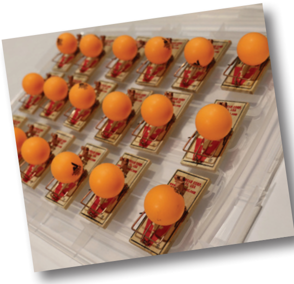
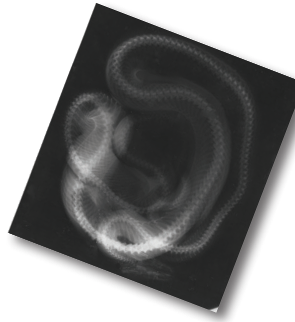
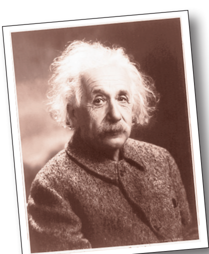
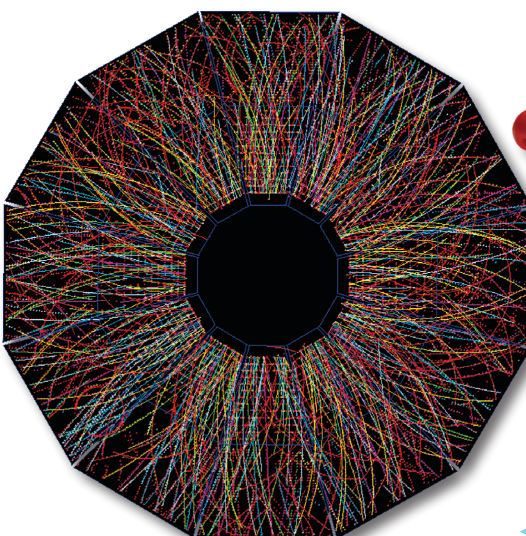
MERIT BADGE SERIES

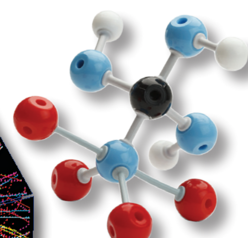




NUCLEAR SCIENCE







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MERIT BADGE SERIES

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Requirements

Always check scouting.org for the latest requirements.

1. Do the following:

   (a) Explain radiation and the difference between ionizing and non-ionizing radiation.

   (b) Explain the ALARA principle and the measures required by law to minimize these risks. Describe what safety requirements you will need to consider while performing the requirements in this merit badge.

   (c) Describe the radiation hazard symbol and explain where it should be used.

   (d) Explain how we are exposed to ionizing radiation from outside the earth as well as on earth every day. List four examples of Naturally Occurring Radioactive Materials, NORM, that are in your house or grocery store and explain why they are radioactive.

   (e) Explain the difference between radiation exposure and contamination. Describe the hazards of radiation to humans, the environment, and wildlife. Calculate your approximate annual radiation dose and compare to that of someone who works in a nuclear power plant.

2. Do the following:

   (a) Tell the meaning of the following: atom, nucleus, proton, neutron, electron, quark, isotope; alpha particle, beta particle, gamma ray, X-ray; ionization, radioactivity, radioisotope, and stability.

   (b) Choose an element from the periodic table. Construct 3-D models for the atoms of three isotopes of this element, showing neutrons, protons, and electrons. Write down the isotope notation for each model including the atomic and mass

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numbers. In a separate model or diagram, explain or show how quarks make up protons and neutrons.

3. Do ONE of the following; then discuss modern particle physics with your counselor:

   (a) Visit an accelerator, research lab, or university where scientists study the properties of the nucleus or nucleons.

   (b) List three particle accelerators and describe several experiments that each accelerator performs, including basic science and practical applications.

4. Do TWO of the following; then discuss with your counselor:

   (a) Build an electroscope. Show how it works. Place a radiation source inside and explain the effect it causes.

   (b) Make a cloud chamber. Show how it can be used to see the tracks caused by radiation. Explain what is happening.

   (c) Perform an experiment demonstrating half-life. Discuss decay chains.

5. Do ONE of the following; then discuss with your counselor the principles of radiation safety:

   (a) Using a radiation survey meter and a radioactive source, show how the counts per minute change as the source gets closer to or farther from the radiation detector. Place three different materials between the source and the detector, then explain any differences in the measurements per minute. Explain how time, distance, and shielding can reduce an individual's radiation dose.

   (b) Describe how radon is detected in homes. Discuss the steps taken for the long-term and short-term test methods, tell how to interpret the results, and explain when each type of test should be used. Explain the health concern related to radon gas and tell what steps can be taken to reduce radon in buildings.

