# Nuclear Science: Going Beyond Chemistry

Science began when humans first sought to understand nature as the interactions of forces and matter. What causes seasons? What are stars? Why do we get sick? These questions once were dismissed as mysteries: Deities or spirits caused things to happen for reasons people could not understand. Science proposes to understand nature's materials and processes so we can predict and control events in our lives.

Over 2,000 years of science, researchers learned principles of matter and how it behaves. Within the last 200 years, we discovered that all substances are made of about 100 elements—each made of a unique kind of atom. Studying the characteristics of atoms and their interactions became the field of chemistry.

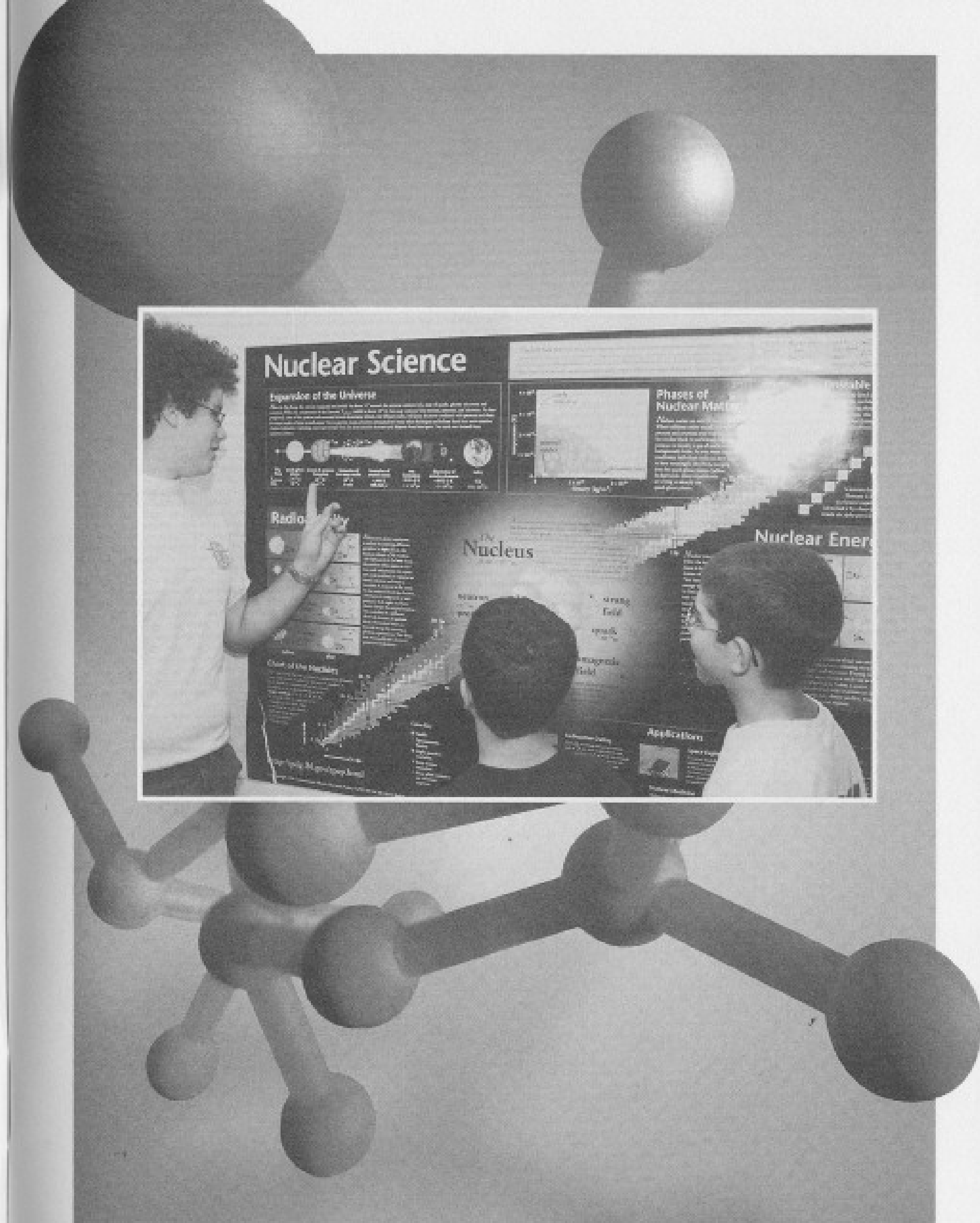
Physicists continued to try to understand the structure of atoms. They learned that all atoms are made of a few *subatomic* particles. Some atoms transform and give off *radiation*. Investigators moved atoms around using electrical charges and shot atoms or parts of atoms into each other, broke atoms down, and built them up. They built huge machines to break atoms apart to study their subatomic particles.

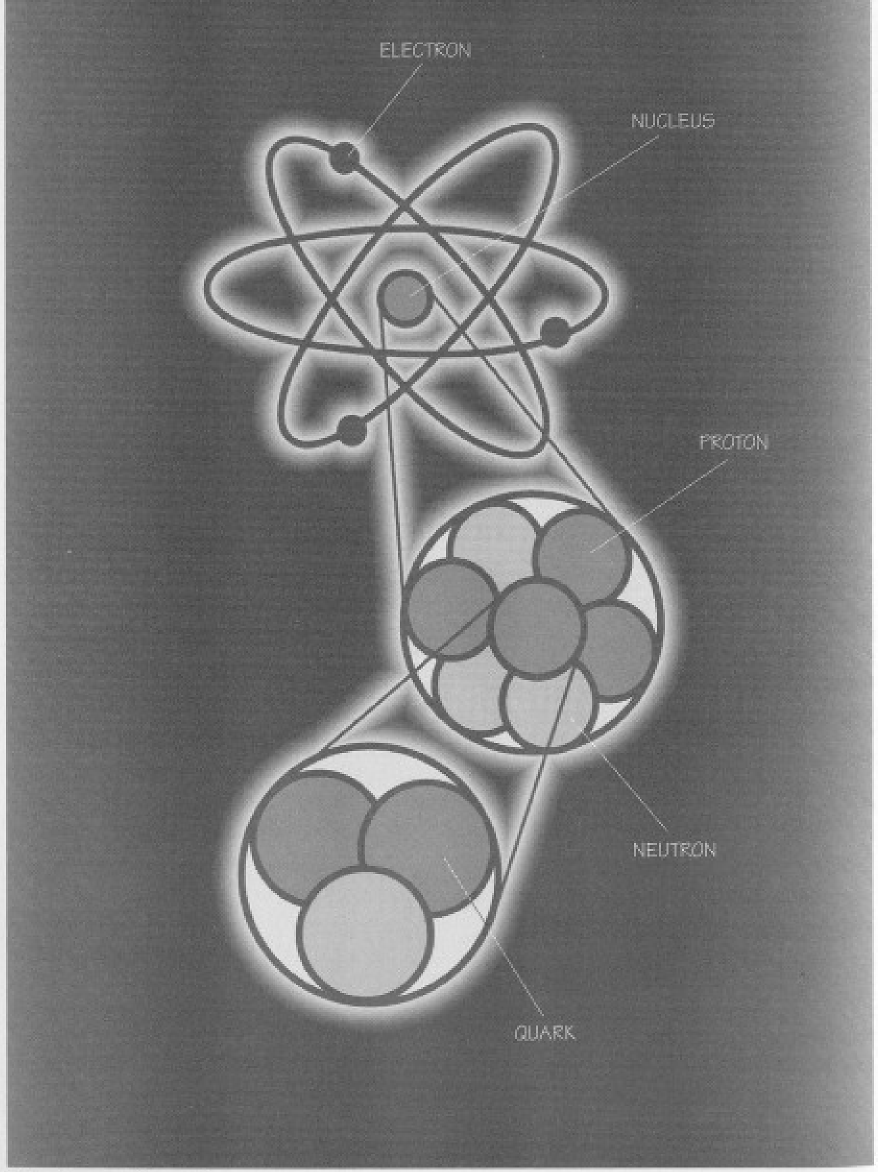
The study of atomic structure is still a part of the field of nuclear science. Nuclear science also

- Investigates natural and manufactured radiation—how they are produced and their practical uses
- Explains the principles applied to protect people from radiation
- Examines how atomic nuclei behave when they join together or split apart
- Seeks to understand the processes that occurred at the very beginning of the universe

Just as with science in general, nuclear science gives us a simpler—and at the same time more interesting—explanation of the natural world. The ultimate goal of nuclear science is to find out if there is one fundamental rule that explains how matter and forces interact. Earning the Nuclear Science merit badge is a chance for you to learn about this exciting field at the cutting edge of science today.

> It doesn't take a nuclear physicist to understand the basics of nuclear science. A little background in chemistry and physics will help, but even for the nonscientific Scout, the Nuclear Science merit badge lies well within grasp.






**Structure of an atom**

# Atoms Then and Now

The first scientists to discuss atoms were Greeks who lived about 400 B.C. A Greek teacher, Leucippus, taught his students about atoms. His most famous student was Democritus. The Greeks believed that if you cut a piece of copper, and cut it again and again many times, you would finally end up with a piece of copper that could not be cut. This would be an *atom* of copper.

Democritus believed (mistakenly) that atoms were held together by little hooks.

An *atom* is the smallest piece or unit of an element having the properties of that element. *Elements* are fundamental substances that can't be broken into simpler substances by chemical means. Familiar elements include hydrogen, oxygen, iron, and gold. Each element consists of one basic kind of atom.

Many early scientists and philosophers did not believe the theory of atoms. Even Aristotle, one of the greatest thinkers in history, said there was no such thing. But the idea would not go away. The Roman philosopher Lucretius (circa 99–55 B.C.) wrote about nature and mentioned atoms in his Latin poem called *De Rerum Natura (On the Nature of Things)*.

Many scientists wrote in poems because there were few books, and poems were easier to remember.

Centuries passed, and atoms remained a part of scientific thought. In the 1500s and 1600s, well-respected men like Copernicus, Galileo, Francis Bacon, and Sir Isaac Newton began to disagree with the great Aristotle. They believed that atoms exist.

## John Dalton's Theory of Atoms

By 1803, an English schoolteacher had done much work to prove that atoms exist. He was the first to show how atoms work and to estimate the relative masses of different atoms. He added much to what scientists knew. John Dalton used his theory of atoms to explain how chemical reactions work.

Atoms are the smallest bit of an element. Different elements have atoms of different masses. (*Mass* is the quantity of matter that something contains. Your mass is always the same, while your weight might change if you go to a different place. In space, for instance, your weight would be zero, but your mass would be the same as it is on Earth.)

Amedeo Avogadro was an Italian who came up with a better way of measuring the mass of atoms. He showed that Dalton was on the right track but had made mistakes. Avogadro was a good scientist but not a good writer. Nobody understood much about his work until another Italian, Stanislao Cannizzaro, explained Avogadro's work in 1858.

What Avogadro discovered the hard way in the 1800s—that scientists must be able to write clearly if they want others to understand their findings—is still true today.

Cannizzaro also added a new word to science: *molecule.* A molecule is what forms when atoms combine.

By the 1870s, scientists everywhere were studying atoms. In Russia, Dmitri Mendeleev put all atoms on a chart and showed that atoms could be divided into groups according to their similarities. Some of his ideas were wrong, but other scientists corrected his chart, and today it is known to scientists and students as the highly useful *periodic table* of the elements.

The periodic table of the elements lists all the elements arranged by atomic number. Elements are grouped to show similar chemical characteristics.

- Alkali metals
- Alkaline earth Metals
- Transitional metals
- Lanthanide series
- Actinide series
- Other Metals
- Nonmetals
- Noble gases

| | I A | II A | III B | IV B | V B | VI B | VII B | VIII B | VIII B | VIII B | I B | II B | III A | IV A | V A | VI A | VII A | VIII A |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 H 1.01 Hydrogen | | | | | | | | | | | | | | | | | 2 He 4.00 Helium |
| 2 | 3 Li 6.94 Lithium | 4 Be 9.01 Beryllium | | | | | | | | | | | 5 B 10.81 Boron | 6 C 12.01 Carbon | 7 N 14.01 Nitrogen | 8 O 16.00 Oxygen | 9 F 19.00 Flourine | 10 Ne 20.18 Neon |
| 3 | 11 Na 22.99 Sodium | 12 Mg 24.31 Magnesium | | | | | | | | | | | 13 Al 26.95 Aluminum | 14 Si 28.09 Silicon | 15 P 30.97 Phosphorus | 16 S 32.07 Sulfur | 17 Cl 35.45 Chlorine | 18 Ar 39.95 Argon |
| 4 | 19 K 39.10 Potassium | 20 Ca 40.08 Calcium | 21 Sc 44.96 Scandium | 22 Ti 47.88 Titanium | 23 V 50.94 Vanadium | 24 Cr 52.00 Chromium | 25 Mn 54.95 Manganese | 26 Fe 55.85 Iron | 27 Co 58.93 Cobalt | 28 Ni 58.70 Nickel | 29 Cu 63.55 Copper | 30 Zn 65.39 Zinc | 31 Ga 69.72 Gallium | 32 Ge 72.61 Germanium | 33 As 74.92 Arsenic | 34 Se 78.96 Selenium | 35 Br 79.90 Bromine | 36 Kr 83.80 Krypton |
| 5 | 37 Rb 85.47 Rubidium | 38 Sr 87.62 Strontium | 39 Y 88.91 Yttrium | 40 Zr 91.22 Zirconium | 41 Nb 92.91 Niobium | 42 Mo 95.94 Molybdenum | 43 Tc (98) Technetium | 44 Ru 101.07 Ruthenium | 45 Rh 102.91 Rhodium | 46 Pd 106.4 Palladium | 47 Ag 107.87 Silver | 48 Cd 112.41 Cadmium | 49 In 114.82 Indium | 50 Sn 118.71 Tin | 51 Sb 121.74 Antimony | 52 Te 127.60 Tellurium | 53 I 126.90 Iodine | 54 Xe 131.29 Xenon |
| 6 | 55 Cs 132.91 Cesium | 56 Ba 137.33 Barium | 57 - 71 | 72 Hf 178.49 Hafnium | 73 Ta 180.94 Tantalum | 74 W 183.85 Tungsten | 75 Re 186.21 Rhenium | 76 Os 190.23 Osmium | 77 Ir 192.22 Iridium | 78 Pt 195.08 Platinum | 79 Au 196.97 Gold | 80 Hg 200.59 Mercury | 81 Tl 204.38 Thallium | 82 Pb 207.2 Lead | 83 Bi 208.98 Bismuth | 84 Po (209) Polonium | 85 At (210) Astatine | 86 Rn (222) Radon |
| 7 | 87 Fr (223) Francium | 88 Ra 226.03 Radium | 89 - 103 | 104 Rf (261) Rutherfordium | 105 Db (261) Dubnium | 106 Sg (263) Seaborgium | 107 Bh (262) Bohrium | 108 Hs (265) Hassium | 109 Mt (266) Meitnerium | 110 Ds (269) Darmstadtium | 111 Rg (272) Roentgenium | 112 Uub (277) Ununbium | 113 Uut Ununtrium | 114 Uuq (285) Ununquadium | 115 Uup Ununpentium | 116 Uuh (289) Ununhexium | 117 Uus Ununseptium | 118 Uuo (293) Ununoctium |

Atomic masses in parentheses are those of the most stable of common isotope.

