atom by stripping off electrons. Ionizing radiation can change the chemical composition of many things — including living tissue.

The three main types of ionizing radiation are alpha and beta particles and gamma rays:

- *Alpha* particles are the most energetic of the three types of ionizing radiation. But despite their energy, they can travel only a few inches in the air. Alpha particles lose their energy almost as soon as they collide with anything. A sheet of paper or your skin's surface can easily stop them.

- *Beta* particles are much smaller than alpha particles. They can travel in the air as much as 100,000 miles per second for a distance of about 10 feet. Beta particles can pass through a sheet of paper, but may be stopped by a thin sheet of aluminum foil or glass.

- *Gamma* rays, unlike alpha or beta particles, are waves of electromagnetic energy. Gamma rays travel at the speed of light (186,000 miles per second). Gamma radiation is very penetrating and is best shielded by a thick wall of concrete, lead, or steel.



Alpha particles can easily be stopped by a sheet of paper. Beta particles can pass through paper, but not aluminum foil or glass. Gamma rays are more powerful and can be stopped by thick concrete, lead or steel.

Radioactive "Half-Lives"

The radioactivity of a material decreases with time. The time that it takes a material to lose half of its original radioactivity is referred to as its *half-life*. For example, a quantity of iodine-131, a material that has a half-life of 8 days, will lose half of its radioactivity in that amount of time. In 8 more days, it will lose half of the remaining radioactivity, and so on. Eventually, the radioactivity will essentially disappear. Each radioactive element has a characteristic half-life. The half-lives of various radioactive elements may vary from millionths of a second to millions of years.

As a radioactive element gives up its radioactivity, it often changes to an entirely different element — one that may or may not be radioactive. Eventually, a stable element forms. This transformation may take place in several steps and is known as a *decay chain.* Radium, for example, is a naturally radioactive element with a half-life of 1,622 years. It emits an alpha particle and becomes radon, a radioactive gas with a half-life of only 3.8 days. Radon decays into polonium and, through a series of steps, into bismuth and ultimately to lead. Lead is a stable, non-radioactive element.

Radiation: Units of Measure

Scientists and engineers use a variety of units to measure radiation. These different units can be used to determine the amount, type, and intensity of radiation. Just as heat can be measured in terms of its intensity or its effect using units like degrees and calories, amounts of radiation can be measured in *curies*, *rems*, *millirems*, and *rads.*

The *curie*, named after the scientists Marie and Pierre Curie, describes the intensity of a sample of radioactive material in terms of atoms of the material that decay each second. This rate — 37 billion atoms per second for one gram of radium — is the basis of this measurement.

A *rem* is a measurement of the effects of radiation on the body, much as degrees Celsius are measurements of the effects of sunlight heating sand on a beach.

The unit used most often to measure the radiation exposure for a person is the *millirem* (mrem). It is one-thousandth of a rem. The millirem is used because usually very small amounts of radiation are being measured.

A *rad* is the unit of measure for the physical absorption of radiation. Much like sunlight heats pavement by giving up energy to it, radiation gives up rads of energy to objects in its path. The international units of absorbed dose are sieverts and grays.

Metric Prefixes Used With Radiation Units:

milli- $^1/_{1,000}$ (thousandth)

micro- $^1/_{1,000,000}$ (millionth)

nano- $^1/_{1,000,000,000}$ (billionth)

pico- $^1/_{1,000,000,000,000}$ (trillionth)

Amounts We Receive

Most Americans receive about 360 mrem per year from all sources of radiation, including radon and medical exposure. About 40 mrem per year comes from the natural radioactivity in our own bodies. Most of our natural background radiation comes from cosmic radiation from outer space and from radioactive materials in the earth's rocks and soil.

Radon is a naturally occurring radioactive gas that results from the decay of radium. Radon is the single largest source of radiation exposure. On average, radon accounts for 200 mrem of our exposure each year.

The actual amount of background radiation depends on the location, elevation, rock and soil content, and weather conditions. For example, a person living on the Atlantic coast receives about 65 mrem of natural background radiation per year, while a person in Denver, Colorado, receives about 125 mrem, excluding radon. The difference in the natural background radiation is due in large part to Denver's higher elevation. The higher the elevation, the thinner the atmosphere, meaning that the atmosphere filters out less cosmic radiation. Naturally radioactive minerals in the rocks and soil also add to the higher level of background radiation.

We are also exposed to man-made sources of radiation, principally dental and medical x-rays, medical tests, and radiotherapy used in treating disease. About 15%, or about 50 mrem, of the radiation exposure that the average American receives comes from medical sources.

Tools To Measure Radiation

Ionizing radiation cannot be detected by our senses. However, we can measure and monitor it with simple scientific instruments. Three commonly used devices are dosimeters, film badges, and Geiger counters.