   (c) Visit a place where X-rays are used. Draw a floor plan of this room. Show where the unit, the unit operator, and the patient would be when the X-ray unit is operated. Explain the precautions taken and the importance of those precautions.

6. Do ONE of the following; then discuss with your counselor how nuclear energy is used to produce electricity:

   (a) Make a drawing showing how nuclear fission happens. Observe a mousetrap reactor (setup by an adult) and use it to explain how a chain reaction could be started. Explain how a chain reaction could be stopped or controlled in a nuclear reactor. Explain what is meant by a "critical mass."

   (b) Visit a local nuclear power plant or nuclear reactor either in person or online (with your parent or guardian's permission). Learn how a reactor works and how the plant generates electricity. Find out what percentage of electricity in the United States is generated by nuclear power plants, by coal, and by gas.

7. Give an example of each of the following in relation to how energy from an atom can be used: nuclear medicine, environmental applications, industrial applications, space exploration, and radiation therapy. For each example, explain the application and its significance to nuclear science.

8. Find out about three career opportunities in nuclear science that interest you. Pick one and find out the education, training, and experience required for this profession and discuss this with your counselor. Tell why this profession interests you.

Contents

Nuclear Science: Going Beyond Chemistry 6
The Nature of Atoms 8
The Standard Model: Elementary Particles 16
What Is Radiation? 25
Putting Radiation to Work: Nuclear Technologies 37
Fission and Fusion: Nuclear Energy 48
Health Physics. 62
Nuclear Science Careers. 77
Nuclear Science Resources. 81

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.

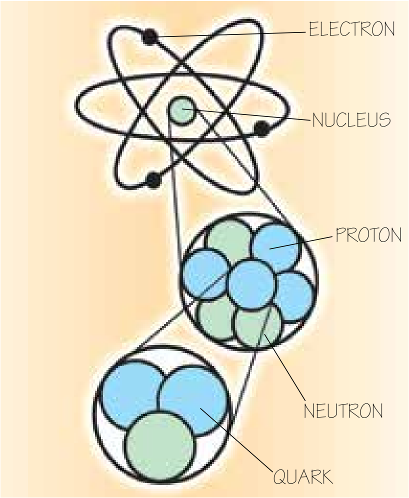
Physicists continued to try to understand the structure of atoms. They learned that all atoms are made of a few *subatomic* particles. Some atoms transform and give off *radiation.* Investigators moved atoms around using electrical charges and shot atoms or parts of atoms into each other, broke atoms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

The Nature of Atoms

The idea that everything is made of atoms goes back to the Greek philosopher Leucippus, who lived about 400 B.C.E. Leucippus and his student Democritus were among the first to believe that if you cut a piece of any material, such as copper, and cut it again and again many times, you would finally end up with a piece of the material that could not be cut. This would be an *atom* of that substance. Democritus believed (mistakenly) that atoms were held together by little hooks. Later, the philosopher Lucretius included the work of Leucippus and Democritus into his work *De Rerum Natura (On the Nature of Things)*.

Titus Lucretius Carus (circa 99–55 B.C.E.), a Roman poet and philosopher, mentioned atoms in his famous Latin work *De Rerum Natura (On the Nature of Things).*

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, copper, and gold. Each element consists of one basic kind of atom.

Not everyone was convinced. Plato, Aristotle, and other early scientists did not believe in atoms. Aristotle's ideas became the basis of science for more than a thousand years. But in the 15th century, Lucretius' work was rediscovered. Over many years scientists like Copernicus, Galileo, Francis Bacon, and Isaac Newton began to disagree with the great Aristotle on many ideas, including atoms.

John Dalton's Theory of Atoms

By 1803, John Dalton of England had done much work to prove that atoms exist. He combined his own work with that of other scientists to show how atoms behave in different conditions and to estimate the masses of different atoms. His theory of atoms was the first to explain chemical reactions as atoms combining and recombining with other atoms.

> Atoms are the smallest bit of an element, and different elements have atoms of different masses. *Mass* is the amount 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 is zero, but your mass is the same as it is on Earth.

Amedeo Avogadro in Italy came up with a better way to measure the masses of atoms. He showed that Dalton was on the right track but had made some mistakes. Avogadro was a good scientist but not a good writer. His work was not understood until another Italian, Stanislao Cannizzaro, explained Avogadro's ideas in 1858. Cannizzaro was the first to use the word **molecule** to describe chemical combinations of atoms.

By the 1870s, scientists everywhere were studying atoms. In Russia, Dmitri Mendeleev divided atoms into groups and represented them on a chart. Some of his ideas were wrong, but other scientists corrected his chart, and today this is the highly useful *periodic table of the elements.*

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.

