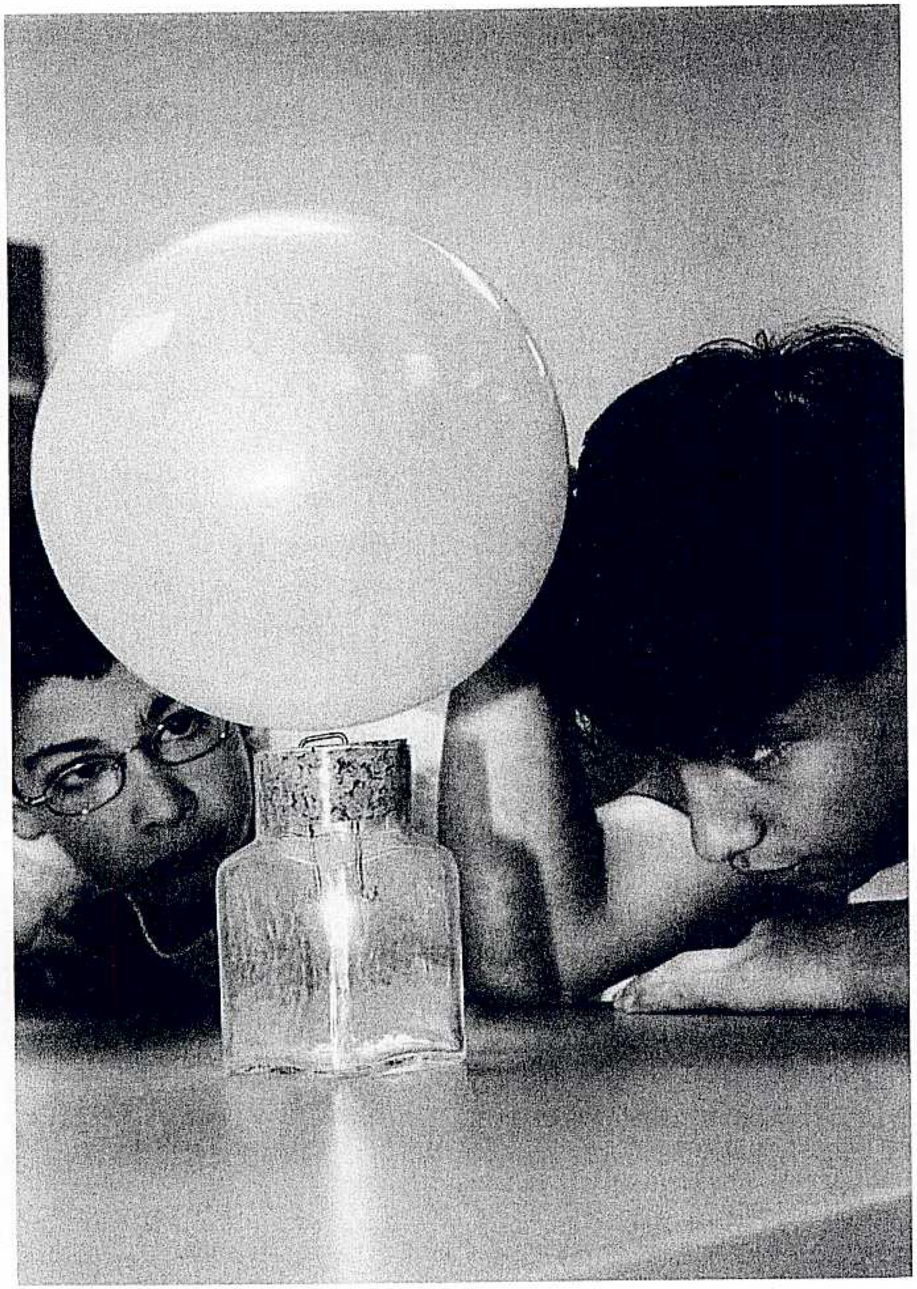


What Is Radiation?

The German physicist Wilhelm Conrad Roentgen discovered X-rays while experimenting with a glass vacuum tube in 1895. He covered the tube with black paper and passed an electric current through the tube. A dark image appeared on a photographic plate nearby.

Roentgen assumed that unknown, invisible rays were coming from the vacuum tube and darkening his photographic plates. The rays passed easily through the paper covering the tube. What other materials would they penetrate?

Roentgen tried to block X-rays and found that some materials worked and some did not. The bones of a human hand blocked the rays, but the soft parts or flesh of a hand did not. He found he could photograph the bone structure of his wife's hand with the rays.

Roentgen called his discovery *X*-rays because he could not identify them.

Roentgen's discovery won him the 1901 Nobel Prize in physics, revolutionized medicine, and opened the door to future advancement in physics.