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 57 La 138.91 Lanthanum | 58 Ce 140.12 Cerium | 59 Pr 140.91 Praseodymium | 60 Nd 144.24 Neodymium | 61 Pm (145) Promethium | 62 Sm 150.4 Samarium | 63 Eu 151.96 Europium | 64 Gd 157.25 Gadolinium | 65 Tb 158.93 Terbium | 66 Dy 162.50 Dysprosium | 67 Ho 164.93 Holmium | 68 Er 167.26 Erbium | 69 Tm 168.93 Thulium | 70 Yb 173.04 Ytterbium | 71 Lu 174.97 Lutetium |
| 89 Ac 227.03 Actinium | 90 Th 232.04 Thorium | 91 Pa 231.04 Protactinium | 92 U 238.03 Uranium | 93 Np 237.05 Neptunium | 94 Pu (244) Plutonium | 95 Am (243) Americium | 96 Cm (247) Curium | 97 Bk (247) Berkelium | 98 Cf (251) Californium | 99 Es (252) Einsteinium | 100 Fm (257) Fermium | 101 Md (258) Mendelevium | 102 No (259) Nobelium | 103 Lr (260) Lawrencium |

Any process that gives atoms an electric charge is called *ionization*.

## The Discovery of Ions and Electrons

Researchers continued to study the nature of atoms. Svante Arrhenius of Sweden found that some atoms carry an electric charge. These atoms could move through water and cause chemical reactions. He named them *ions*, from the Greek word for "traveler."

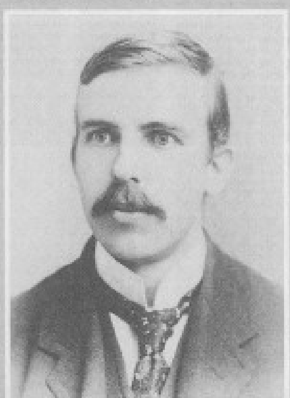
The Irish physicist G. Johnstone Stoney believed that electric current was actually the movement of extremely small, electrically charged particles. In 1891, he suggested these particles be called *electrons*. Electrons have a negative electric charge.

In 1897, British physicist J. J. Thomson proved the existence of electrons and showed that all atoms contain them. He believed (mistakenly) that the electrons were stuck in the atoms like raisins in a cake and (correctly) that ions were made when an atom had either too many or too few electrons.

## Isotopes—Alike but Different

Scientists learned more by studying different kinds of atoms. In 1903, Frederick Soddy was studying lead atoms in England. He found that there were three different forms of lead. Three different atoms all acted chemically like lead, but they had different masses.

Soddy named atoms of the same element with different masses *isotopes*, meaning "same place" in Greek. Though these atoms had different masses, they were in the same place on Mendeleev's chart.



**Sir Ernest Rutherford** (1871–1937) has been called the "father of nuclear physics." He discovered and named some of the field's fundamental concepts: alpha, beta, and gamma rays; the nucleus; the proton; and an element's half-life. In 1908, Rutherford won the Nobel Prize in chemistry for showing that radioactive elements actually become other elements when they decay—a finding that startled the scientific world. Most important was his discovery of the nucleus, the atom's core.

## Parts of the Atom

At about the same time, a scientist from New Zealand was making the first of his many important discoveries. Ernest Rutherford found that most of an atom is empty space with a tiny core in the center. He called this core the *nucleus* (plural, *nuclei*). Rutherford described the nucleus as being the middle of the atom, with the electrons going around the nucleus much like a swarm of bees.

By 1913, Danish physicist Niels Bohr had a new picture of the atom. He put the nucleus in the middle with the electrons traveling in many rings or orbits around it, like the orbits of the planets around the sun. Bohr's original model made a major advance in the understanding of the atom. It shows that the more energy an electron has, the farther from the nucleus the electron will be.

Some of Bohr's ideas had to be modified. By 1928, physicists had a more correct picture of the arrangement of electrons, thanks largely to the work of Erwin Schrodinger and Wolfgang Pauli of Austria and Max Born and Werner Heisenberg of Germany. Their work showed that electrons do not move in fixed orbits. Electrons travel in an unpredictable manner, but the general shape of an electron's movement does follow a pattern. One pattern is a sphere, while another is a dumbbell shape. The shape of the movement depends on the electron's energy and the type of *shell* the electron is in.

Also about 1913, Henry G. J. Moseley of England found a way to count the number of positive electric charges in a nucleus. He called the number of charges the *atomic number* of the atom.

Ernest Rutherford predicted scientists would soon find a piece of an atom that carried one positive charge. Rutherford proved himself correct with his discovery of the *proton* in 1914.

An electron *shell* is the region around the nucleus in which electrons of the same energy move.

The *atomic number*, or *Z*, is the number of protons in the nucleus of an atom. The number of protons determines the kind of element.

### The Neutron

During this period, William Harkins of the United States and Antoine-Philibert Masson of Australia were working on a big question. Why was Moseley's atomic number different from atomic mass? Rutherford read their work, did some of his own, and in 1920 said scientists would find a particle in the nucleus with no electrical charge.

Many experiments looked for the predicted neutral particle. Rutherford tried a new experiment with James Chadwick of England. It failed. Finally in 1932, 12 years after Rutherford's prediction, Chadwick found the *neutron*—a particle of an atom with no electric charge, about equal in size to a proton.

After the neutron's discovery, Werner Heisenberg suggested the nucleus was made of only protons and neutrons. Niels Bohr changed his model. Now he believed the nucleus was made of protons and neutrons and the electrons went around the nucleus in shells.

The discovery of the neutron gave scientists another way to describe an atom. The total number of protons and neutrons of an atom is the *mass number.* Isotopes, therefore, are atoms with the same atomic number (the same number of protons) but different mass numbers (different numbers of neutrons).

> Today, the term *atomic mass* is used in place of the older term "atomic weight." It is the actual mass of the nucleus. The sum of the protons and neutrons in the nucleus of an atom is called the *mass number,* or *A.* If you round the atomic mass to the nearest whole number, that value is equal to the mass number. Oxygen, for example, with eight protons and eight neutrons, has a *mass number* of 16, while its *atomic mass* is 15.99491461 AMU (atomic mass units).

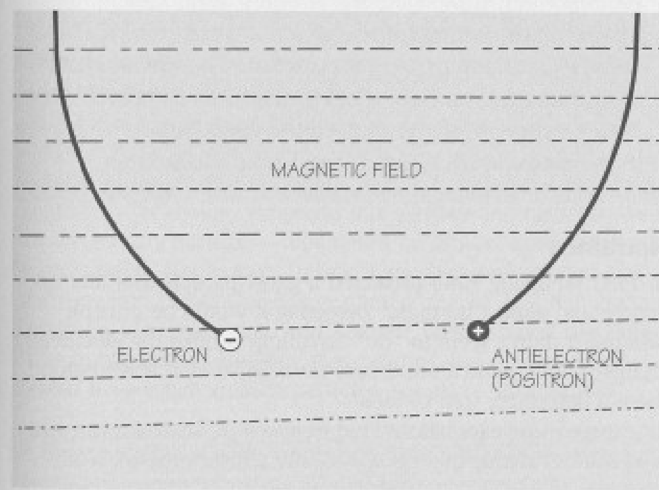
## What We Now Know

Recent decades have brought more discoveries about atoms. Giant *particle accelerators* bigger than city blocks explore the unseen world of the very small. Tiny particles that make up large particles have been identified. Almost undetectable "ghost" particles that zip through matter have been tracked down.

### Antimatter

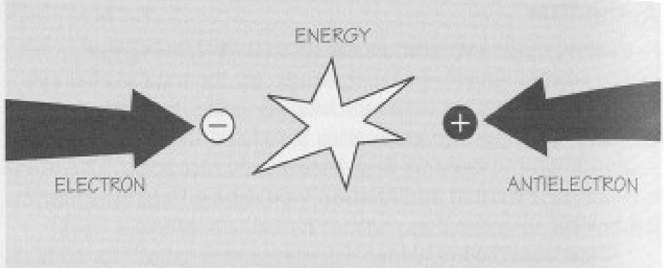
Even *antimatter* has been found to exist in the real world, not just in science fiction. In 1928, at age 26, theoretical physicist Paul Dirac wrote that for every kind of matter there existed an equal and opposite antimatter. He stated that when matter and antimatter came together, both would disappear. The only trace of their mutual annihilation would be a burst of energy left behind.

Dirac's prediction alerted scientists to the possibility of finding antimatter. In 1932 at the California Institute of Technology, Carl Anderson was studying cosmic ray *cloud chamber* photographs. One picture was of an electron that turned the wrong way. This *antielectron* behaved exactly the opposite of a normal electron. Anderson called it the *positron* because of its positive charge. (Normal electrons are negatively charged, remember.)




**Antimatter behaves exactly the opposite of its matter counterpart.**

Other scientists tracked down more antiparticles, and people began to wonder about the possible existence of antiworlds, antistars, or even an antiuniverse. Antimatter could be a tremendous source of energy. A tiny piece of matter meets an equal amount of antimatter, and *POW!*—no ashes, no waste, just pure energy.




**When matter meets antimatter, they both disappear in a burst of energy.**

**Richard Feynman** (1918–1988) is considered one of the most influential physicists of the 20th century. He described how charged particles (and their *antiparticles*) interact through *electromagnetic* force. To analyze these particle interactions, he developed diagrams and mathematical procedures to reveal their relationships. He shared the 1965 Nobel Prize in physics with S. I. Tomonaga and J. Schwinger.

## Neutrinos

In 1930 Wolfgang Pauli predicted a ghost particle that had no charge and almost no mass. Detecting it would be difficult because it didn't seem to "do" anything—unlike the electrically charged *alpha particles* and *beta particles,* which leave behind them a detectable trail of ions.

It took 26 years before Fred Reines and Clyde Cowan gathered hard evidence that *neutrinos,* the ghost particles, really exist. Six years later, in 1962, Leon Lederman, Melvin Schwartz, and Jack Steinberger used the Brookhaven National Laboratory accelerator to discover two types of neutrinos.

Neutrinos can pass through solid matter with only a slight chance of a collision. A beam of neutrinos can travel completely through Earth without losing intensity. The ability of neutrinos to penetrate matter makes them useful in the study of nuclear particles. Using particle accelerators, physicists have learned much about the makeup of neutrons and protons by observing rare collisions between neutrinos and atomic nuclei.

## The Modern Nucleus

In the years since Rutherford discovered the nucleus, physicists have learned that atomic nuclei come in many sizes and shapes. They can be round like a tennis ball or shaped like a football. On Earth, nuclei vary in size from hydrogen, with one proton, to uranium, with 238 protons and neutrons.

A *nuclide* is a nucleus that exists for a measurable length of time.

We know that protons and neutrons constantly move about inside the nucleus in different shells. Maria Goeppert-Mayer and J. Hans D. Jensen, cowinners of the 1963 Nobel Prize in physics, created the *nuclear shell model* to explain many of the nuclear properties. According to this model, nuclei "like" to have their shells filled. When a shell is filled, we say it has reached a "magic number." Magic nuclei are much more stable than their neighbors.

Often the nucleus behaves as if it were a raindrop. It can vibrate or, if shaped like a football, spin. Aage Bohr and Ben Mottelson described the motions of the nucleus and shared the 1975 Nobel Prize in physics for their work on the structure of the nucleus.

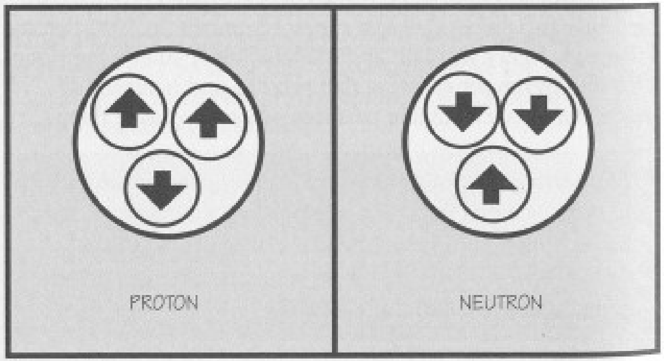
## Quarks and Gluons

In 1964, Murray Gell-Mann and George Zweig of the California Institute of Technology proposed that protons and neutrons were not *elementary* particles—they could be broken down further. Using particle accelerators, researchers shattered protons and neutrons into pieces Gell-Mann named *quarks.* In 1990, Jerome Friedman, Henry Kendall, and Richard Taylor shared the Nobel Prize in physics for showing that protons and neutrons do indeed have much smaller particles—quarks—inside them.

*Elementary particles* have no known smaller parts. Quarks, electrons, and neutrinos are elementary particles. Electrons and neutrinos belong to a group called *leptons.* They have no measurable size; physicists describe them as "pointlike."

Quarks comprise the protons and neutrons that make up the nucleus of every atom. Experiments have identified six quarks: *up* and *down*, which make up most everyday matter; and the much heavier *top, bottom, strange*, and *charm* quarks, which are unstable. Protons consist of two *up* quarks and one *down* quark. Neutrons have two *down* quarks and one *up* quark. Particles called *gluons* keep the quarks from flying away from each other. The theory of gluons and quarks as the building blocks of matter is the current theory of the structure of matter.

David Gross, David Politzer, and Frank Wilczek won the 2004 Nobel Prize in physics for showing how the attraction between quarks is strong when they are far apart but weak when they are close together. This discovery showed that a gluon provides the force that keeps quarks bound inside a nucleus and the force that keeps all nuclei together. The work is an important step toward providing a unified description of all the forces of nature, from the tiny distances within the atomic nucleus to the enormous expanse of the universe.



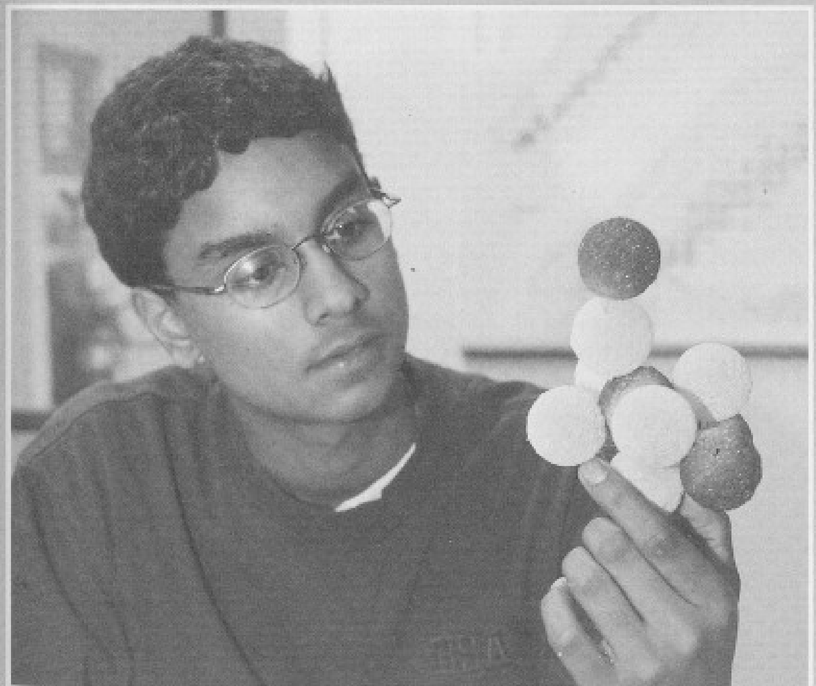

**Quarks form the fundamental building blocks of protons and neutrons. Gluons keep the quarks together.**

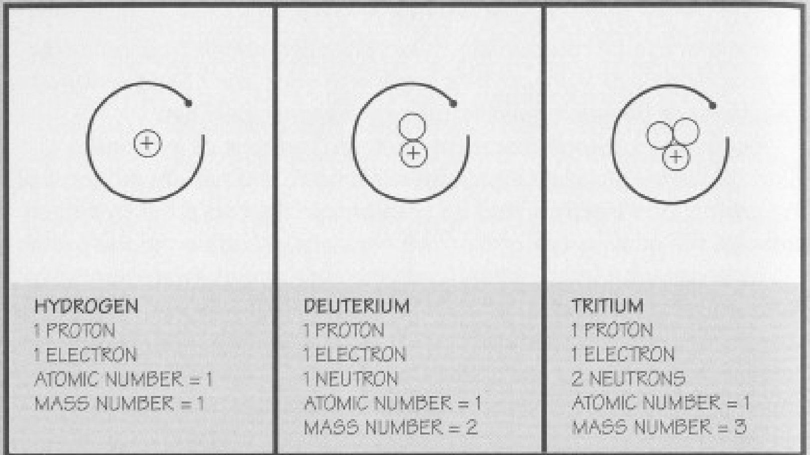
# Make 3-D Models of Atoms

Models that can be touched are called *physical models.* You will make physical models of atoms to help explain to your merit badge counselor the difference between mass number and atomic number.