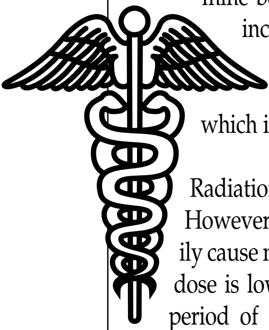
People who routinely work with or around radiation sources wear dosimeters or film badges. These include workers in medicine, research, industry, and nuclear energy. Thermoluminescent dosimeters contain a special semiconductor that becomes energized when it is exposed to radiation. Film badges contain a piece of film that is sensitive to radiation. These badges are read regularly to determine a worker's total exposure to radiation over a period of time.

Geiger counters measure radiation levels at a given time.

To measure radiation levels at any given time, a Geiger counter is used. A Geiger counter contains a special gas-filled tube that separates two electrodes. When radiation passes through the tube, it interacts with the gas, causing an electrical pulse that can be measured on a meter or by audible clicks. The number of pulses in a given time is a measure of the intensity of radiation.

The Health Effects of Radiation

Radiation is one of the most widely studied of all natural phenomena. Scientists understand the health effects of high levels of radiation. However, the effects of low levels of radiation are more difficult to determine because the major effect is a very slight increase in cancer risk. But because so many other factors also increase the risk of cancer, it is difficult to know which is the cause in many cases.

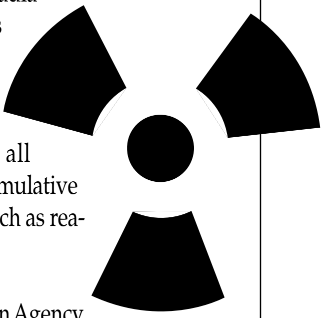


Radiation can chemically change living cells. However, cell transformation does not necessarily cause noticeable health effects. If the radiation dose is low, or a person receives it over a long period of time, the body can usually repair or replace the damaged cells without any detectable health effects.

Exposure to high levels of radiation can cause serious health effects, including burns, cell damage, and death. The degree of the effect depends on the intensity of the dose, the length of the exposure, and the type of body cells exposed. Sudden large doses exceeding 100,000 mrem can cause radiation sickness, with short-term symptoms including nausea, vomiting, extreme tiredness, and hair loss. Long-term effects include increased cancer risks. A dose of over 500,000 mrem at one time is usually fatal unless medical treatment is available.

Radiation Limits

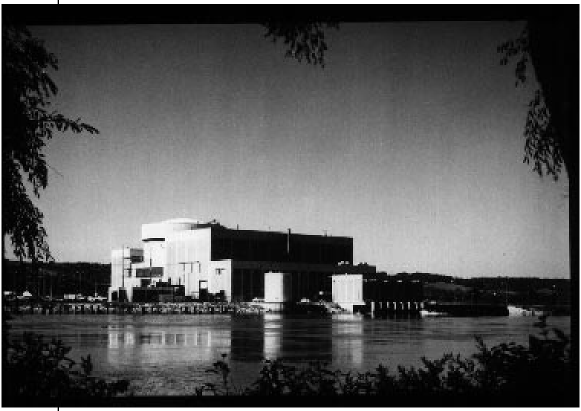
Government regulations limit the amount of man-made radiation that the public may receive. Most people in the United States receive radiation doses of about 25,000 mrem over their entire lifetimes. Most scientists believe that radiation absorbed in small doses over several years is not harmful. However, U.S. Government regulations assume that the effects of all radiation exposures are cumulative and should be limited as much as reasonably possible.



The Environmental Protection Agency limits the amount of radiation the general public may receive from the nuclear fuel cycle. This amount is limited to an annual exposure of 25 mrem in addition to the natural background and medical radiation normally received. For people working in an occupation that involves radiation, regulations forbid exposures above 5,000 mrem in any one year.

Nuclear Power Plants

Nuclear power plants are fueled by uranium. Uranium is used because, under precise conditions, its atoms can be split apart to release large amounts of energy in the form of heat. This process is known as *nuclear fission.* In a nuclear reactor, uranium atoms are split apart in a controlled, continuous process called a *chain reaction.* The heat from the chain reaction inside the reactor is used in a power plant to turn water into steam, which drives a turbine-generator to produce electricity.