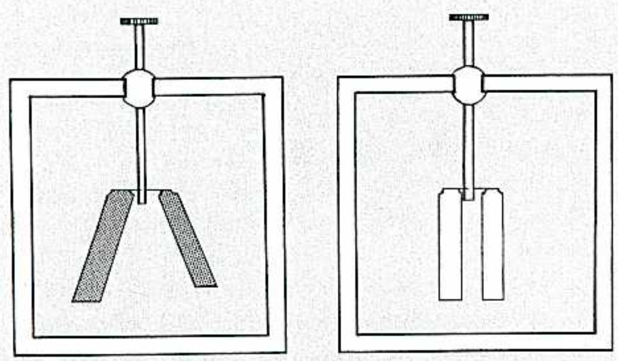
X-rays proved to be important not only in medicine, but also in giving scientists new insights into the nature of radiation and the structure of the atom. Scientists soon found that X-rays made ions of the atoms in air. Because of this, we call X-rays *ionizing radiation.*

Radiation is any energy or particle that comes from a source and travels from one place to another. Sunlight, sound waves, and microwaves are types of radiation. The high-energy kind of radiation produced by X-ray machines or given off by radioactive elements is *ionizing radiation.* Sunlight, sound, and microwaves do not make ions. They are nonionizing. In this pamphlet, the term "radiation" generally means ionizing radiation.

Radioactivity in Nature

Henri Becquerel, a French scientist, discovered that uranium, like X-rays, would fog a photographic plate. Uranium made rays of its own. In 1898, Marie Curie named this property *radioactivity.* A radioactive element gives off charged particles, or rays.

Becquerel wanted to know if the radiation from uranium caused ions in air like X-rays. To find out, he created a box with two metal leaves hanging from a metal rod. If the rod or bar is charged with electricity, the metal leaves will become charged. Because the same types of electrical charges repel each other, the leaves will repel each other and stand apart. Becquerel named his invention the *electroscope.*

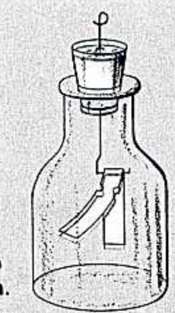


An electroscope can detect ionizing radiation.

If the air in the electroscope becomes ionized, the charge will leak out of the leaves. Becquerel found that uranium brought near the electroscope would discharge it. This told him that uranium radiation was ionizing radiation.

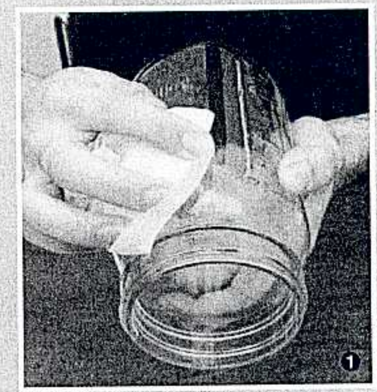
In 1910, Theodore Wolf, a French Jesuit priest, used an electroscope to show that radiation is all around us every day.

Build an Electroscope

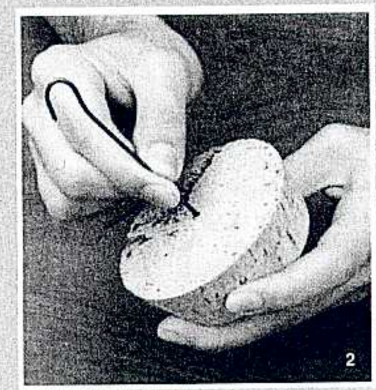


Build an electroscope to detect ionizing radiation.

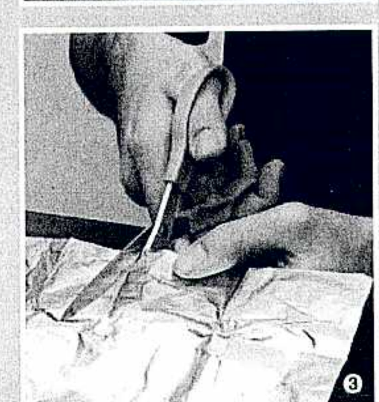
Step 1—Choose a bottle with a medium-width mouth and a cork or stopper that fits. Clean and dry the bottle.



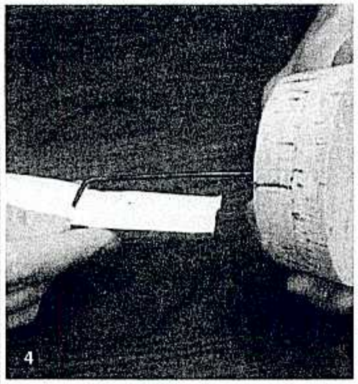
Step 2—Remove the paint from a 6-inch piece of coat hanger wire. Bend a loop in the top and push the wire carefully through the bottle cork or stopper. Bend the end of the wire into a ½-inch-long hook or L.

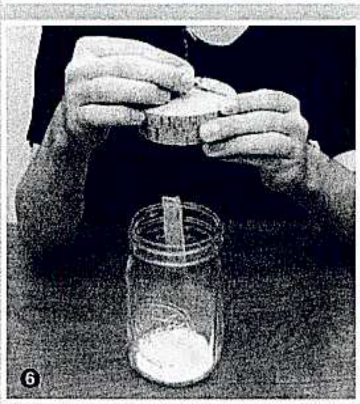


Step 3—Cut a strip of thin aluminum foil ½ inch wide and 6 inches long. Fold the strip in half. Cut notches into the fold to make the leaves flexible.



If you need a source for the thorium gas lantern mantle required for building an electroscope, try contacting Gas-Lights.com. Call toll-free 877-409-1618, or visit the company's Web site (with your parent's permission) at *http://www.gas-lights.com.*





Step 4—Glue the fold onto the wire hook. Do not use much glue. Be sure the foil touches the wire.

Step 5—Heat a spoonful of table salt in an oven at 350 degrees, then drop the salt into the dry bottle. This will absorb moisture from the air in the bottle.