Begin by studying pictures of the three isotopes of hydrogen. Hydrogen is the simplest and lightest element. Ordinary hydrogen has one proton, one electron, and no neutrons. In the two other hydrogen isotopes, the nucleus has one or two neutrons in addition to the proton.

Now use your imagination (and whatever materials are handy) to make a 3-D model of each atom. One way would be to use table-tennis balls for protons and neutrons, which are big (compared to elementary particles) and about the same size. Darken or color the balls that represent neutrons. In the deuterium and tritium models, stick the protons and neutrons together tightly.






To represent the quarks that make the protons and neutrons, you can use marbles of two different colors—green for *up* quarks, for instance, and blue for *down* quarks. In each hollow table-tennis ball, cut a hole the size of a marble. For each proton, put two green marbles and one blue marble inside the ball. Push two blue marbles and one green marble into each neutron. (To help you remember which is which, label the green marbles *u* and the blue marbles *d*.) After inserting the marble quarks, cover the holes in the balls with clear tape.

Modeling the electron may be tricky. Electrons are constantly moving like race cars on a track. Also, electrons move very far from the nucleus. You would need to put the electron on the other side of your town to show the proper distance.

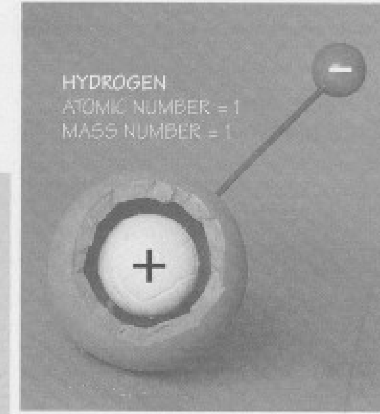
If you can't figure out a good way to represent the electron's movement around the nucleus, just use a piece of wire or a clear plastic drinking straw to attach the electron to your model. You might use marbles or candies for the electrons, which are much smaller than the protons and neutrons. The electron is so small that no one has ever been able to measure its size.

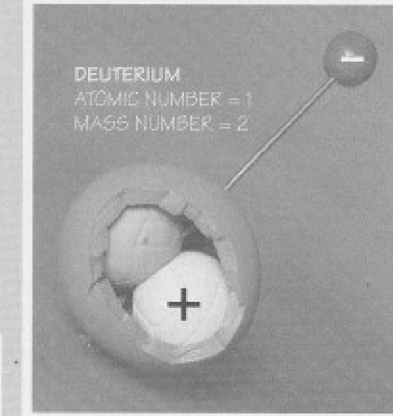
When you display your models to your counselor, be prepared to show that you understand the terms *nucleus, proton, neutron, quark, electron, isotope, atomic number,* and *mass number.* Also show that you know the electron is constantly moving, and (despite the straw or wire in your model) isn't physically fastened to the nucleus.

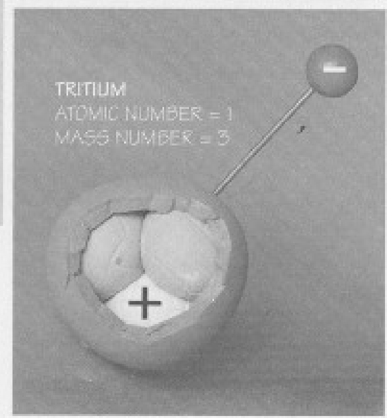
You might try other materials to make your models, such as balls of clay, painted balls of polystyrene foam, or different-sized marshmallows or candies. You could even bag the quarks in plastic wrap—some physicists describe protons and neutrons as "bags" containing quarks.

If you wish, you can make models of three isotopes of an element other than hydrogen. Try carbon-12, carbon-13, and carbon-14. These models will be considerably bigger and will require more materials than models of hydrogen.

In the nucleus of a real atom, extremely strong forces hold the protons and neutrons together. A huge amount of energy is concentrated in the nucleus because of these strong holding forces.



# Learn About Particle Accelerators

Particle accelerators, sometimes called atom smashers, are machines that can create beams of electrically charged particles and accelerate them to nearly the speed of light. This acceleration increases the particles' energy of motion. Think of the difference between catching a baseball that is gently underhanded to you and catching a fastball fired at you by a major-league pitcher. Energy is the universal container that holds things together. If you want to break open a container such as an atom or a proton to see what's inside, you must overcome that container's energy. From accelerators, scientists get the energy they need to break open and explore the makeup of atomic and subatomic particles.

**The Tevatron** at Fermi National Accelerator Laboratory (Fermilab, for short) in Batavia, Illinois, is the world's highest-energy particle accelerator and collider. Scientists use the Tevatron to smash beams of protons and antiprotons into one another. From out of the tiny cataclysmic fireballs come new clues about the most basic building blocks of matter and the forces acting on them.

**The Relativistic Heavy Ion Collider** at Brookhaven National Laboratory on Long Island in Upton, New York, is the world's largest facility for nuclear physics research. It is designed to accelerate ions to *relativistic* (near-light) speeds and smash them together. The goal is to re-create the super-hot, ultradense, souplike form of matter, called a *quark-gluon plasma,* that existed in the universe's first microseconds and set the stage for the formation of the universe as we know it.

**The B Factory** at the Stanford Linear Accelerator Center in Menlo Park, California, is used to accelerate and smash together beams of electrons and their antimatter counterparts, positrons. However, these two colliding beams are asymmetric, meaning they are not of equal energies, unlike the colliding beams of RHIC and the Tevatron. The asymmetric B Factory is designed to produce large quantities of *B mesons,* subatomic particles containing a *bottom quark.* Studying B mesons may help us know why the formation of matter was favored over antimatter in our universe.

**The Thomas Jefferson National Accelerator Facility (Jefferson Lab)** in Newport News, Virginia, is a fixed-target accelerator that creates a continuous stream of high-energy electrons. The machine steers the electrons into a nuclear target, which then shatters into smaller particles. Scientists analyze these fragments to measure and study the quark content of the nucleus.

Other particle accelerators operate at universities and national laboratories across the United States. Your counselor can help you find one to visit.

During your visit, ask questions. These will get you started.

- How does the accelerator work? Is it a linear accelerator (linac, for short) or a circular accelerator? What type of particles does it accelerate?
- How much energy does it take to run the accelerator?
- What type of experiments is this machine designed to do?
- What are the most exciting discoveries that have been made here?
- What types of people work here? What is it like to work here? What training do you need to get a job here?
- Are there radiation hazards around this machine? Why or why not? How are people protected from potential hazards?

# What Is Radiation?

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

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

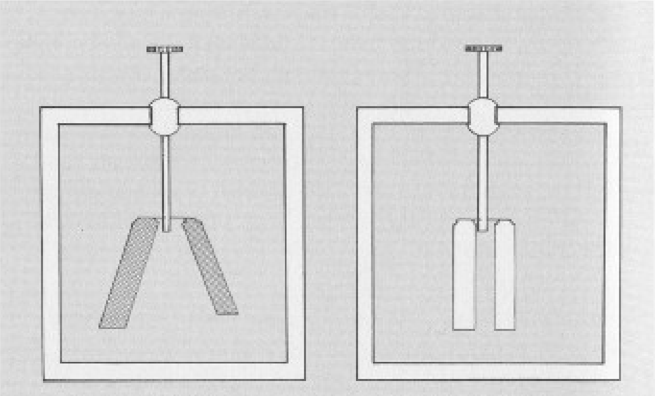
X-rays proved to be important not only in medicine, but also in giving scientists new insights into the nature of radiation and the structure of the atom. Scientists soon found that X-rays made ions of the atoms in air. Because of this, we call X-rays *ionizing radiation.*

*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.*



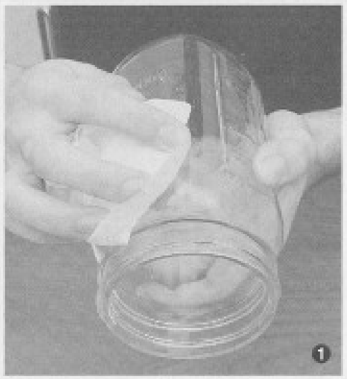

**An electroscope can detect ionizing radiation.**

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.

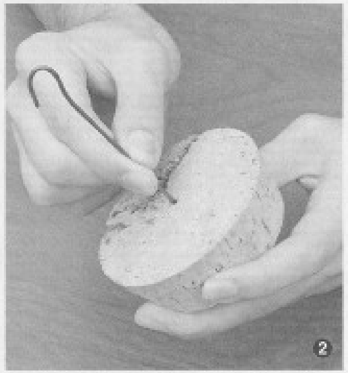
In 1910, Theodore Wolf, a French Jesuit priest, used an electroscope to show that radiation is all around us every day.

# Build an Electroscope

**Build an electroscope to detect ionizing radiation.**

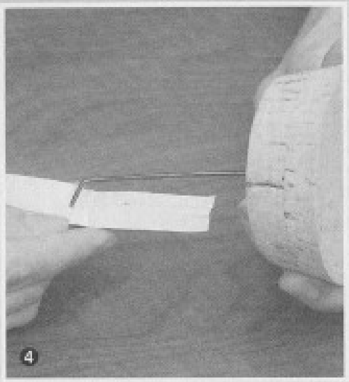


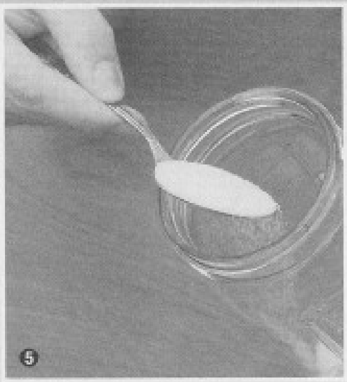
**Step 1**—Choose a bottle with a medium-width mouth and a cork or stopper that fits. Clean and dry the bottle.

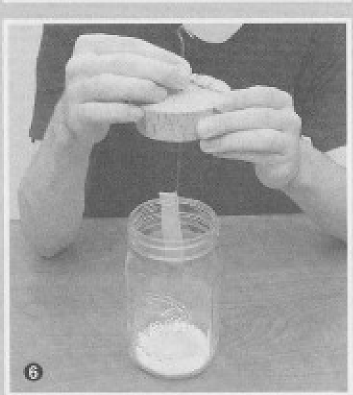


**Step 2**—Remove the paint from a 6-inch piece of coat hanger wire. Bend a loop in the top and push the wire carefully through the bottle cork or stopper. Bend the end of the wire into a ½-inch-long hook or L.

**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.




**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.

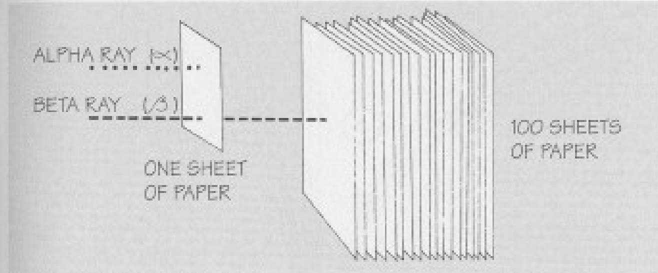
**Step 3**—Put the piece of mantle into the electroscope and charge it as before.

**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.

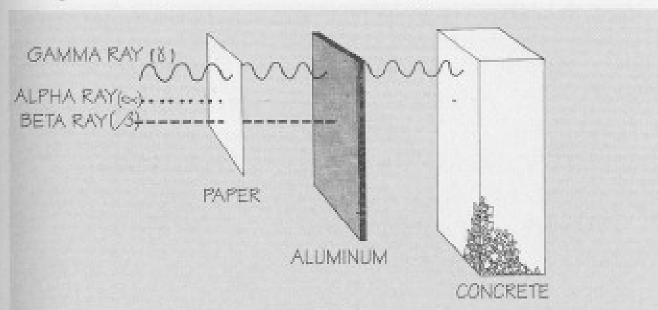
## Types of Radiation

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.



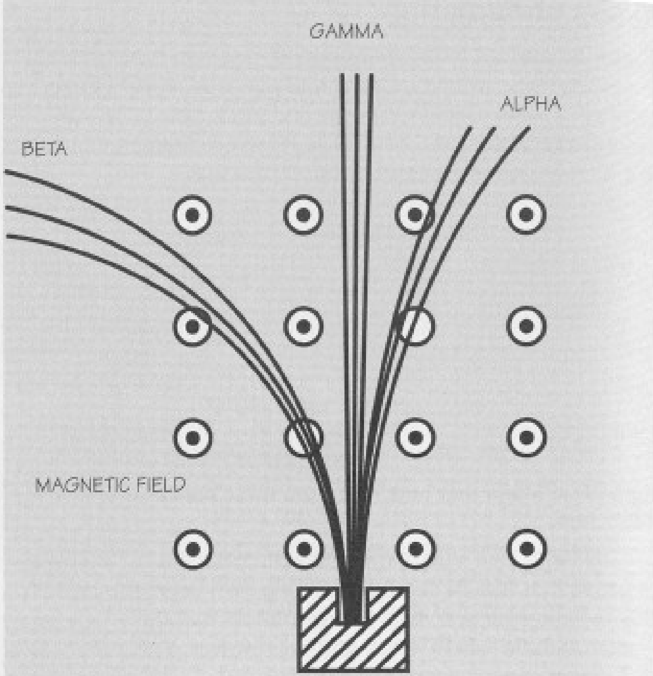

**Rutherford found that beta rays were more penetrating than alpha rays.**

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.

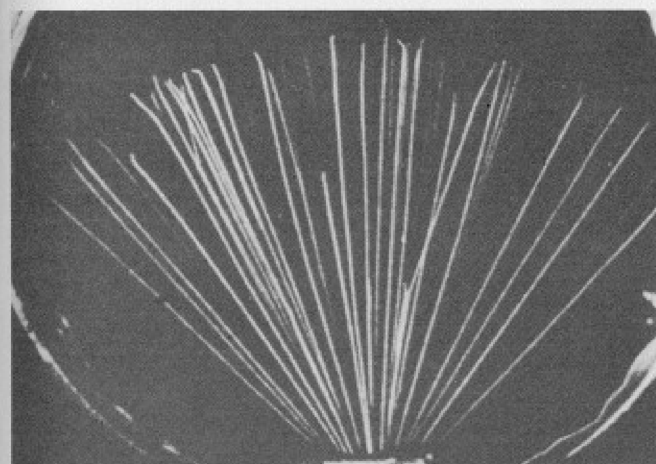



**In 1903, Marie Curie pictured how radiation is bent by magnets. The paths of alpha particles (positively charged) are bent one way, and the paths of beta particles (negatively charged) are bent the opposite way.**

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.