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."

IUPAC Periodic Table of the Elements

Key:

atomic number **Symbol** name abridged standard atomic weight

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 **H** hydrogen 1.0080 ± 0.0002																	2 **He** helium 4.0026 ± 0.0001
3 **Li** lithium 6.94 ± 0.06	4 **Be** beryllium 9.0122 ± 0.0001											5 **B** boron 10.81 ± 0.02	6 **C** carbon 12.011 ± 0.002	7 **N** nitrogen 14.007 ± 0.001	8 **O** oxygen 15.999 ± 0.001	9 **F** fluorine 18.998 ± 0.001	10 **Ne** neon 20.180 ± 0.001
11 **Na** sodium 22.990 ± 0.001	12 **Mg** magnesium 24.305 ± 0.002											13 **Al** aluminium 26.982 ± 0.001	14 **Si** silicon 28.085 ± 0.001	15 **P** phosphorus 30.974 ± 0.001	16 **S** sulfur 32.06 ± 0.02	17 **Cl** chlorine 35.45 ± 0.01	18 **Ar** argon 39.95 ± 0.16
19 **K** potassium 39.098 ± 0.001	20 **Ca** calcium 40.078 ± 0.004	21 **Sc** scandium 44.956 ± 0.001	22 **Ti** titanium 47.867 ± 0.001	23 **V** vanadium 50.942 ± 0.001	24 **Cr** chromium 51.996 ± 0.001	25 **Mn** manganese 54.938 ± 0.001	26 **Fe** iron 55.845 ± 0.002	27 **Co** cobalt 58.933 ± 0.001	28 **Ni** nickel 58.693 ± 0.001	29 **Cu** copper 63.546 ± 0.003	30 **Zn** zinc 65.38 ± 0.02	31 **Ga** gallium 69.723 ± 0.001	32 **Ge** germanium 72.630 ± 0.008	33 **As** arsenic 74.922 ± 0.001	34 **Se** selenium 78.971 ± 0.008	35 **Br** bromine 79.904 ± 0.003	36 **Kr** krypton 83.798 ± 0.002
37 **Rb** rubidium 85.468 ± 0.001	38 **Sr** strontium 87.62 ± 0.01	39 **Y** yttrium 88.906 ± 0.001	40 **Zr** zirconium 91.224 ± 0.002	41 **Nb** niobium 92.906 ± 0.001	42 **Mo** molybdenum 95.95 ± 0.01	43 **Tc** technetium [97]	44 **Ru** ruthenium 101.07 ± 0.02	45 **Rh** rhodium 102.91 ± 0.01	46 **Pd** palladium 106.42 ± 0.01	47 **Ag** silver 107.87 ± 0.01	48 **Cd** cadmium 112.41 ± 0.01	49 **In** indium 114.82 ± 0.01	50 **Sn** tin 118.71 ± 0.01	51 **Sb** antimony 121.76 ± 0.01	52 **Te** tellurium 127.60 ± 0.03	53 **I** iodine 126.90 ± 0.01	54 **Xe** xenon 131.29 ± 0.01
55 **Cs** caesium 132.91 ± 0.01	56 **Ba** barium 137.33 ± 0.01	57-71 lanthanoids	72 **Hf** hafnium 178.49 ± 0.01	73 **Ta** tantalum 180.95 ± 0.01	74 **W** tungsten 183.84 ± 0.01	75 **Re** rhenium 186.21 ± 0.01	76 **Os** osmium 190.23 ± 0.03	77 **Ir** iridium 192.22 ± 0.01	78 **Pt** platinum 195.08 ± 0.02	79 **Au** gold 196.97 ± 0.01	80 **Hg** mercury 200.59 ± 0.01	81 **Tl** thallium 204.38 ± 0.01	82 **Pb** lead 207.2 ± 1.1	83 **Bi** bismuth 208.98 ± 0.01	84 **Po** polonium [209]	85 **At** astatine [210]	86 **Rn** radon [222]
87 **Fr** francium [223]	88 **Ra** radium [226]	89-103 actinoids	104 **Rf** rutherfordium [267]	105 **Db** dubnium [268]	106 **Sg** seaborgium [269]	107 **Bh** bohrium [270]	108 **Hs** hassium [269]	109 **Mt** meitnerium [277]	110 **Ds** darmstadtium [281]	111 **Rg** roentgenium [282]	112 **Cn** copernicium [285]	113 **Nh** nihonium [286]	114 **Fl** flerovium [290]	115 **Mc** moscovium [290]	116 **Lv** livermorium [293]	117 **Ts** tennessine [294]	118 **Og** oganesson [294]