Step 6—Insert the stopper tightly. Push the wire down until the foil leaves are about ½ inch from the bottom.

To use your electroscope:

Step 1—Comb your hair with a plastic comb and touch the comb to the wire's top loop. This gives the leaves electrical charges alike. They will repel each other. As they lose their charge, they will come back together. This process takes about five minutes.

Step 2—Obtain a piece of a gas lantern mantle made with thorium, a radioactive material.

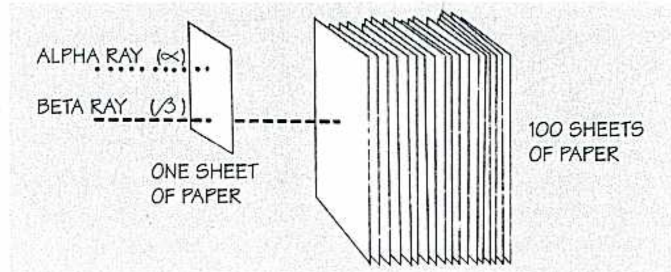
Step 3—Put the piece of mantle into the electroscope and charge it as before.

Step 4—Compare the amount of time it takes to discharge the electroscope with the radioactive material in it and without the radioactive material. Does thorium radiation discharge the electroscope?

Hint: If you ionize the air, the charge will leak faster. Radiation will ionize air.

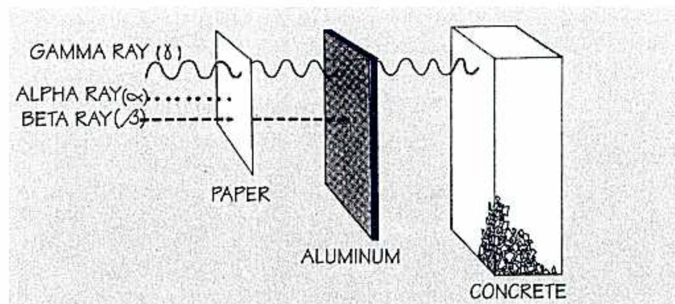
Types of Radiation

Ernest Rutherford found that uranium had two types of radiations. One type, which he named *alpha rays,* would not go through a sheet of paper. The second kind, *beta rays,* was more penetrating. One sheet of paper would stop an alpha ray, but it took a hundred sheets to stop beta rays.



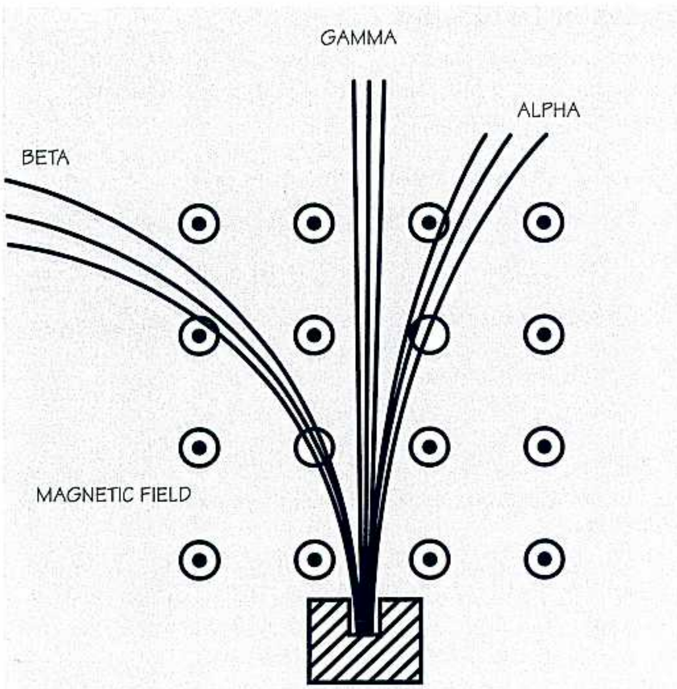
Rutherford found that beta rays were more penetrating than alpha rays.

In 1900, Paul Villard of France discovered a third type of radiation that was far more penetrating than beta rays. He called this radiation *gamma rays.* We now know that these rays are similar to radio waves, light, and microwaves. The difference is that gamma rays have much more energy.



Gamma rays are the most penetrating kind of natural radiation. Thick concrete or lead is needed to stop them. In 1914, Rutherford showed that gamma rays and X-rays act alike.

More work showed that alpha rays and beta rays are tiny pieces of atoms. They are more accurately called *alpha particles* and *beta particles.* Alpha particles are made up of two protons and two neutrons, identical to the nuclei of helium atoms. Beta particles are free-flying electrons.

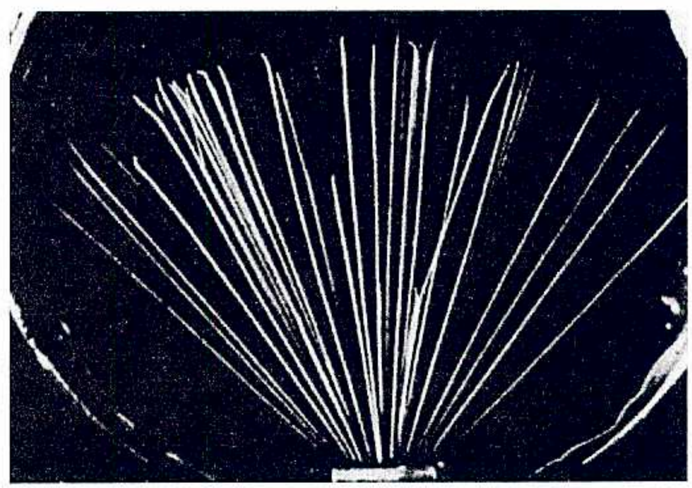


In 1903, Marie Curie pictured how radiation is bent by magnets. The paths of alpha particles (positively charged) are bent one way, and the paths of beta particles (negatively charged) are bent the opposite way.