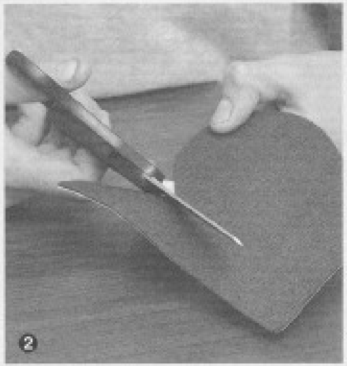
**Antoine Henri Becquerel** (1852–1908), a French physicist, experimented with phosphorescent uranium salts to determine if they gave off X-rays. He discovered instead their natural radioactivity. In 1903, he was awarded half of the Nobel Prize in physics for his discovery. (The other half went to Marie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



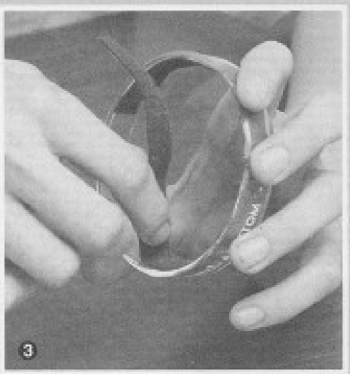
**A cloud chamber is a clear-sided vessel containing water vapor that shows the paths or tracks of electrically charged particles passing through. Shown here are alpha particle tracks.**

# Build a Cloud Chamber



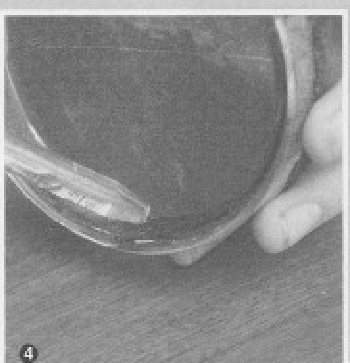
When radioactive elements decay, they emit high-speed alpha and beta particles, as well as gamma rays, all of which are too small for your eye—or even a microscope—to see. A cloud chamber will allow you to study the trails left behind by radioactive materials.

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



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

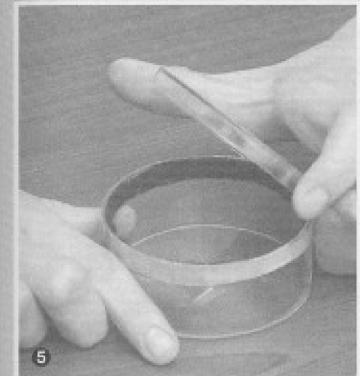
**Step 2**—If creating your own cloud chamber from a container you have at home, glue a piece of dark-colored felt to the inside of the cover using a rubber-based glue. (If using the container from the cloud chamber kit, the dark-colored bottom will be fine.) Allow the glue to dry completely.



**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.

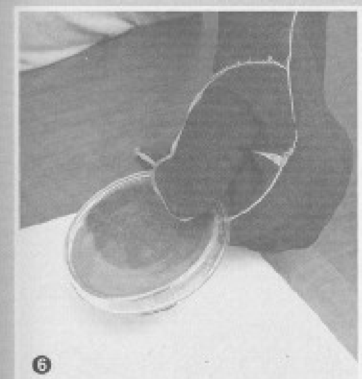
**Step 4**—Use an eyedropper to saturate the felt in the bottom of the container with 91 percent isopropyl alcohol, and place a radioactive source (available at a rock or hobby shop) in the container.

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



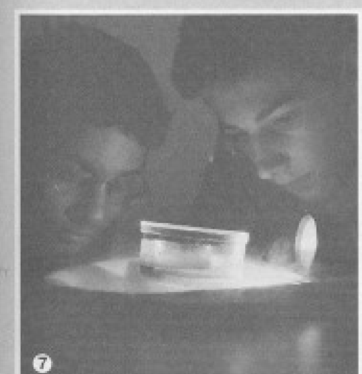
**Step 5**—Place the cover tightly on the container.

> 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.

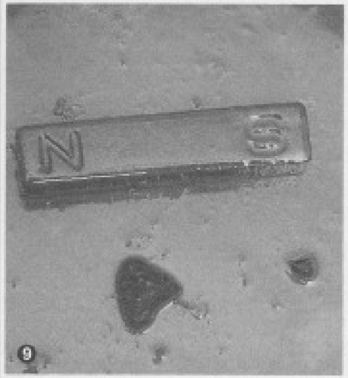


**Step 6**—Turn the container over so the dark colored side is on the bottom. Wearing thick gloves, set the container on a cake of dry ice (solid carbon dioxide).

**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 $1\frac{1}{4}$ inches in diameter.

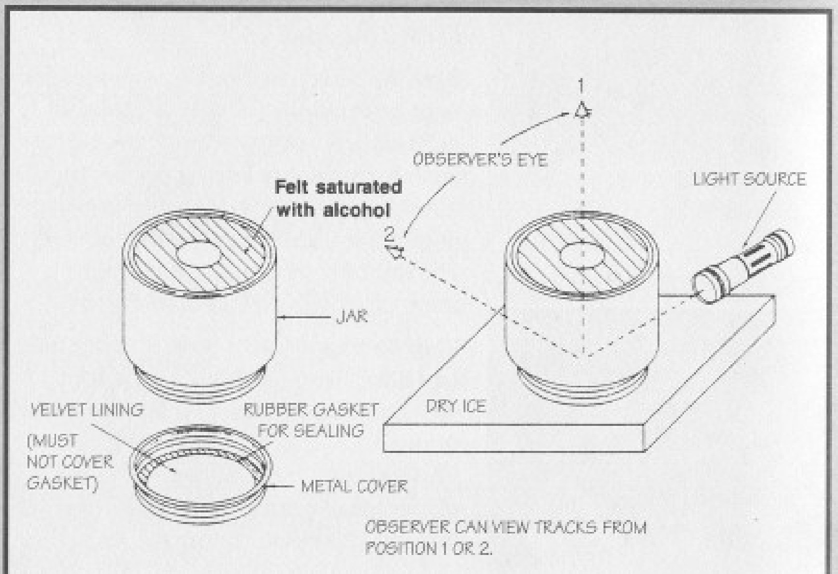


**Step 8**—Examine the fog, which should be falling like rain. Near the bottom, which should be near the temperature of dry ice (-77 degrees Celsius), short tracks should form, showing the paths of electrically charged particles passing through the cloud chamber.




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

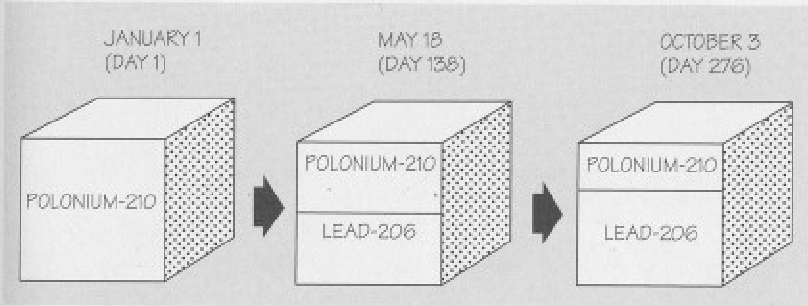
Atoms that have too much energy are unstable. They give off the extra energy to become stable. Atoms that give off energy (radiation) are called *radioisotopes.*

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.



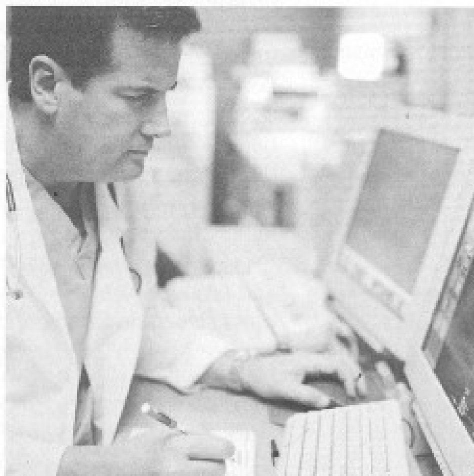

**Polonium-210 changes to lead-206 with a half-life of 138 days.**

# 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.**

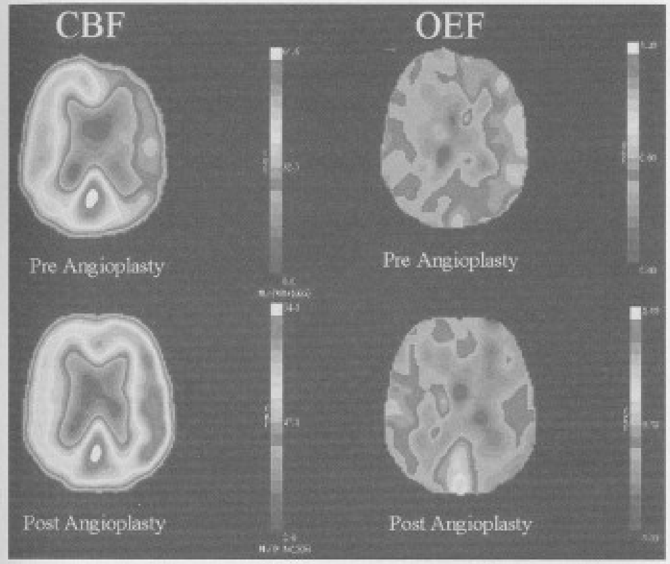
## Nuclear Medicine

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.**

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

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.

**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).

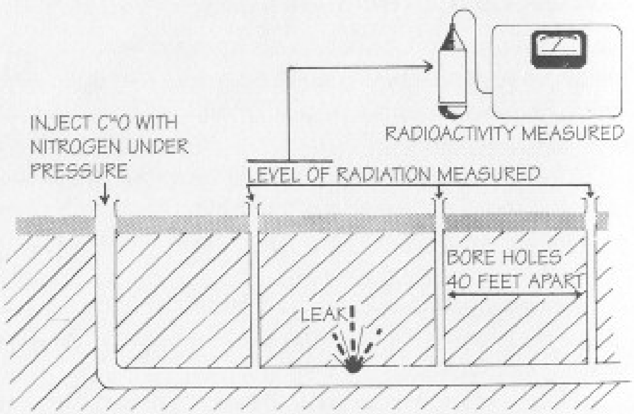
List any differences you observe during a 30-day period. After the first seven to 10 days (for barley or wheat), cut off at the soil line a sample of plants from each group. Measure the height of the plants. Dry both samples at 150 degrees Fahrenheit overnight. Weigh both groups and compare. What did 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

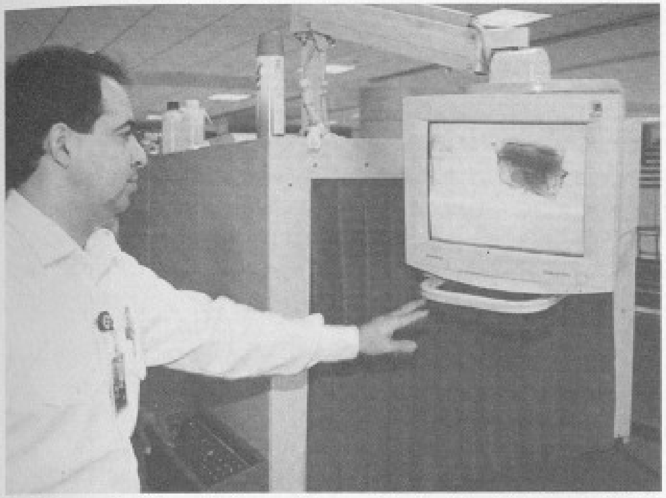
Industry uses radioisotopes in developing new products and devices. Radioisotopes have been used in devices to measure the levels of liquid in a tank, the thickness of metals or plastics, the wear on machine parts, or the mixing of two substances. Radiation is used to sterilize baby powder, bandages,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

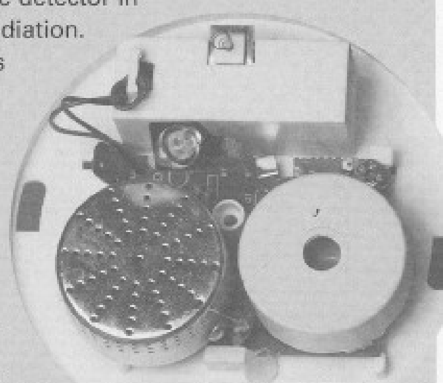
This technique of taking pictures *(radiographs)* with X-rays is a versatile and reliable method of inspection to determine a material's strength or to check for flaws. It lets inspectors see inside materials without taking them apart. This works the same way Roentgen x-rayed his wife's hand or your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

## Radiation in Science

The uses of radiation in science and research are many and varied. Here are a few examples to consider.

### Radiocarbon Dating

All living things have some radioactive carbon-14 in them. Because living things no longer take in carbon-14 when they die, we can measure the amount left in substances that once were living, such as wood, and figure out when the living thing died. Archaeologists and paleontologists use this measurement in their studies.

This technique, called *radiocarbon dating*, also is used in environmental studies to learn how Earth's climate has changed in the past and to help researchers predict how the global climate might change in the future. The carbon-14 technique is an essential tool in many fields including atmospheric science, oceanography, geology, and climatology.

A single atom surrounded by a million others can be identified by neutron activation analysis—an extremely sensitive procedure. If you put 1/40 of a gram of salt in a gallon of water, you couldn't taste the salt. But neutron activation analysis could find it.

### Space Exploration

The Mars rover *Sojourner* used alpha particles to identify chemical elements in Martian rocks. An instrument on the rover bombarded selected rocks with alpha particles, then read the X-rays generated from the rocks. Because each chemical element produces a distinctive X-ray, the instrument could determine the composition of the rocks.

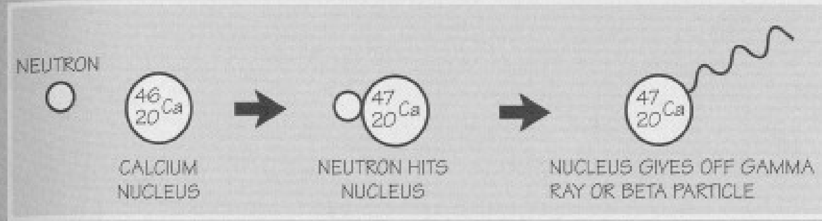
On many spacecraft, heat produced by the natural radioactive decay of plutonium (a metallic, heavy element) is converted to electricity to power the craft's onboard scientific instruments. This type of electrical power supply has been used in several U.S. space missions including *Viking* to Mars, *Voyager* and *Pioneer* to the outer planets, *Galileo* to Jupiter, and *Cassini* to Saturn.

### Neutron Activation

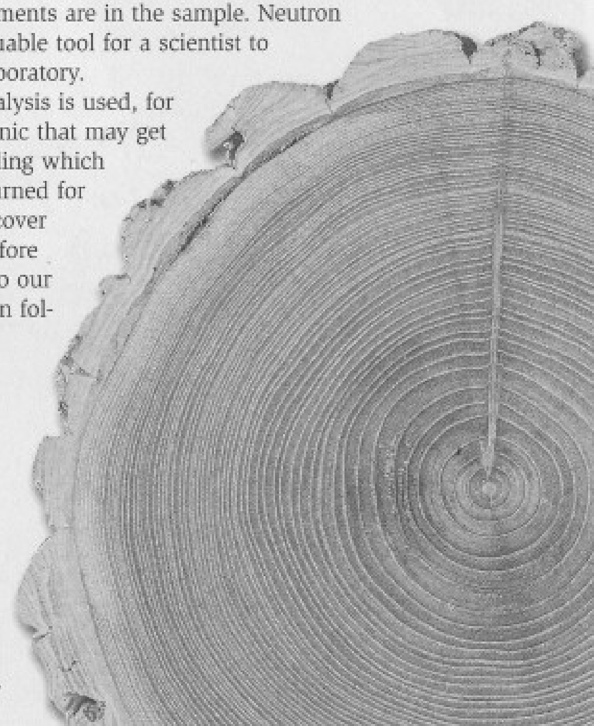
Shooting neutrons into stable atomic nuclei can make them radioactive, a process called *neutron activation*. When nuclei are activated, they get rid of the extra energy by giving off a beta particle or gamma ray.