57 **La** lanthanum 138.91 ± 0.01	58 **Ce** cerium 140.12 ± 0.01	59 **Pr** praseodymium 140.91 ± 0.01	60 **Nd** neodymium 144.24 ± 0.01	61 **Pm** promethium [145]	62 **Sm** samarium 150.36 ± 0.02	63 **Eu** europium 151.96 ± 0.01	64 **Gd** gadolinium 157.25 ± 0.03	65 **Tb** terbium 158.93 ± 0.01	66 **Dy** dysprosium 162.50 ± 0.01	67 **Ho** holmium 164.93 ± 0.01	68 **Er** erbium 167.26 ± 0.01	69 **Tm** thulium 168.93 ± 0.01	70 **Yb** ytterbium 173.05 ± 0.02	71 **Lu** lutetium 174.97 ± 0.01
89 **Ac** actinium [227]	90 **Th** thorium 232.04 ± 0.01	91 **Pa** protactinium 231.04 ± 0.01	92 **U** uranium 238.03 ± 0.01	93 **Np** neptunium [237]	94 **Pu** plutonium [244]	95 **Am** americium [243]	96 **Cm** curium [247]	97 **Bk** berkelium [247]	98 **Cf** californium [251]	99 **Es** einsteinium [252]	100 **Fm** fermium [257]	101 **Md** mendelevium [258]	102 **No** nobelium [259]	103 **Lr** lawrencium [262]

INTERNATIONAL UNION OF PURE AND APPLIED CHEMISTRY

The periodic table of the elements groups elements by similar chemical characteristics.

G.J. Stoney of Ireland studied electricity. He explained electric current as the movement of extremely small, negatively charged particles. In 1891 he used the name *electrons* for these particles.

In 1897, the 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 happen when an atom has either too many or too few electrons.

Ionization is any process that gives atoms an electric charge.

Isotopes—Alike but Different

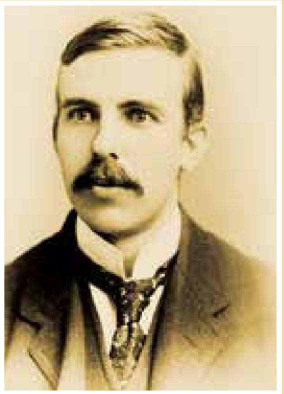
Scientists learned more by studying different kinds of atoms. In the early 1900s, Frederick Soddy of England investigated lead atoms and found three different "forms" of lead. These atoms had different masses, but they all reacted chemically like lead. Soddy named atoms of the same element with different masses *isotopes,* meaning "same place" in Greek.

Isotopes are atoms with the same number of protons, a different number of neutrons, different masses, and have the same chemistry. They may have very different physics and some isotopes are radioactive.

Parts of the Atom

At about the same time, Ernest Rutherford of New Zealand made the first of his many important discoveries. He confirmed what others believed—that an atom is mostly 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 it like a swarm of bees.

Sir Ernest Rutherford (1871–1937), known as "the father of nuclear physics," discovered and named some of the field's fundamental ideas: alpha, beta, and gamma rays; the nucleus; the proton; and half-life. In 1908, Rutherford won the Nobel Prize in chemistry for showing that radioactive elements become other elements when they decay. Most important was his discovery of the nucleus, the atom's core. (Note that during this time, nuclear science was still considered a part of chemistry—the study of how atoms combine.)



By 1913, Danish physicist Niels Bohr made a major advance in the understanding of the atom. His model had the nucleus in the middle but with electrons traveling in rings or "orbits" around it, like planets orbiting the sun. The further from the nucleus the electron is, the more energy it has.

About the same time, Henry Moseley of England found a way to determine the number of positive electric charges in a nucleus. He called this the *atomic number* of the atom.

After Moseley's death in World War I, his work on atomic numbers continued in Germany, France, and Britain. 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.

The *atomic number,* or Z, is the number of protons in the nucleus of an atom. This defines an element as atoms with the same atomic number. The atomic number determines the place of the element in the periodic table.

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 atomic number different from atomic mass?* Based on their work, Rutherford predicted the existence of a particle in the nucleus that had mass but no electrical charge.

Researchers looked for this neutral particle. Rutherford and James Chadwick of England tried experiments, which failed. Finally in 1932, 12 years after Rutherford's prediction, Chadwick found the *neutron*—a particle of an atom about the mass of a proton but with no electric charge.

The discovery of the neutron helped scientists explain both the atomic mass of an atom and what isotopes were. 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).