In 1903, Marie and Pierre Curie isolated a new radioactive substance they called *radium.* To describe the amount of radiation given off by any material, scientists needed a new unit. They called it the *curie* after the famous researchers. One curie (Ci) of a radioactive substance will give off 37 billion radiations each second, an amount equal to the activity in 1 gram of radium. Scientists now more commonly use the much-smaller *becquerel* (Bq) as a unit for measuring radioactivity: 37 billion becquerel equal 1 curie, and 1 becquerel equals 1 decay (disintegration) per second.

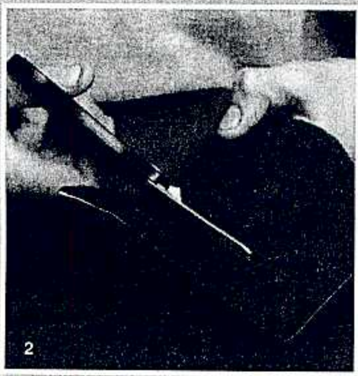
Antoine Henri Becquerel (1852–1908), a French physicist, experimented with phosphorescent uranium salts to determine if they gave off X-rays. He discovered instead their natural radioactivity. In 1903, he was awarded half of the Nobel Prize in physics for his discovery. (The other half went to Marie and Pierre Curie.) The unit used to measure small amounts of radioactivity is called the becquerel in his honor.

Marie Curie (1867–1934), born in Poland, became the first European woman to receive a doctorate in a scientific field. The first person to use the term *radioactive,* Curie also ranks as the first winner of two Nobel Prizes: in physics, in 1903, for the work she and her husband, Pierre, did on Becquerel's discovery; and in chemistry, in 1911, for her discovery of the elements polonium and radium. After years of radiation exposure during research, Curie died of leukemia at age 67.



A cloud chamber is a clear-sided vessel containing water vapor that shows the paths or tracks of electrically charged particles passing through. Shown here are alpha particle tracks.

Build a Cloud Chamber



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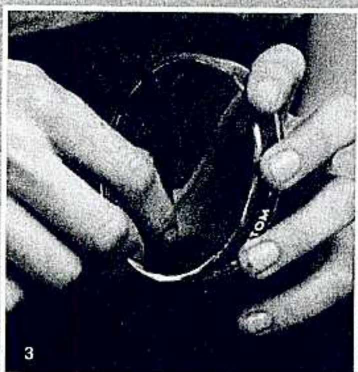
When radioactive elements decay, they emit high-speed alpha and beta particles, as well as gamma rays, all of which are too small for your eye—or even a microscope—to see. A cloud chamber will allow you to study the trails left behind by radioactive materials.

This activity can be created with household items, and you also can purchase an experiment kit made specifically to achieve the same results.*



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Step 1—Select a clear glass or plastic jar for the cloud chamber. It must have a tight-fitting cover and be leakproof.

Step 2—If creating your own cloud chamber from a container you have at home, glue a piece of dark-colored felt to the inside of the cover using a rubber-based glue. (If using the container from the cloud chamber kit, the dark-colored bottom will be fine.) Allow the glue to dry completely.

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Step 3—In the bottom of the container, glue another piece of felt, cut in a doughnut shape, using the same glue as in step 2. (The kit will come with a piece already sized for the experiment.) Again, let the glue dry completely.

Step 4—Use an eyedropper to saturate the felt in the bottom of the container with 91 percent isopropyl alcohol, and place a radioactive source (available at a rock or hobby shop) in the container.

*The cloud chamber kit is available through homeschooling supply stores, such as Home Training Tools, *http://www.hometrainingtools.com.*

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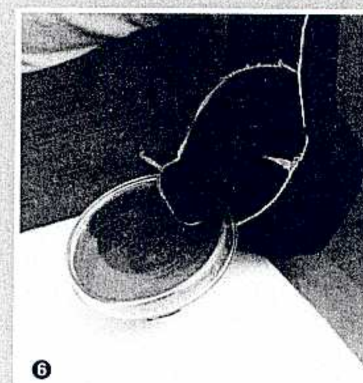
Step 5—Place the cover tightly on the container.

Always wear thick gloves to handle dry ice. Never handle it bare-handed, as it can severely damage skin. Also, wear eye protection if you need to shave the dry ice to make it level enough to support the container.



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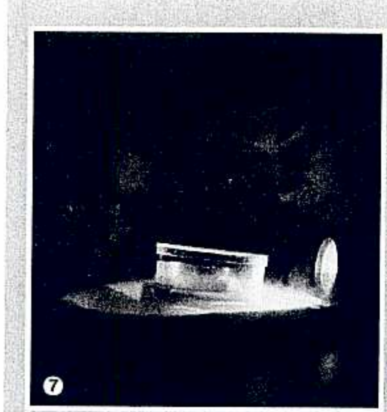
Step 6—Turn the container over so the dark colored side is on the bottom. Wearing thick gloves, set the container on a cake of dry ice (solid carbon dioxide).