Gamma rays are not all alike. Some have more energy than others. The gamma ray given off from neutron activation of a calcium nucleus is different from a gamma ray given off from neutron activation of a gold nucleus. By looking for the gamma ray or beta particle that comes off from a sample, a scientist can tell which elements are in the sample. Neutron activation analysis is a valuable tool for a scientist to identify materials in the laboratory.

Neutron activation analysis is used, for example, for detecting arsenic that may get into fish we eat, or for finding which elements are in the coal burned for electric power. We can discover heavy metals in sewage before releasing the pollutants into our environment. Ecologists can follow the movement of tiny amounts of insecticides in the environment.




Elements can be identified by the radiation "fingerprint" they give off. (Atoms can be drawn in many ways. This pamphlet uses the form shown here, a circle with the symbol of the element, mass number, and atomic number. Electrons may or may not be shown. Electrons do not play an active part in nuclear reactions.)



**Neutron activation allows scientists to measure the pollution that was in the air decades ago, when this tree was alive and growing.**

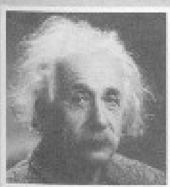
# Splitting Atoms: Nuclear Energy

Almost everyone has heard of Albert Einstein's famous equation, $E = mc^2$. The equation is a short way of saying that matter can be changed to energy. To find out how much energy (E) you get from a mass of matter (m), you multiply by the speed of light squared ($c^2$).

If you do the math, you get a very big number because *c* is a very big number. The speed of light is 30,000,000,000 (30 billion) centimeters per second. If you square this number (multiply *c* times *c*), you get 900,000,000,000,000,000,000 (900 billion billion). So, how much energy do you get from changing matter into energy? One gram of mass (one dime) will make 900 billion billion *ergs* of energy. That is equal to the energy from about 700,000 gallons of gasoline.

In the early 20th century, however, Einstein's equation was not fully verified. No one yet knew how to convert mass to energy. The ideas and work of many other scientists would be needed to show how to do it.

An *erg* is a small amount of energy. A burning match will produce 10 million ergs.

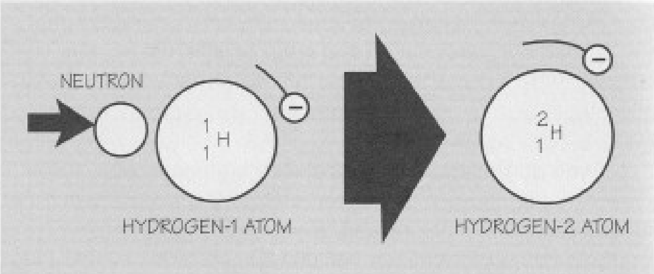


**Albert Einstein** (1879–1955), born in Germany, became interested in physics as a child playing with his father's compass. In 1905 at age 26, Einstein earned a doctorate and published four groundbreaking theories. His theory that light exists in "packets," or *photons,* won him a 1921 Nobel Prize. His special *theory of relativity* added time as a fourth dimension and controversially claimed that time and distance are relative to the observer. He also published his famous equation, $E = mc^2$, which explains that matter and energy are different forms of the same thing. At the end of his life, Einstein tried to create a *unified field theory* that would link together everything from subatomic particles to the universe as a whole. Today, some physicists still pursue Einstein's vision of a unified theory.

## Neutrons as Atomic Bullets

By the 1930s, new discoveries were leading researchers in promising new directions. After James Chadwick discovered the neutron in 1932, scientists began shooting neutrons like bullets into atomic nuclei. The results of these collisions told researchers much about the properties of the nuclei.

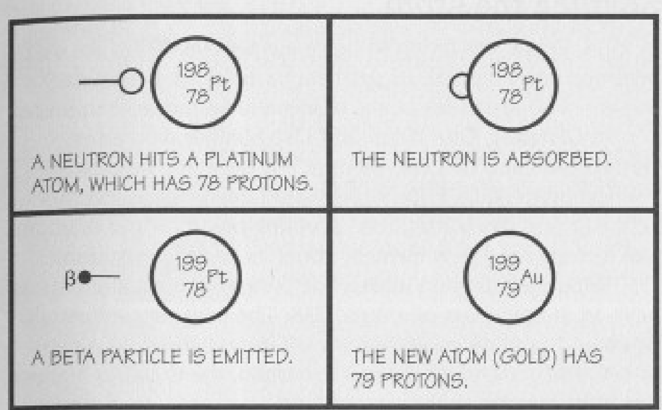
Two things can happen to an atom hit by a neutron. One possibility is that it will add one unit to the atom's mass number. When a neutron is added to the nucleus, the atomic number stays the same; only the mass number is changed.




**A neutron can add one unit to an atom's mass number.**

Sometimes, the neutron breaks down as it hits an atom. The breakdown produces a proton, which remains in the nucleus, and an electron (a beta particle), which flies out.

The second thing, therefore, that can happen to a nucleus when a neutron hits it is that it will give off a beta particle and the nucleus will now have one more proton than before. This adds one unit to the atomic number. If the atom gives off a beta particle after catching a neutron, one unit will be added to the mass number and one unit will be added to the atomic number, changing the atom into a new element. Enrico Fermi found that if you shoot an atom with a neutron, when the beta particle comes out, the atom always changes into the next heavier element.




**By adding a proton, elements can be changed into different elements. The transformation of one element into another by a nuclear reaction is called *transmutation*.**

What if you hit the heaviest known element, uranium, with a neutron? You could make a new, even heavier element. Fermi tried it. The uranium (element 92) disappeared, but no new element 93 could be found. Where did it go? What was going on?

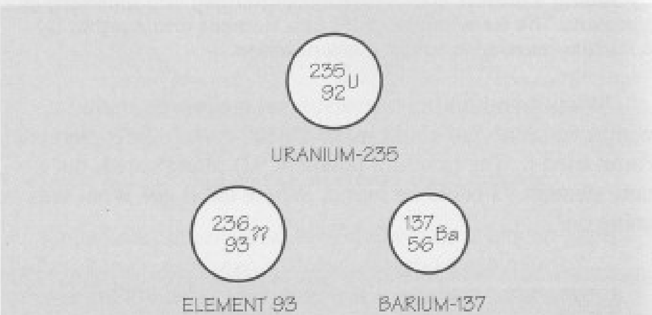
**Enrico Fermi** (1901–1954) was born in Italy and came to the United States to teach. He won the 1938 Nobel Prize in physics for discovering nuclear reactions set off by neutrons. In 1942, on a squash court at the University of Chicago, he conducted an experiment that led to the first controlled nuclear reaction and the start of the Atomic Age. Fermi became a leader among the physicists who worked on the Manhattan Project, the name given to the project created by the U.S. government in 1942 to develop the atomic bomb.

## Splitting the Atom

In 1934, Fermi was trying to make element 93. When he shot neutrons into uranium, he got beta particles, as he expected. But when he tested for atoms of element 93, none were found.

In Germany, Otto Hahn and Lise Meitner worked on Fermi's problem. In 1938, Meitner left Germany because of political oppression. Fritz Strassmann joined Hahn, and they kept working. They continued shooting neutrons into uranium and looking for a new element about as heavy as uranium.

What they did find looked like barium. But uranium atoms have an atomic mass of around 238. The new element should be about the same mass. Barium is far too light, with a mass of 137. For uranium to change to barium, the uranium nucleus would have to break into large pieces.




**Researchers looked for element 93 but found barium, which was too small to have come from uranium unless the uranium nucleus split when hit by a neutron.**

Hahn and Strassmann wrote to Lise Meitner about their research. She concluded that when uranium is hit with a neutron, it must break in half. Dr. Meitner cowrote a paper on this idea in 1939. An American biologist, William Arnold, read the paper and decided to call the splitting of atoms *fission*—the word biologists used for the splitting of cells.

**Lise Meitner** (1878–1968) of Austria codiscovered the 91st element, protactinium, with Otto Hahn in Berlin in 1918. Her continued work with Hahn (and another scientist, Fritz Strassmann) led to the 1938 discovery of nuclear fission, the process by which an atom splits, releasing tremendous amounts of energy. Fission was later used in World War II to produce the atomic bomb, but Meitner refused to contribute to the creation of nuclear weapons. Element 109 was named meitnerium in her honor.

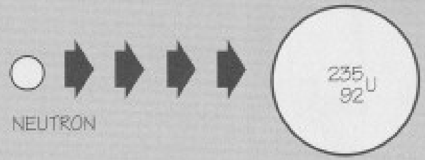
**Otto Hahn** (1879–1968) of Germany received a doctorate in chemistry and, working under Ernest Rutherford, discovered a new radioactive substance called radioactinium. In 1907, he began 30 years of research with Lise Meitner. Their work, with that of Fritz Strassmann, led to the discovery of nuclear fission, which won Hahn the 1944 Nobel Prize in chemistry. He campaigned against the use of fission to produce nuclear weapons.

**Ernest Lawrence** (1901–1958), born in South Dakota, taught physics at Yale, then took a job at the University of California at Berkeley. He invented the cyclotron, a circular type of particle accelerator that speeds up nuclear particles. This device later was used in cancer treatments and won him the 1939 Nobel Prize in physics. Lawrence made important contributions to the Manhattan Project, but he later discouraged atomic bomb testing.

**Glenn T. Seaborg** (1912–1999), born in Michigan, earned a doctorate in chemistry and taught at the University of California at Berkeley. Seaborg codiscovered plutonium, the element used to fuel some nuclear reactors and to make nuclear weapons. In 1951, the former Scout won the Nobel Prize for understanding the chemistry of plutonium and the nearby elements. With colleagues, he identified 10 new elements and more than 100 isotopes of different elements. From 1942 to 1946, he headed the Manhattan Project's plutonium research. Element 106 was named seaborgium in his honor.

## How Fission Works

1. A neutron hits a uranium nucleus.




2. The nucleus stretches and bends.


3. The nucleus breaks, releasing two smaller parts called fission fragments, along with neutrons and lots of energy.

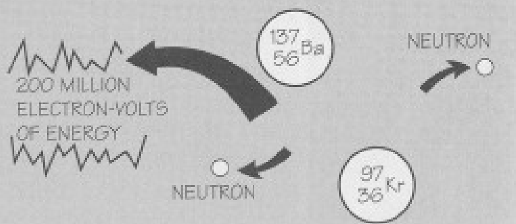



**Diagram Nuclear Fission**
Your drawing of nuclear fission should show the incoming neutron, the nucleus it hits, the nucleus splitting, and what is released: fission fragments, neutrons, and lots of energy.

Some atoms other than uranium-235 can be fissioned. Plutonium also can be split for energy.

## Chain Reaction

Fission would not be useful for producing energy if we had to shoot each nucleus with a neutron to break it. That would use more energy than it would produce.

But each fission releases extra neutrons. These neutrons can be used to split other nuclei.

Fermi found that with the element he was using—uranium—slow neutrons hit nuclei better than fast ones did. Fermi used *moderators* to slow down the neutrons.

In December 1942, Fermi and a group of other scientists completed the first atomic *pile*. This was a stack of blocks of graphite containing uranium in carefully spaced lumps. The graphite was the moderator. Rods of cadmium in the pile soaked up neutrons before they could hit the uranium. These *control rods* kept the reaction from starting. Then, when the experiment ended, the rods would be used to stop the reaction.

Slowly, one by one, the rods were pulled out. The reaction started and then went faster and faster. The *chain reaction* was continuing on its own. Neutrons from one fission were causing more fissions. The world had entered the nuclear age.

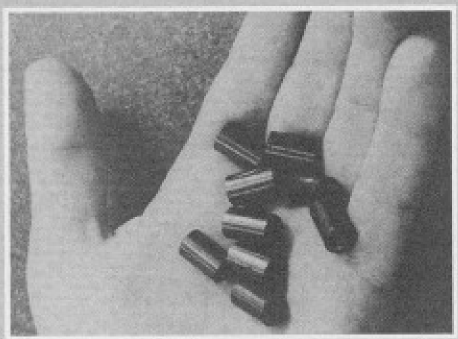
The stack of blocks Fermi used was called a nuclear pile. Modern devices for hosting chain reactions are called *nuclear reactors*. A *critical mass* of nuclear fuel is necessary to sustain a chain reaction. Too little fuel produces too few neutrons to keep the fissions going.

Neutrons are best slowed by low-mass atoms such as hydrogen, deuterium, or carbon (graphite). These make the best moderators.

## Modern Nuclear Reactors

Today's nuclear reactors look much different from Fermi's pile of graphite, uranium, and cadmium, but the principles on which they work are the same. Reactors are used to produce and control nuclear energy. The energy released by splitting nuclei creates large amounts of heat. This heat can be used to make steam, and the steam spins turbines to generate electricity.

The energy in one uranium fuel pellet—the size of the tip of your little finger—equals the energy in 17,000 cubic feet of natural gas; 1,780 pounds of coal; or 149 gallons of oil. In American reactors the fissionable fuel is uranium-235 (U-235), a scarce isotope of uranium. U-235 is the only natural material that nuclear reactors can use to produce a chain reaction. Nuclei of the much more abundant U-238 isotope usually absorb neutrons without splitting.



**A fuel rod consists of pellets of fuel inside a metal tube. Each of these uranium pellets has nearly the same energy as a ton of coal.**

The reactor's *core* contains rods of nuclear fuel inside a tanklike structure called the reactor vessel. Control rods containing neutron-absorbing materials such as cadmium are pushed into the core or pulled out to slow down or speed up the chain reaction. The control rods also are part of the safety systems that prevent the chain reaction from going too fast.

The moderator fills the spaces between the fuel rods. Most of today's nuclear reactors use water as a moderator.

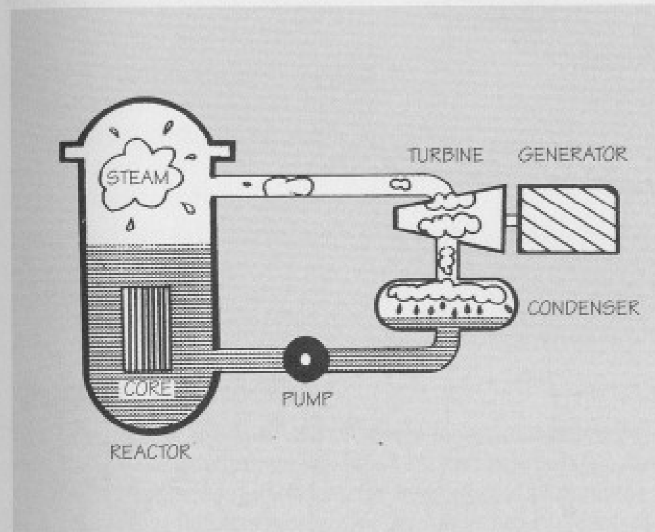
Water also works to cool the core. It carries off the heat made by the chain reaction, transferring it to where it can be used to generate electricity. Water, therefore, is both a moderator and a coolant. Because nuclear power plants require enormous amounts of water for cooling, most are built near lakes or large rivers.

## Kinds of Reactors

All commercial power reactors in the United States are *light water reactors.* They use light (ordinary) water as the moderator and coolant. Canadian reactors are *heavy water reactors.* They use heavy water, which has deuterium in place of ordinary hydrogen.