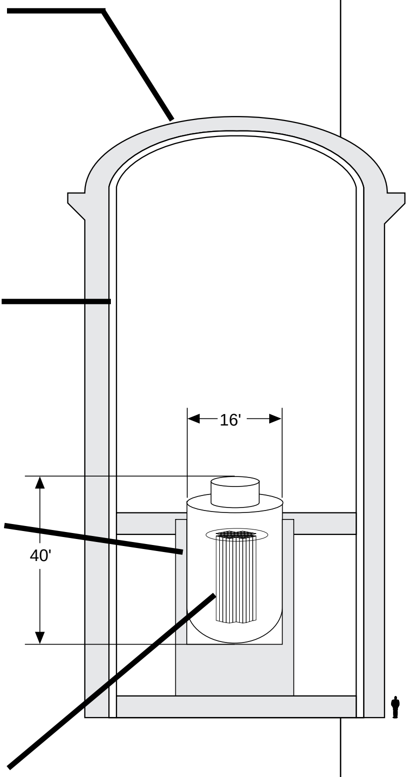
Fort Calhoun Plant (Omaha Public Power District) is shown

The nuclear fuel inside an operating nuclear reactor is highly radioactive. For this reason, these radioactive materials are sealed inside ceramic, encased in metal, and held inside a heavy steel reactor vessel during operation. Nuclear power plants also have multiple protective barriers, including a massive concrete-and-steel containment building. These barriers prevent the radioactive materials inside the reactor from entering the environment in the event of an accident.

Radiation limits for nuclear power plants have been established by the Nuclear Regulatory Commission, an independent Government agency. To be licensed for commercial operation, nuclear power plants must limit the maximum annual radiation exposure at the plant's boundary to no more than 10 mrem above the natural background radiation level. In practice, however, nuclear power plants release only a tiny fraction of the amount permitted by regulations.

Nuclear power plants have generated electricity commercially for over three decades. Nuclear power plant safety compares favorably with other methods of producing electricity.

Nuclear Power Plant Safety Barriers



Using Radiation

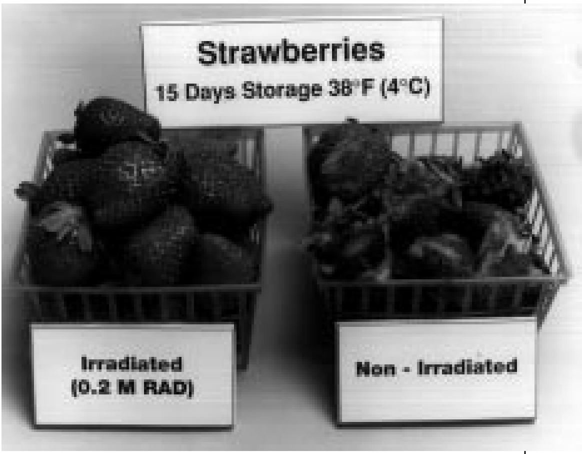
Radiation is one of the many natural energy forces that has been used to benefit humanity. With it, major contributions have been made possible in the fields of medicine and industry. However, its use requires special precautions, such as protective barriers and careful transportation regulations.

Medical and dental x-rays have been used for over 50 years to diagnose broken bones and tooth decay. Carefully focused radiation can destroy cancer cells without causing major damage to healthy cells nearby. Radioisotopes and computer imaging devices allow doctors to examine internal organs that are not normally visible by x-rays.

Shannon Seals, a nuclear pharmacist at Syncor International Corporation, prepares a radiopharmaceutical. Seals, who manages a facility, says demand is rapidly growing for radiopharmacists.

It is now standard practice to use radiation to sterilize medical products such as syringes. Radiation may also be preferable to heat for sterilizing bandages and ointments, which can be damaged by high temperatures.

In industry, radiography is used in much the same way as doctors use x-rays. This technique is used to locate defects in metal casings and welds that might not show up otherwise, and to determine microscopic thicknesses of materials such as metal foils. Radiography can also be used to locate structural defects in statues and buildings.



Radiation helps prevent certain foods from spoiling.

Radiation has applications in a variety of other fields. We use it to test the authenticity of art and date prehistoric objects accurately. We also use it to prevent certain foods from spoiling without significantly reducing the nutritional value, or making the food radioactive.

Courtesy of The Frank H. McClung Museum, The University of Tennessee, Knoxville.

Archaeologists have found successive layers of Indian occupation buried in the river bottoms of Tennessee. Within these layers are abundant fragments of carbonized wood and hickory nut shell. By radiocarbon dating the fragments of charcoal in each layer, historians can establish a chronnogy of settlement. The bottom of this excavation dates to 7500 B.C..

Radiation: A Natural Energy Force

Radiation has been a part of our environment since the earth was formed. Yet, we have only learned of its existence in the last century. Through research and education, we have learned about its effects and potential hazards. We understand the need to monitor and control the amounts of radiation we receive. We also understand that radiation can be beneficial and improve our quality of life.

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

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

U.S. Department of Energy

Printed on recycled paper