Step 7—Direct an intense, well-focused light beam at the jar. A well-focused light source from a microscope works well. A flashlight can sometimes be used successfully if the beam is intense enough and sufficiently well-focused. The light beam should be no more than 1 to 1¼ inches in diameter.



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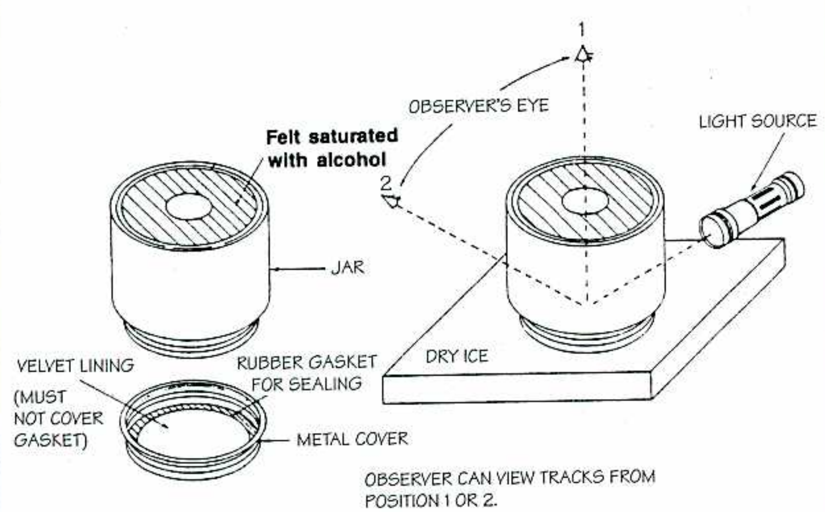
Step 8—Examine the fog, which should be falling like rain. Near the bottom, which should be near the temperature of dry ice (-77 degrees Celsius), short tracks should form, showing the paths of electrically charged particles passing through the cloud chamber.

If the cloud chamber fails to show any rain (precipitation), either the bottom of the container is not cold enough or there is too little alcohol. If there is a steady rain but no tracks, check the container for leaks. If there is no air leak, there might be a chemical contamination from the felt or the glue. This can sometimes be corrected by airing out the jar for a day, but you probably will have to start over to achieve the desired results.

Step 9—Hold a magnet up to the container and observe its effect on the tracks. Note the pole markings on the magnet.



Radioisotopes and Half-Life

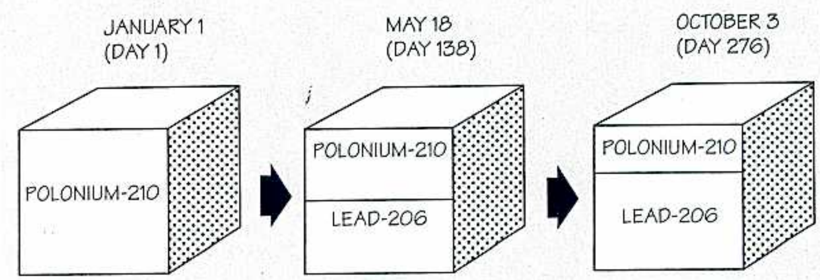
Atoms that have too much energy are unstable. They give off the extra energy to become stable. Atoms that give off energy (radiation) are called *radioisotopes*.

Rutherford found that radioactive materials get less radioactive as they get older. The radioactive nuclei change into stable (nonradioactive) nuclei as they give off radiation, a process called *radioactive decay*.