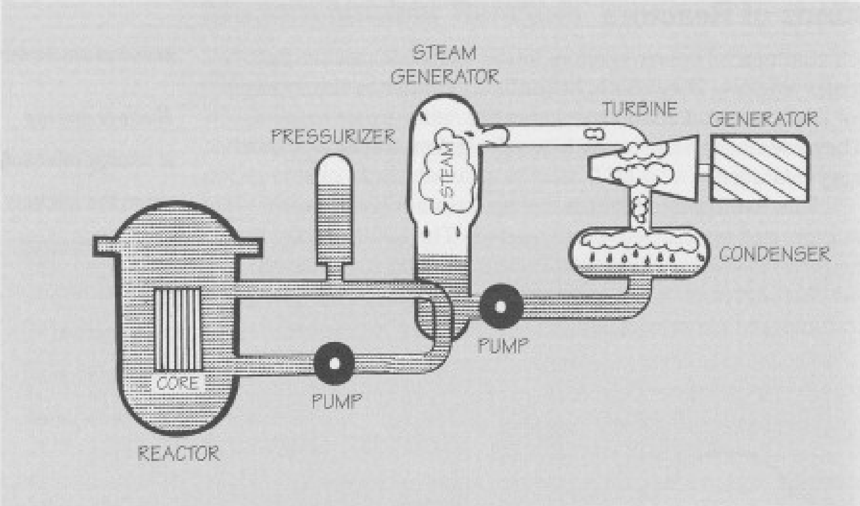
The two types of light water reactors are *boiling water reactors* and *pressurized water reactors.* The boiling water type boils the moderator water in the core, making steam inside the reactor vessel. Pipes carry the steam to the power plant's turbines and generators.

*Nuclear energy* is energy released when the nucleus of an atom splits (fission), joins with another nucleus (fusion), or disintegrates (radiation). "Nuclear energy" rather than "atomic energy" is the most exact name for the energy produced in a nuclear reactor.

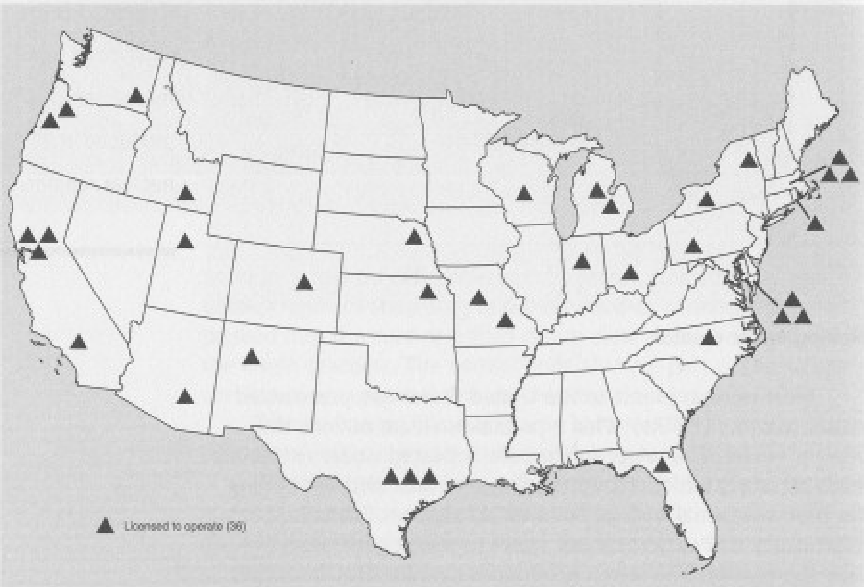



**Boiling water reactor**

Most nuclear plants in the United States use pressurized water reactors (PWRs). This type makes steam outside the reactor vessel. The water in the core is heated under extremely high pressure, which allows the water to heat without boiling far past its normal boiling point of 212 degrees Fahrenheit. Pipes carry this extremely hot water to steam generators outside the reactor. The steam generators transfer heat from the pressurized water to a separate supply of water, which boils and produces steam.

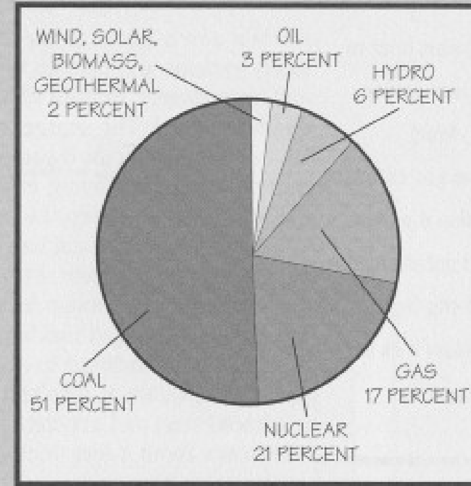



**Pressurized water reactor (PWR)**




**As of 2004, 103 power nuclear reactors were operating in the United States. The 36 smaller reactors pinpointed above are located mainly at universities and other places where training and research are conducted.**

Nuclear power—the second-largest source of electricity in the United States—supplies about 21 percent (one-fifth) of the nation's electricity each year. Unlike fossil fuels (coal, oil, and gas) burned to make electricity, nuclear power does not produce *greenhouse gases*—carbon dioxide and other gases that trap heat in Earth's atmosphere much as a glass greenhouse captures sunlight. Nuclear plants do not release solid pollutants such as coal ash and sulphur. However, used nuclear fuel produces dangerous radiation long after the end of its useful life. This *radioactive waste* must be safely stored and disposed of.




**U.S. electricity by source**

## Radioactive Wastes

The fissioning of uranium-235 produces many radioactive isotopes, such as strontium-90, cesium-137, and barium-140. An especially dangerous nuclear-reactor byproduct is plutonium-239. Plutonium remains radioactive for thousands of years, and even in small amounts it can cause cancer.

Safely disposing of these radioactive wastes is a major issue in nuclear power. The current plan in the United States calls for depositing long-lived radioactive waste underground. In the meantime, nuclear power plants in the United States store used fuel and other wastes in pools of water at the plants.

Living next door to a nuclear power plant would expose you to less radiation than you would get in one round-trip flight from New York to Los Angeles.

## Reactor Safety

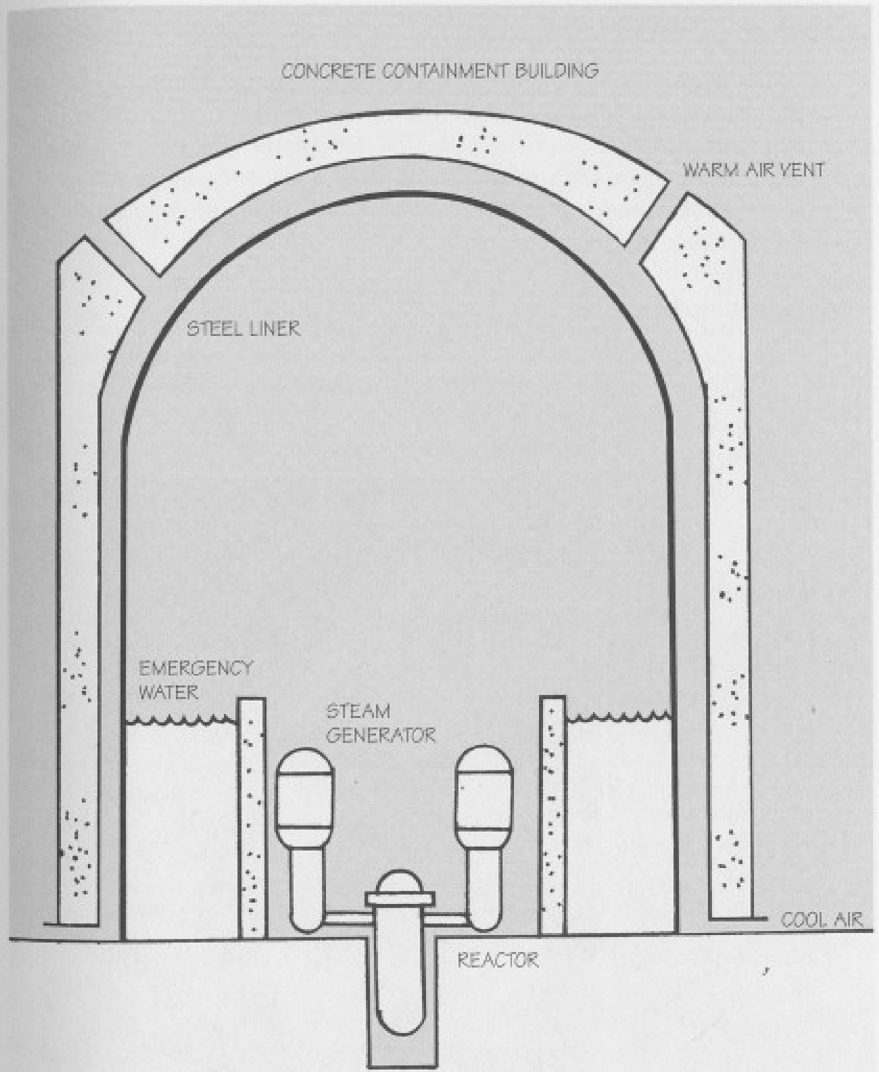
Nuclear power plants in the United States have emergency safety systems and backup systems that work automatically and immediately. Built-in sensors watch temperature, pressure, and water level. The sensors connect to systems that adjust or shut down the reactor if something is not working right. If cooling water leaks away, emergency cooling systems make up the water loss and keep the reactor from overheating.

Plants have physical barriers to keep radiation from escaping into the environment. Most of the radioactive by-products of the fission process remain locked inside the nuclear fuel pellets. The pellets are sealed inside strong metal rods. The fuel rod assemblies are enclosed in a steel reactor vessel with walls about 8 inches thick. The reactor vessel itself is in a massive, reinforced steel and concrete structure called the containment, with walls about 4 feet thick.

## Nuclear Reactors as Factories

Besides generating electric power, a nuclear reactor also can be a kind of factory or manufacturing plant for making things radioactive. Most radioactive materials used commercially are made in nuclear reactors or cyclotrons. For example, hitting stable cobalt with neutrons in a reactor transforms the cobalt into a radioisotope—cobalt-60—that has been used to treat cancer and to sterilize medical supplies and consumer products.

Usually only one type of radioactive material can be produced at a time in a cyclotron, but a reactor can produce many different radioisotopes at once. After the materials are made, they are packaged and shipped to users nationwide, including hospitals, laboratories, universities, and manufacturing plants.



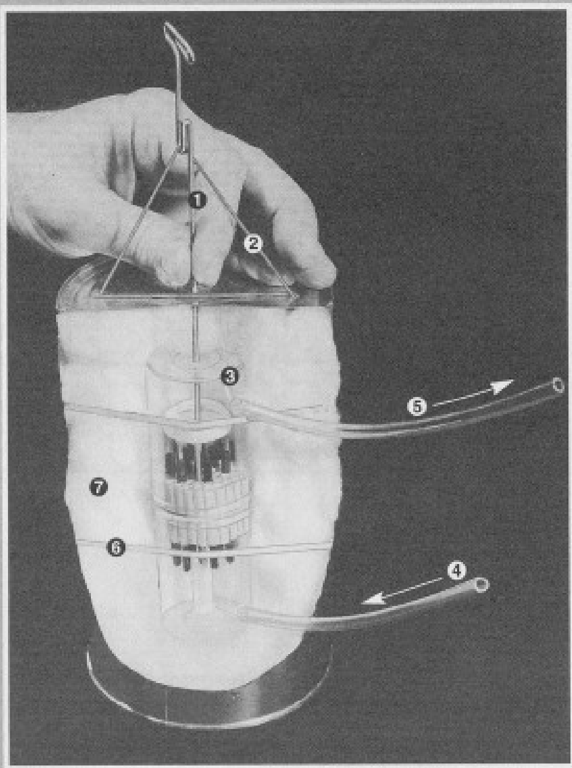

**Nuclear reactors are housed in containment buildings with thick concrete floors and thick walls of steel or of concrete lined with steel. The concrete and steel are there to prevent radioactive materials from escaping into the air.**

# Make a Reactor Model

For optional requirement 4b, build this simple cross-section model of the pressure vessel for a pressurized water reactor. Lack of space prevents detailed instructions here, but by looking at the materials list and the labels on the photos, you should be able to make the model. Note the clever rubber band "scram" spring simulating the automatic shutoff system of a real reactor.

## Materials Needed

- ☐ 1 large juice can
- ☐ 2 plastic pill bottles (about 2½ inches tall and 1½-inch diameter)
- ☐ 1 plastic pill bottle top (1-inch diameter)
- ☐ 1 wire coat hanger
- ☐ 13 soda straws (12 thin, one thick)
- ☐ 12 to 16 kitchen matches
- ☐ 2 6-inch swab sticks
- ☐ 2 6-inch pieces of ½-inch plastic tubing
- ☐ Rubber bands, cotton batting, assorted color marking pens
- ☐ Quick-drying glue

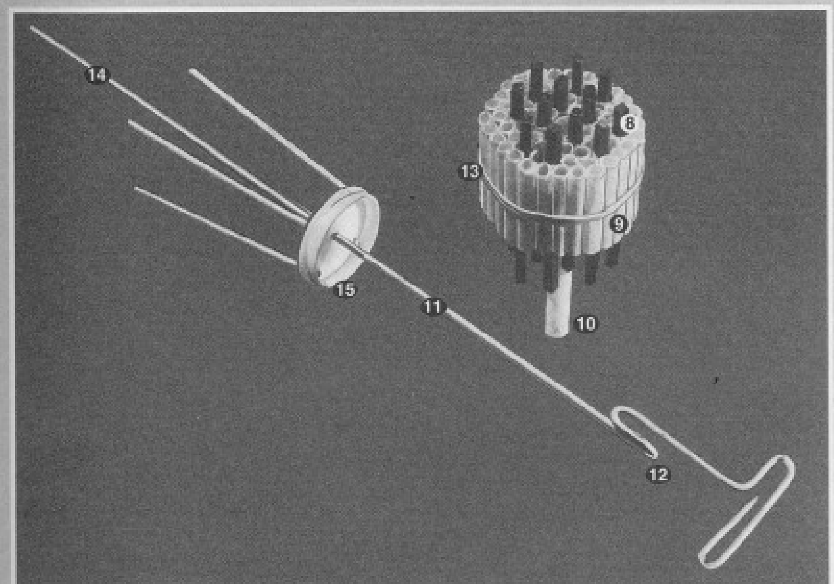



### Completed Model

1 Control rods partially withdrawn
2 Rubber band scram spring
3 Pressure vessel
4 Cool water in
5 Hot water out
6 Rubber bands to hold vessel in place
7 Shielding

### Reactor Controls

8 Fuel elements (matches colored red)
9 Core lattice (1-inch thin straws)
10 Channel for central control mechanism (thick straw cut to 3 inches)
11 Central control mechanism shaft (coat hanger wire)
12 Hook for rubber band scram spring
13 Rubber band
14 Control rods (swabsticks)
15 Soft plastic cap (1-inch diameter)




Thanks to Scouter Bob LeCompte, a former member of the Atomic Energy Commission (forerunner to the Nuclear Regulatory Commission), for the original design of this reactor model.