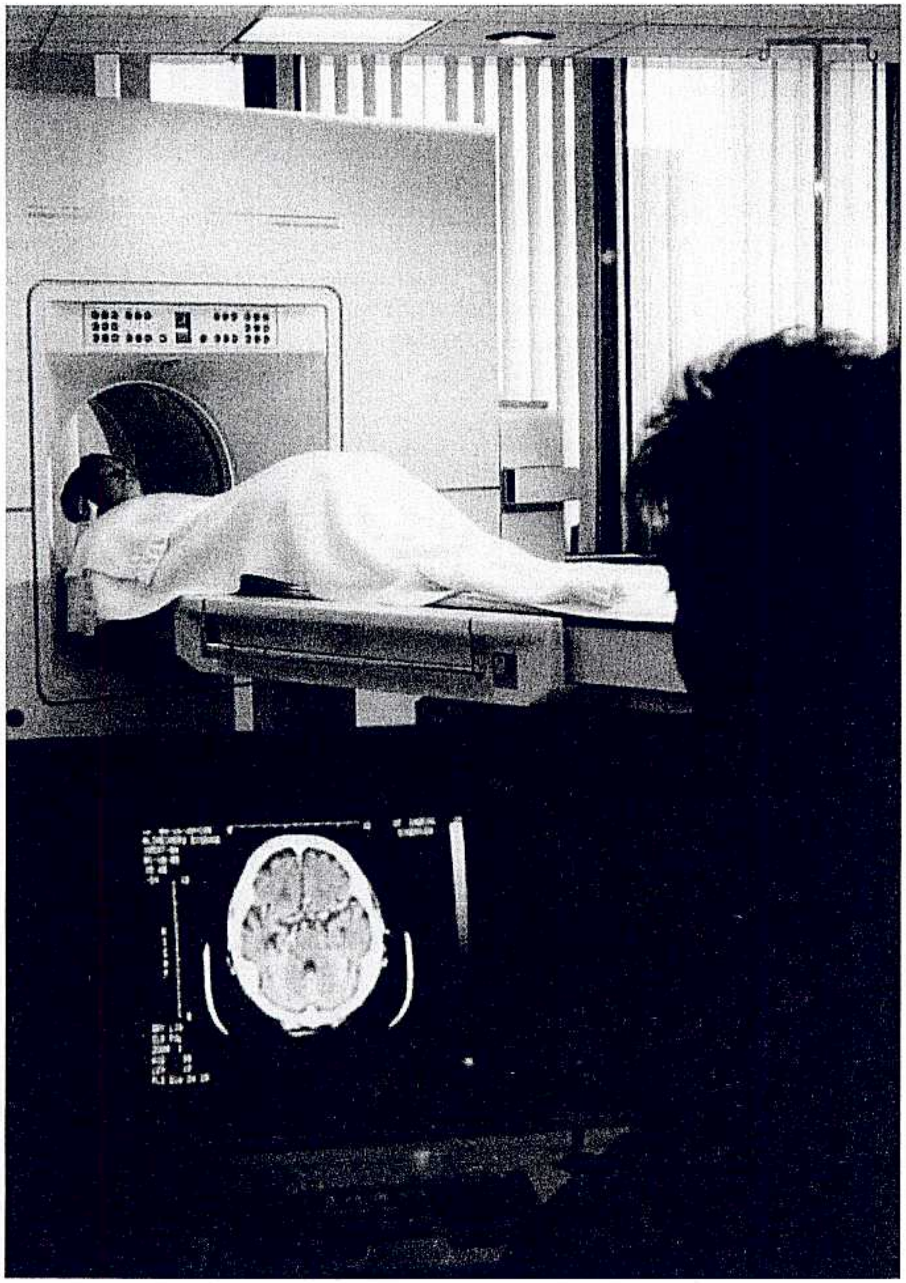
Decay—the transformation of a radioactive element into a different element by giving off particles—leads to a less energetic, more stable nucleus.

Rutherford called the amount of time it takes an element to lose one-half of its radioactivity its *half-life*. Different radioactive elements have different half-lives. The half-life of iodine-131 is eight days; strontium-90, 29 years; uranium-238, 4.5 billion years. Nobelium-251 has a half-life of less than one second.

Of the 111 known elements, there are about 2,500 isotopes; almost all are radioactive. Scientists estimate there are at least another 1,500 yet to be discovered.



Polonium-210 changes to lead-206 with a half-life of 138 days.

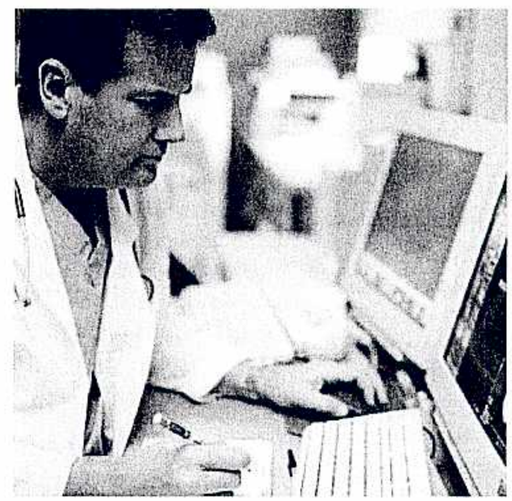


Putting Radiation to Work: Nuclear Technologies

We use radiation in many forms, both natural and manufactured, for many different purposes. From medical X-rays and cancer treatments to investigating crimes, choosing where to drill for oil, inspecting airline luggage, and powering scientific instruments onboard space probes, nuclear technologies are among our most versatile tools.

Radiation in Medicine

Radiation is used so widely for medical diagnosis and treatment that virtually every U.S. hospital has some form of nuclear medicine unit or *radiology* (X-ray) department. Physicians use X-ray pictures of the bones and internal organs to look for injuries and diseases, such as broken bones or lung disease, inside a patient's body. Dentists use X-ray pictures to reveal cavities and other problems in teeth.



X-rays are made the same way today as Roentgen made them in 1895. Electrons are shot through a vacuum tube and, when they hit a metal plate, X-rays are given off.

Visit an X-ray Room

Make arrangements with your counselor to visit an X-ray room. Talk with the operator about his or her job. Be sure to ask the operators about the precautions taken when X-ray is used, including using the principles of time, distance, and shielding to keep their radiation dose *as low as reasonably achievable* (ALARA).

In an X-ray room, the operators stand behind a shield of leaded material, with a leaded glass window for observing the patient, so they do not get radiation exposure with every patient.

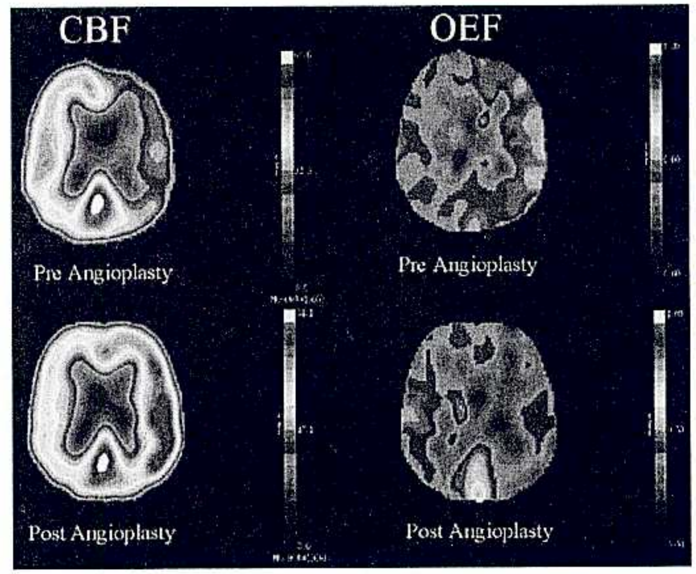
Nuclear Medicine

Nuclear medicine uses small amounts of radioactive substances or *tracers* for diagnosing various diseases. The tracers are injected, inhaled, or swallowed; then they travel through the body to the organ or tissue being examined. Different kinds of tracers are taken up mainly by one organ or cell type in the body. Radioactive iodine (iodine-131), for example, collects in the thyroid gland. Strontium-85 is a bone seeker. Different forms of technetium-99 are used for brain, bone, liver, and kidney imaging.

Special cameras detect the radiation emitted by the tracer and produce pictures or images of the organ or tissue on a computer screen or photographic film. From the images, physicians can see how well the organ or organ system is working. They may also spot tumors, areas of infection, or other problems.

Radiation Therapy

Radiation therapy uses high-energy radiation (X-rays) to treat cancer. The radiation destroys the cancer cells' ability to reproduce, and the body naturally gets rid of the weakened cells. Damage to normal body cells are minimized. Types of cancer that often are treated with radiation therapy include cancer of the larynx (the voice box) and prostate cancer.



A nuclear medicine technique that uses antimatter is positron emission tomography (PET). When a short-lived positron emitter such as oxygen-15 meets its matter counterpart, positron and electron annihilate each other in a detectable burst of energy. The PET image that results shows how well an organ, such as the brain, is functioning.

Doses of radioactive materials also can be used inside the body to treat diseases. Patients may swallow radioisotopes or get them in shots (injections). Other times, pieces of a radioisotope are surgically implanted. A small radioactive source inserted into a tumor can destroy cancer cells.

For thyroid disorders, such as Graves' disease, treatment with radioactive iodine is so successful that it has virtually replaced thyroid surgery.

Rosalyn Yalow (1921–), born in New York City, earned a doctorate in nuclear physics and, while working at the Bronx VA Hospital, developed the Radioisotope Service. This led to the 1950s development of *radioimmunoassay (RIA),* which measures tiny quantities of hormones, viruses, etc., in the blood, enabling doctors to detect problems such as hepatitis in blood banks. RIA has also made possible much of today's medical progress in diabetes research. Yalow won the 1977 Nobel Prize in physiology/medicine.

NASA astronauts eat irradiated foods in space to protect them from foodborne illnesses.

Radiation in Agriculture

Radioisotopes can be used to kill pests that destroy crops. Radioactive materials are used to preserve seeds and keep harvested crops from spoiling. With radiation, foods like potatoes can be preserved for long periods.

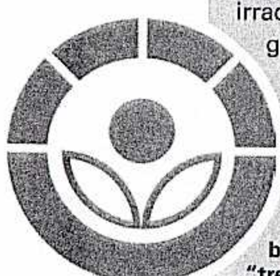
Nuclear technology methods can detect pollutants, pesticides, or fertilizers hidden in plants. By showing how plants absorb fertilizer, radioactive materials help researchers learn when fertilizer should be applied and how much is needed. This helps prevent the overuse of fertilizers, a major source of soil and water pollution.

Test Irradiated Foods

Treating foods with ionizing radiation kills harmful bacteria and parasites that can make people sick. Irradiation also can keep fruits and vegetables fresher longer. It gives potatoes a longer shelf life by keeping them from sprouting.

Three different types of ionizing radiation can be used on foods: X-rays, streams of high-energy electrons, or gamma rays. The radiation does not make food radioactive or less nutritious. Some treated foods may taste slightly different, just as pasteurized milk tastes slightly different from unpasteurized milk.

Many foods can be irradiated, including meat, poultry, grains, herbs and spices, and fresh produce. In the United States, some supermarkets sell irradiated produce and poultry. You can obtain a sample of irradiated ground beef, which has become available at a growing number of stores, for an experiment in irradiation. You can use either fresh or frozen irradiated ground beef. For comparison, also obtain a sample of nonirradiated ground beef in the same condition (fresh or frozen).



Irradiated foods are labeled with a symbol called the radura—simple green petals in a broken circle. The symbol is used worldwide to identify food that has been irradiated. The package also will have the words "treated by irradiation."

Grow Irradiated Seeds

For this experiment, barley seeds are best; wheat or oats are good. You can use any seeds, however. Select groups of 50 to 100 seeds for treatment. Remove especially big or small seeds and all broken, discolored, or misshapen kernels.

You and your counselor should take your seeds to a medical or industrial X-ray source. Many medical professionals (dentists, hospitals or clinics, chiropractors) have X-ray machines in their offices and may conduct the irradiation for you.

Ask your counselor and the operator to help you calculate the time for seed exposure. Be sure the seeds are spread in an even layer when irradiated.