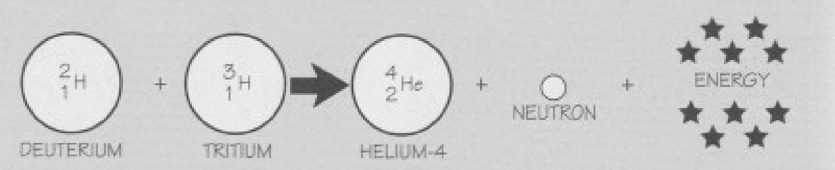
## Fusion Research

Fission splits nuclei; *fusion* combines them. Tremendous amounts of energy are released when atomic nuclei fuse. The energy of the sun comes from the fusion of hydrogen nuclei to form helium. Experiments with ways to control nuclear fusion could result in virtually unlimited power from fusion reactors. While fission reactors split heavy elements (uranium and plutonium), fusion reactors join light elements (mainly deuterium and tritium, isotopes of abundant hydrogen).

The fuel for fusion is in the form of a *plasma*—a very hot gaslike mixture of ions. Fusion reactions take place when the plasma is hot enough, dense enough, and contained for long enough for the atomic nuclei in the plasma to start fusing together.

> For nuclei to fuse, they must be going very fast. To go fast enough, they must be extremely hot. A great amount of energy is required to heat and create the plasma. Fusion reactors will be useful for producing electric power only if they can be made to produce more energy than they consume.

One promising fusion design uses extremely powerful laser beams to heat deuterium and tritium gas and turn it to plasma. Compressing the plasma fuel causes fusion.

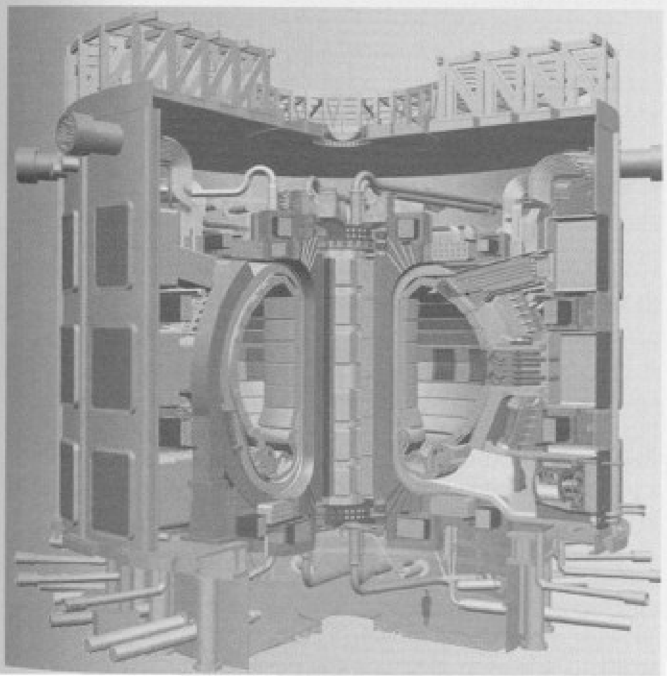



**The deuterium-tritium fusion reaction produces helium.**

## ITER

An experiment called *ITER* (Latin for "the way") aims to provide the know-how to build the world's first nuclear fusion plant for generating electricity. ITER is an experimental reactor based on the *tokamak* concept—a doughnut-shaped magnetic vessel in which conditions for controlled fusion reactions are created. The experiment will test all the main new features needed for a power plant fueled by hot plasma that is held in place (confined) by magnets.

Plans call for ITER to begin operating in 2014 and last for 20 years. Constructing and operating ITER will be an essential step in determining whether people can successfully use magnetic confinement of plasma for generating electricity in the 21st century. The project is an international collaboration of scientists and engineers from China, Europe, Japan, Korea, Russia, and the United States.



# Radiation Hazards and Safeguards

Ionizing radiation can be dangerous to living things precisely because it *is* ionizing—it strips electrons from atoms. An ionized molecule can then chemically react with other molecules to form new compounds. These ionized molecules and new compounds can alter the vital processes and functions inside a living thing.

Ionizing radiation can damage any living tissue in the human body. The body tries to repair the damage, but the natural repair process may fail if the damage is too severe or widespread.

## Hazards to People

The effects of radiation on human health fall into two general categories: *stochastic* and *nonstochastic* (or *deterministic*).

### Stochastic Health Effects

Exposure to low levels of radiation over a long time can cause stochastic effects. Stochastic effects are unpredictable. Because radiation affects different people differently, some effects of exposure occur randomly and do not always depend on the size of a dose. All that can be said for sure is that the greater a person's radiation exposure, the more likely that person is to develop health problems like cancer.

Cancer is the uncontrolled growth of cells. Normally, natural processes control the rate at which cells grow and replace themselves. Ionizing radiation can disrupt the natural controls, allowing runaway cell growth. This is why ionizing radiation's ability to strip away electrons and break chemical bonds in atoms and molecules makes it such a potent *carcinogen* (cancer producer).

Radiation also can make changes in DNA, the "blueprints" that cells follow as they repair and copy themselves. Changes in DNA are called *mutations*. Generally (but not always), mutations are harmful, and they may be passed on to new cells that are made when the damaged cell divides.

**What is the cancer risk from radiation?** Health physicists estimate that, if each person in a group of 10,000 people is exposed to 1 rem of ionizing radiation, in small doses over a lifetime, we would expect five or six more people to die of cancer than would otherwise. In this group of 10,000 people, we can expect about 2,000 to die of cancer from all causes other than radiation. The lifetime exposure to 1 rem of radiation, therefore, would increase the number of cancer deaths to about 2,005 or 2,006.

Compare this to the lifetime odds of dying from other causes, such as

- A fall—1 in 246
- An auto accident—1 in 247
- A pedestrian accident—1 in 608
- Drowning—1 in 1,126
- Fire and smoke—1 in 1,116
- A plane crash—1 in 4,023
- Any injury (all types)—1 in 23

—From the U.S. Environmental Protection Agency and the National Safety Council

### Nonstochastic Health Effects

An *acute* exposure—that is, getting a big dose of radiation in a short time—produces nonstochastic effects. Nonstochastic effects are also called *deterministic* effects because they can be predicted with certainty (determined) from what has happened in the past to people exposed to bursts of intense radiation.

Unlike cancer, which can take years to show up, health problems from acute exposure usually appear quickly. Acute effects include burns and *radiation sickness*.

One measure of radiation exposure is known as a *rem.*

Radiation sickness (also called radiation poisoning) can be fatal. The symptoms include nausea, vomiting, weakness, hair loss, skin burns, and bleeding (hemorrhage). A person who receives a lethal dose of radiation may die within hours or days, depending on the size of the dose. Common treatments for radiation sickness include blood transfusions and using antibiotics to fight infection. In some cases, a bone marrow transplant can be lifesaving.

| Exposure (rem) | Health Effects |
|---|---|
| 25 | Changes in the blood |
| 100 | Radiation sickness |
| 200 | Radiation sickness with worse symptoms in less time |
| 400 | Death probable within two months* |
| 600 | Death probable within one to two weeks* |

*One-half of any group of people exposed to a single quick dose of 400 rem likely will die within 60 days. A single quick dose of 600 rem or more usually causes death within a week, although people have survived doses up to 800 rem.

# Radiation Units

Radiation is measured in several different units. The *roentgen* (R) is for measuring the ionizing ability of X-rays or gamma rays in air. The unit was named for Wilhelm Conrad Roentgen, who discovered X-rays.

Different kinds of ionizing radiations have different effects on humans. The *rem* (*r*oentgen *e*quivalent, *m*an) measures the intensity of the radiation, the type of the radiation, and its effect on the body. The rem is used for health and safety purposes, describing the biological effect of radiation on people. One rem is approximately the dose from any radiation corresponding to exposure to one roentgen of gamma radiation.

If one rem is divided into 1,000 equal parts, each part is one *millirem* (mrem).

The International System unit (see the chart) for measuring the biological danger of radiation is the *sievert* (Sv). One sievert equals 100 rem.

To describe the quantity of radiation physically absorbed by some material, the unit used is the *rad* (*r*adiation *a*bsorbed *d*ose). The International System unit for absorbed dose is the *gray* (Gy). One gray equals 100 rad.

**Converting Radiation Units**

Just as the meter may be used instead of the foot, or the liter instead of the quart, another set of radiation units may be used, called the International System (SI). This table shows how to convert one system to the other.

| Multiply this | by this | to get this |
|---|---|---|
| **SI Units** | | **Common Units** |
| coulomb per kilogram (C/kg) | 3876 | roentgen |
| becquerel (Bq) | 0.000000000027 | curie |
| sievert (Sv) | 100 | rem |
| gray (Gy) | 100 | rad |
| **Common Units** | | **SI Units** |
| roentgen (R) | 0.000258 | coulomb per kilogram |
| curie (Ci) | 37,000,000,000 | becquerel |
| rem | 0.01 | sievert |
| rad | 0.01 | gray |

## Radiation Hazards to Wildlife

Although we know much about the dangers of radiation to humans, its effects on wildlife are less understood. Scientists have tended to assume that as long as people were protected, animals and plants would be, too.

But that idea is changing, and more research is now being done to learn how best to safeguard wildlife. Many researchers are focusing on how wild plants and animals have been affected by the radioactivity released from the exploded nuclear reactor at Chernobyl. For example, some researchers are finding that worms in a nearby lake are changing their behavior in ways that may help protect them from radiation damage.


# The Chernobyl Nuclear Accident

In April 1986, operators at the Chernobyl power plant in Ukraine, in southeastern Europe, were conducting a test of a nuclear reactor, in which several safety systems and processes were bypassed. Conditions to conduct the test were not as planned, but they proceeded anyway, and the reactor exploded, releasing a cloud of radiation. Killed at once were 31 people, mostly firefighters responding to the emergency. About 200 people suffered acute radiation poisoning. High radiation levels within 20 miles of the plant forced the evacuation of some 150,000 people.

For millions of people exposed to radioactive fallout from Chernobyl, the long-term health effects are uncertain. At least 2,000 children and young adults in the most severely contaminated areas got cancer of the thyroid. Other forms of cancer also may be on the rise.

The explosion spread radioactive contamination across a large area, particularly in Belarus, Russia, and Ukraine. Some land is so contaminated that it can no longer be farmed. In grazing animals such as cattle and goats, radioactivity has built up in the meat and milk.

> Unlike most nuclear reactors in the West, the Chernobyl reactor had no enclosure to prevent radioactive materials from escaping.

Wildlife in the forests also is contaminated from feeding on radioactive lichens and berries. Predators such as wolves and foxes are more contaminated than the grazing animals they eat, because the radioactivity from their prey concentrates in their bodies.

### Radiation Hazards to the Environment

The environment is as big as the planet (bigger, when you include the atmosphere extending 1,000 miles overhead), so for requirement 6 you may want to focus on a specific environmental issue such as radioactive waste. Radioactive wastes produced by nuclear reactors, research, and medical laboratories pose a potentially serious environmental problem.

The safe and permanent disposal of radioactive waste is both difficult and expensive. The United States government has been working on a plan to isolate radioactive waste in an underground storage site at Yucca Mountain in Nevada.

A storage site for nuclear waste must be in an area without earthquakes or weaknesses in the ground. The site must be dry so that containers of waste will not rust or corrode and leak into underground water supplies. The site must be built and protected so that future generations do not accidentally dig into it and release radioactivity.

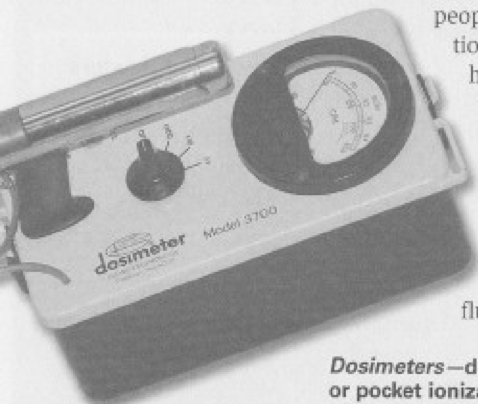
Many types of radiation detectors are in use. Your counselor can probably discuss some of the other types with you.

## Radiation Detectors

Using our normal senses, people cannot detect radiation. You cannot hear, smell, see, taste, or feel it. So how do we know it's there? How do we protect ourselves from it?

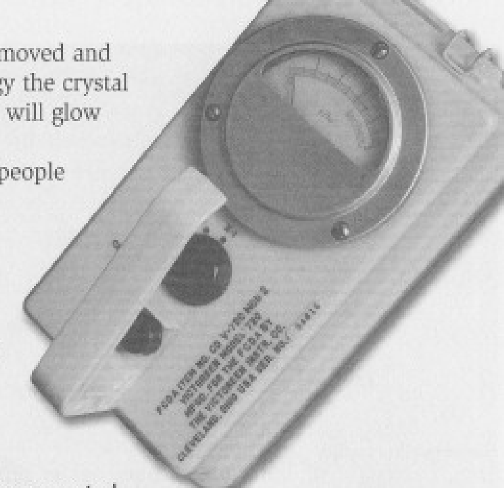
Many types of radiation detectors are in use. You have learned that radiation makes changes in photographic film and will create ions in matter through which it passes. One way to detect radiation, therefore, is to wrap pieces of film in dark paper and put them in holders or badges that people wear on their clothes. When radiation passes through the dark paper and hits the film beneath, it darkens the film. The darker the film, the more radiation the person has received.

Another example is an easy-to-carry radiation monitor called the *thermoluminescent dosimeter* (TLD). This monitor contains a small crystal of a substance (like lithium fluoride) that absorbs energy when hit by radiation. When the crystal is removed and heated, it will glow. The more energy the crystal received from radiation, the more it will glow when heated.




***Dosimeters*—devices such as film badges, TLD badges, or pocket ionization chambers—measure the doses of radiation a person has received.**

A radiation detector that most people have heard of is the *Geiger counter.* Basically, this instrument counts radiation as it passes through a gas-filled tube and makes ions in the gas. If the instrument has a speaker, you hear a click each time a radiation passes through. The more clicks, the more radiation is being detected.



**A Geiger counter clicks as it counts ions created when radiation passes through the instrument's gas-filled tube. Faster clicks mean higher radiation.**

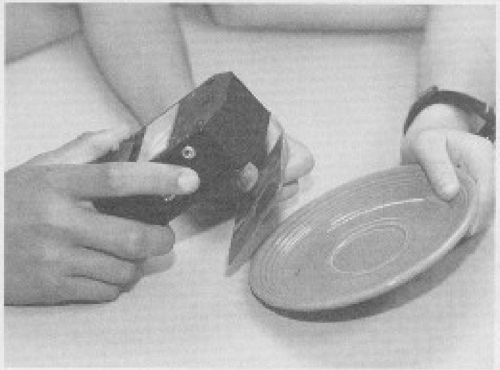
## Use a Radiation Survey Meter

Most emergency response groups, such as fire departments and ambulances, have radiation detectors that you might be able to use for this activity. You also could check with nearby colleges, physics labs, or even high schools.

Different types of radiation survey meters are used to detect different types and energies of radiation.

- **Ionization (ion) chambers.** Used mainly to determine the exposure rate from gamma ray and X-ray emitters, ion chambers are particularly useful for measuring machine-produced X-rays.
- **Geiger-Müller (GM) detectors.** Easy-to-use, portable GM detectors (familiar to most people as Geiger counters) are good for many types of radiation surveys. They are most efficient for detecting high-energy beta emitters such as phosphorus-32, but they can be used to measure low-energy beta emitters such as carbon-14.
- **Scintillation detectors.** Scintillation detectors are used to detect gamma radiation and they are much more sensitive to gamma and X-rays than are GM detectors. They may have an audible output like GM detectors.

For a radiation source, you might use an old radium-dial watch or a radioactive lantern mantle. A good Geiger counter can detect the radiation in potash, in very low-sodium salt, or in any high-potassium fertilizer. You will *not* be able to detect the radiation from a smoke detector.



**Your counselor or other qualified adult will show you how to properly use a radiation survey meter. When monitoring for low-energy beta emitters with a GM survey meter, you must pass the detector slowly across and very close to the surface you are checking.**

Radioactive material spread about or deposited on skin, clothing, or any place in the environment where it should not be is *contamination*. A person contaminated with radioactive material will receive radiation exposure until the material is removed. Radiation survey meters are used to detect contamination so that it can be removed or kept ALARA.

## Natural Background Radiation

To give you some perspective on the hazards from radiation, remember that sunlight—the most essential radiation of all—also can be harmful in big doses. Too much sunlight can cause burns and skin cancer, just as an overexposure to ionizing radiation can.

And also like sunlight, ionizing radiation is a natural part of our environment. Radiation exists all around us in nature. Soil, rocks, air, food, water, and even your body contain radioactive substances. Radioactive carbon-14 is in all the food we eat. *Cosmic rays* fall on us from space. Most Americans get about 300 millirem (mrem) each year from natural radiation sources.

**Cosmic Rays.** The sun and other stars give off radiation that we call cosmic rays. The average exposure in the United States from this source is 30 mrem per year. Air protects us from most cosmic rays. The higher the elevation at which you live, the closer you are to space and the more cosmic radiation you receive. People in Denver, a city that is almost the highest point in the United States, may get 50 mrem each year.

# Test for Radon Indoors

Radon is a naturally occurring radioactive gas. It is produced by the radioactive decay of radium, an element found in soil and rocks in all parts of the United States.

Colorless and odorless, radon gas may seep indoors unnoticed from the soil and rocks beneath buildings. It can enter homes through drains or cracks in the foundation. In some areas that have a lot of radon in the ground, the gas may build up indoors to unhealthy levels.

As radon decays, it gives off radiation in the form of alpha particles that can damage cells in the body, leading to cancer. By some estimates, radon causes about 20,000 deaths from lung cancer each year in the United States. The average U.S. radiation exposure from radon gas in the air is 200 mrem (a figure that can vary greatly, depending on actual levels of radon in the ground where you live and the construction/ventilation properties of the building).

A picocurie is one-trillionth of a curie.

Test kits are available for people to check the radon levels in their homes. The Environmental Protection Agency recommends taking action to reduce radon if the radioactivity from this gas is more than 4 picocuries per liter of air (4 pCi/L). The EPA estimates that 6 percent of U.S. homes exceed 4 pCi/L.

It is fairly simple to test the radon level in your home. First call the National Radon Hotline at 800-SOS-RADON (800-767-7236) to request a brochure. To order a test kit, call the Air Quality Helpline at 800-557-2366, or use the printable coupons at *http://www.nsc.org/ehc/radon/coupon.htm*. Kit prices start at about $10.

With your parent or guardian, decide whether to use the long-term or short-term test method. Short-term tests remain in your home for two to 90 days, depending on the device. Long-term tests take longer—

more than 90 days—but are more likely to tell you your home's year-round average radon level. (Radon levels can vary from day to day and season to season.)

Carefully follow the instructions that come with the kit. Keep the test in place for as long as the instructions say, but for at least 48 hours. Then, mail the kit to the laboratory specified. You should receive the results in a few weeks.

If your testing shows high levels of radioactivity from radon, your parent may wish to call the Radon Fix-It Helpline (toll-free 800-644-6999) for information on reducing radon. Fixing radon problems is not necessarily expensive. Sealing cracks and other openings in the foundation or coating the basement floor and walls with a flexible sealant may stop some radon leaks. The radon might be sucked from below the house and vented outdoors. Ventilating the inside of a home also helps lower the radon level. The air outdoors usually has radioactivity from radon of less than 0.5 pCi/L.

## Exposures From Manufactured Radiation

Would it surprise you to know that your home may be radioactive? If your house is constructed from brick, concrete, stone, or adobe, it gives you an exposure of about 7 mrem a year.

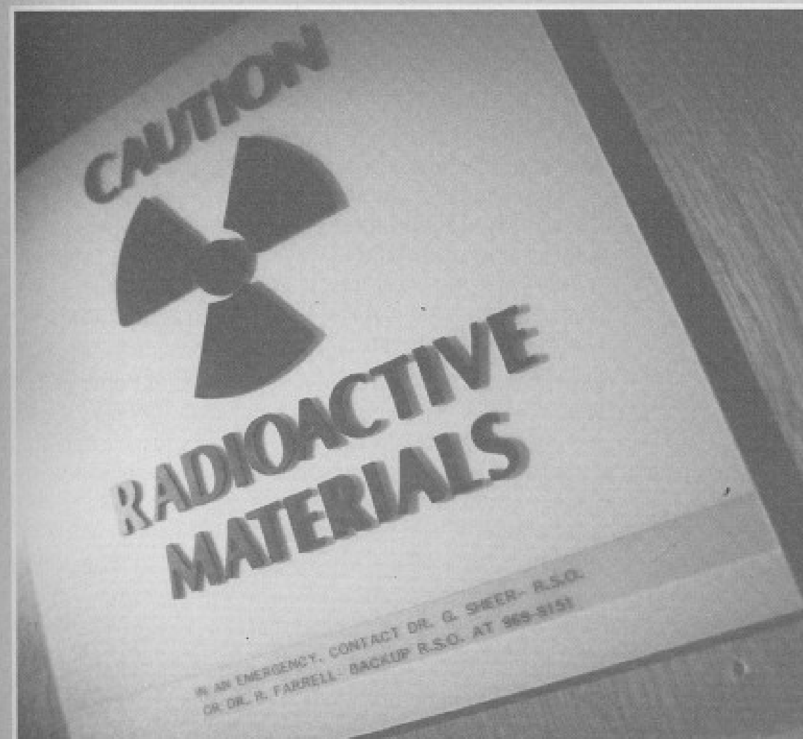
In daily life, people also can get radiation (60 mrem a year, on average) from sources other than those found in nature. Luminous (tritium-dial) wristwatches and some gas lantern mantles emit small amounts. If you've gone through luggage inspection at an airport, you have received a tiny dose of X-radiation. If you live within 50 miles of a nuclear power plant, you get perhaps 0.01 mrem per year. The figure is triple (0.03 mrem—still very small) if you live within 50 miles of a coal-fired power plant, because burning coal releases small amounts of uranium into the air.

Many people are exposed to radiation for medical purposes, such as getting thyroid scans (14 mrem) or dental, chest, and other kinds of X-rays (7 mrem on average). Wearing a plutonium-powered heart pacemaker can expose a person to 100 mrem a year. The benefit of a pacemaker to steady the heartbeat or an X-ray to check for broken bones is much greater than the limited risk from these small radiation exposures. Even so, you should not get X-rays you don't need.

Since the first use of nuclear weapons in 1945, atomic bombs have been tested all around the world. Nuclear explosions spread radioactive dust called *fallout*. Although there has been no testing in the air for many years, some of this fallout is still around, but we absorb less than 1 mrem every year from this source.

## Hazard Symbol

To make sure people know when they are somewhere they might be exposed to high levels of radiation, a distinctive symbol is used to mark the area. The radiation warning symbol is a three-bladed disk in magenta (light purple) on a yellow background. The sign is displayed at laboratories or factory areas where radioactive materials are being used, and in storage areas for radioactive substances.



It's impossible to say exactly what level of radiation is safe or dangerous for a person. While 5 rem (5,000 mrem) each year is used as a maximum limit for radiation workers, any unnecessary exposure should be avoided.

## Radiation Dose Limits and ALARA

The United States has laws to limit people's unnecessary exposure to radiation. Radiation workers may be exposed to no more than 5,000 mrem annually. Health physicists generally agree that an average person who does not work with radioactive materials should not be exposed to more than about 100 mrem per year beyond the 360 mrem (average) background radiation we all receive. That means an ordinary person's exposure normally should not exceed about 500 mrem per year from all sources.

Limiting unnecessary exposure is the idea behind ALARA (as low as reasonably achievable). It is not possible to avoid all radiation exposure, but people can take steps to keep their exposure as low as it reasonably can be.

Three essential steps involve *time, distance,* and *shielding.*

- **Time.** The shorter the time a person is exposed, the less radiation that person will receive. Imagine you are in a laboratory working with a radiation source that gives off 1 rem per hour. If you work with it for one hour, you get 1 rem; for two hours, 2 rem; three hours, 3 rem; and so on. How do you keep the dose down? By keeping the *time* down.
- **Distance.** The farther a person is from a source of radiation, the lower the radiation dose. Radiation levels decrease dramatically with distance. A radiation source that is strong close up is weaker farther away. Alpha radiation (emitted by radon, for instance) travels only a short distance in air. Beta radiation (from carbon-14, among other emitters) may travel several feet in air.
- **Shielding.** Earlier you learned that a piece of paper can stop alpha particles. Aluminum will block beta particles. Gamma rays and X-rays are blocked by a lead or concrete shield. Placing a radioactive source behind a massive object or other effective shield provides a barrier to radiation. In X-ray rooms, operators stand behind a barrier to avoid getting radiation exposure with every patient.

### Calculate Your Approximate Annual Radiation Dose*

| | | Your Annual Dose |
|---|---|---|
| **Approximate Natural Background Radiation:** | | |
| Cosmic rays | | ____ mrem |
| If you live at sea level | 26 mrem | |
| 1,000 feet | 28 | |
| 2,000 feet | 31 | |
| 3,000 feet | 35 | |
| 4,000 feet | 41 | |
| 5,000 feet | 47 | |
| 6,000 feet | 52 | |
| 7,000 feet | 66 | |
| 8,000 feet | 79 | |
| 9,000 feet | 96 | |
| Food and water (U.S. average) | | 40 |
| Air (from radon, U.S. average) | | 200 |
| Soil | | ____ |
| Colorado Plateau (around Denver) | 63 | |
| Atlantic or Gulf Coast | 16 | |
| Elsewhere in the United States | 30 | |
| **Manufactured Sources:** | | |
| Medical X-rays/nuclear medicine | | ____ |
| Arm, leg, hand, or foot X-ray | 1 | |
| Dental X-ray | 1 | |
| Chest X-ray | 6 | |
| Pelvis/hip X-ray | 65 | |
| Skull/neck X-ray | 20 | |
| Upper GI X-ray | 245 | |
| CT scan/MRI (head and body) | 110 | |
| Nuclear medicine (e.g., thyroid scan) | 14 | |
| Home (7 mrem from brick, concrete, stone, or adobe) | | ____ |
| Luminous wristwatch (0.06 mrem if you regularly wear one) | | ____ |
| Gas lantern mantle (0.2 mrem if you use the radioactive kind) | | ____ |
| Jet travel (0.5 mrem per hour in the air) | | ____ |
| Weapons test fallout | | 1 |
| **Total** | | ____ mrem |

How does your approximate annual dose compare to the U.S. average of about 360 mrem per year? It's not unusual for a person to receive far more than the average dose in a year's time (mainly from medical procedures the person may undergo). International standards allow exposure to as much as 5,000 mrem a year for people working with and around radioactive materials.

*Adapted from "Estimate Your Personal Annual Radiation Dose," ©2000, American Nuclear Society, *http://www.ans.org/pi/resources/dosechart/docs/dosechart.pdf*

# Nuclear Science Careers

Nuclear science and technology offer a huge variety of careers, ranging from power generation and environmental protection to medical diagnosis and treatment. Only a few of the possible careers can be described or mentioned here.

To learn more, talk with your counselor and with the people you have met while completing the requirements for the Nuclear Science merit badge. People who work in this field will be your best sources for information. Ask them how they got interested in the field, how they trained for it, what education and experience are required, what they like (and dislike) about their work, and whether they would recommend it as a career (and why or why not).

Professionals in any nuclear science or technology career need good communication skills. It is important to be able to explain your ideas and your research to other people, whether they are in your field or work in other fields, or are members of the general public.

## Basic Training

Preparing for any career in this field starts now, with taking as many science and math courses as you can: biology, chemistry, physics, algebra, and geometry. In college, you probably will major in physics, chemistry, or nuclear engineering.

To enter the field as a scientist or engineer, you will need at least a four-year bachelor's degree. Some positions require a master's degree or doctorate.

Nuclear technologists and technicians also need math and science. Entry-level technologist jobs generally require at least two years of college or extensive technical education.

## Careers in Scientific Research

Nuclear scientists study the structure, properties, and interactions of atomic nuclei and how the elements were formed in the cosmos. Experimental nuclear scientists create and analyze experiments, while nuclear theorists interpret results from experiments and predict new phenomena. The ultimate goal is to understand the building blocks of nature and the physical laws they obey.

To become a nuclear scientist, most people earn a doctorate in physics or chemistry. The path to this degree takes many years of study and research. As college students majoring in physics or chemistry, they may take one or two specialized nuclear science courses and participate with a nuclear science research group.

Then, after graduation from college, they enter a doctoral program, taking courses for the first year or two, then beginning full-time research. Almost all nuclear science graduate students are paid to go to school through fellowships, teaching assistantships, research assistantships, or a combination of these. After obtaining a doctoral degree, many work as a postdoctoral fellow.

Nuclear scientists may choose from several careers.

- Some join a university or college, where they teach courses, guide students, and do research.
- Some conduct full-time research at a national laboratory.
- Some assist with the operations of an accelerator to help those doing experiments.

Some nuclear scientists have been leaders in developing new techniques in the treatment and diagnosis of disease; others help develop new solutions to problems in energy, or homeland or national security.

## Careers in Nuclear Medicine

Every day, tens of thousands of patients in hospitals and clinics have some kind of nuclear medicine procedure. Physicians rely on X-rays and other imaging methods to diagnose medical problems without the need for invasive surgery. Radiation is used to treat leukemia and other types of cancer. Medical equipment is sterilized with radiation. Radioisotopes are used in developing more than 80 percent of all new drugs.

- Nuclear medicine technologists (NMTs) run tests on patients. They may prepare radioactive tracers; position patients for imaging; operate the nuclear instruments; collect, prepare, and analyze blood samples and other biological specimens; and prepare the information for the physician's use in making a diagnosis. NMTs must have a solid background in anatomy, physiology, math, chemistry, physics, laboratory technique, and radiation safety.
- X-ray technicians (also called radiologic technologists) prepare patients for X-rays and do X-ray imaging. Most work in hospitals, clinics, medical offices, and dental offices.
- Health physicists assure the safe use of radiation. Their job is to protect people and the environment from its harmful effects while applying the beneficial uses of radiation.

## Careers in Nuclear Energy

Nuclear energy can help to meet the growing demand for electricity worldwide while not emitting the large amounts of greenhouse gases produced by power plants that burn fossil fuels. Nuclear energy also powers ships, submarines, and satellites, and provides electricity for some spacecraft and space laboratories.

- Engineers design power plants and supervise their operations. They also work in nuclear fuel manufacturing.
- Reactor operators run the controls at commercial power plants that produce electricity.
- Nuclear energy technologists work in uranium mining and processing.
- Radiation protection technicians at nuclear power plants implement radiation control procedures to protect workers, the public, the environment, and the power plants.

## Careers in Agriculture and Food Technology

A growing world population needs more food. Radiation helps people develop plants that yield bigger crops, control pests without toxic chemicals, and make foods safer.

- Operators at irradiation facilities use radiation to destroy harmful microorganisms like salmonella and E. coli.
- Biologists experiment to develop new varieties of hardier, more disease-resistant crops.
- Research assistants help scientists and food engineers collect and analyze data.

### Other Nuclear-Related Career Choices

- Archaeology and paleontology
- Crime investigation
- Science education
- Art appraisal and authentication
- Nuclear industry regulation and inspection