Plant and grow your treated seeds and an untreated control group under the same conditions. Use shallow boxes and soil rich in nutrients. Keep the seeds warm (60 to 70 degrees Fahrenheit) and moist (not soggy).

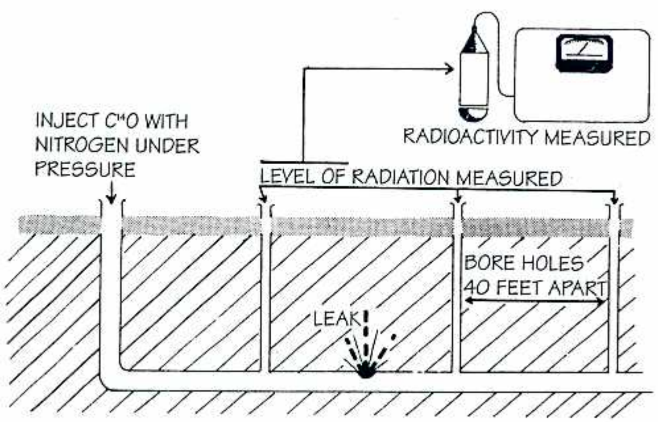
List any differences you observe during a 30-day period. After the first seven to 10 days (for barley or wheat), cut off at the soil line a sample of plants from each group. Measure the height of the plants. Dry both samples at 150 degrees Fahrenheit overnight. Weigh both groups and compare. What did irradiation do to your seeds? Compare the dose to background radiation doses, and compare the effects on the plant to effects this dose would induce in humans.

Learn About Radioisotopes at Work

With your counselor, contact a place where radioisotopes are used, such as a research laboratory, mining site, college or university, hospital or medical center, construction project, oil refinery, or food preparation facility. Visit the facility and make a drawing to help you explain how and why radioisotopes are used there.

Radiation in Industry

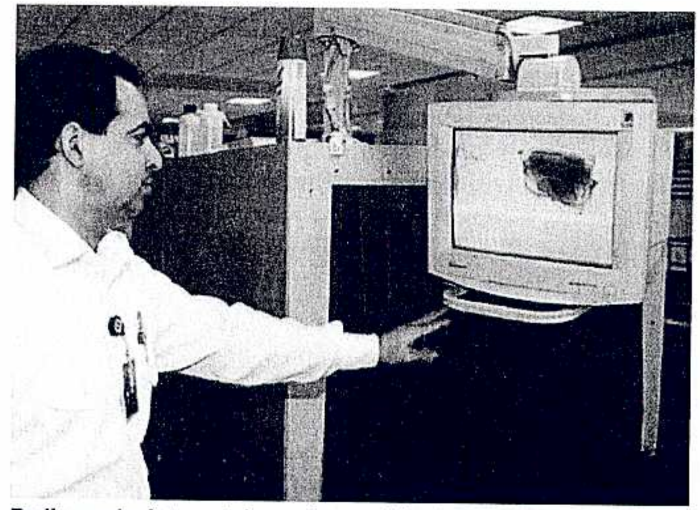
Industry uses radioisotopes in developing new products and devices. Radioisotopes have been used in devices to measure the levels of liquid in a tank, the thickness of metals or plastics, the wear on machine parts, or the mixing of two substances. Radiation is used to sterilize baby powder, bandages, contact lens solution, and many cosmetics.



Small amounts of radioactive substances are commonly used as tracers in industrial applications. Radioisotopes can be added to buried pipes to find leaks or to track the path of the pipe.

X-rays also are used in industry. To check the strength of a weld, for example, X-rays are aimed at the weld with a film on the opposite side. Any dark place in the film shows a weakness in the weld. If no dark spots show up, the weld is OK.

This technique of taking pictures *(radiographs)* with X-rays is a versatile and reliable method of inspection to determine a material's strength or to check for flaws. It lets inspectors see inside materials without taking them apart. This works the same way Roentgen x-rayed his wife's hand or your doctor checks you for broken bones.

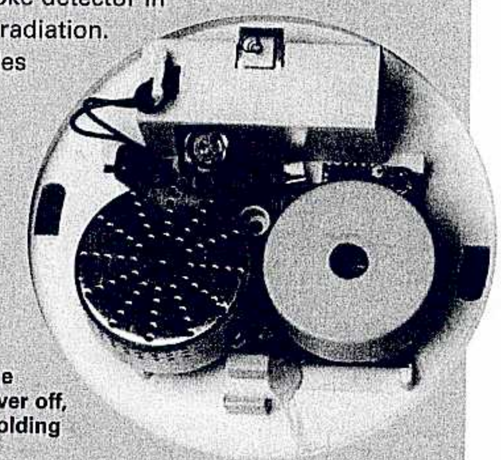


Radiography lets us take a picture of the inside of things without cutting them open.

Smoke Detectors

A common type of smoke detector uses a radioisotope to make a stream of alpha particles. Alpha particles ionize smoke particles when they enter the detector. When the detector senses ionized smoke particles, it sounds the alarm. Because alpha particles can travel only a short distance in air, having a smoke detector in your home gives you virtually no radiation.

Smoke detectors use alpha particles within a chamber to ionize the air between two conducting plates. When smoke enters the air in the chamber, the conductance of the air between the two plates is decreased, and the current is affected. This change in current causes the alarm to go off.



A smoke detector is one example of the beneficial use of radiation. With the cover off, you can see the protective container holding the radioactive americium source.