The *mass number,* or A, of an atom is the sum of the protons and neutrons in its nucleus. The *atomic mass* is the actual measure of mass (amount of matter) in the nucleus. An oxygen atom, for example, with eight protons and eight neutrons, has a mass number of 16. The atomic mass of oxygen is 15.99491461 atomic mass units (AMU). An AMU is a tiny unit used to measure the masses of atoms and molecules.

After the neutron's discovery, Werner Heisenberg suggested the nucleus was made of only protons and neutrons. Niels Bohr changed his own model to explain properties of atoms based on all three *subatomic particles.* Protons and neutrons (also called *nucleons*) make up the nucleus; electrons swirl around the nucleus in *shells.*

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

New discoveries modified Bohr's idea of orbiting electrons. By 1928, physicists had a fuller picture of the behavior of electrons. The work of Austrians Erwin Schrödinger and Wolfgang Pauli and Germans Max Born and Werner Heisenberg showed that electrons do not move in fixed orbits. An electron moves unpredictably within a space that may have a spherical or dumbbell shape. The shape of the electron's travel depends on its energy and the type of shell it is in.

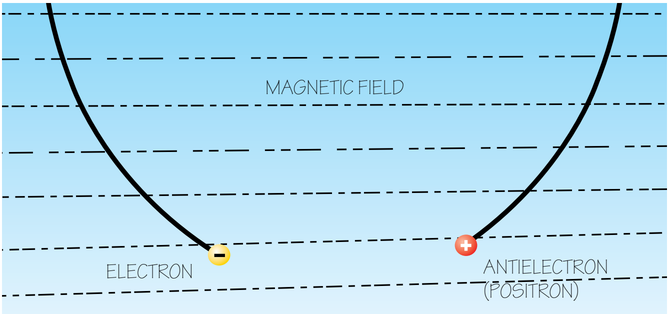
Exploring an Ever-Smaller World

As scientists improve the tools and techniques of nuclear science, we develop a better understanding of the particles and forces that make up the natural world. This increases our ability to explain the behavior of matter and to re-create particles that have not existed in nature since the beginning of the universe.

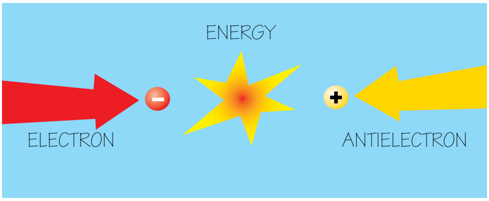
Antimatter

Antimatter, once only imagined in science fiction, has been found to exist in the real world. In 1928, theoretical physicist Paul Dirac predicted that, for every kind of matter, there existed an equal and opposite antimatter. If regular matter and antimatter came together, both would disappear. The only trace of their mutual annihilation would be a burst of energy left behind.

In 1932 at the California Institute of Technology, Carl Anderson was studying *cloud chamber* photographs of particles passing through a magnetic field. (See "Build a Cloud Chamber" in the chapter "What Is Radiation?") One picture showed an electron that turned opposite the way it should have. This *anti-electron* had a positive charge and behaved exactly the opposite of a normal electron. Anderson called it the **positron** because of its positive charge. This was the first observation of antimatter in our world.



Antimatter behaves exactly the opposite of its regular matter counterpart.



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

Particle accelerator experiments discovered more examples of antiparticles. These confirmed Dirac's earlier predictions. Now, accelerators produce antimatter nuclei and atoms. Although antimatter is not seen as a practical way to generate useful energy, it is imagined as an efficient energy storage system, and there are visionary proposals to use antimatter to power future generations of spacecraft.

Richard Feynman (1918–1988) was a 1965 Nobel Prize winner and one of the most influential physicists of the 20th century. He described how charged particles (and their antiparticles) interact through *electromagnetic* force—or, simply put, how light and matter interact. To analyze and accurately predict these particle interactions, he developed a new form of mathematics.

Neutrinos

In 1930 Wolfgang Pauli predicted a particle with no charge and almost no mass. Detecting it would be difficult because it didn't seem to "do" anything—it didn't interact with matter like *ionizing radiation* did. (See the chapter "What Is Radiation?") Pauli envisioned it as a sort of "ghost particle" because it would pass through regular matter with almost no interaction.

It took 26 years before Fred Reines and Clyde Cowan (1995 Nobel Prize winners) gathered hard evidence that the *neutrinos* Pauli predicted really exist. In 1962, Leon Lederman, Melvin

Schwartz, and Jack Steinberger (1988 Nobel laureates) used the Brookhaven National Laboratory accelerator to produce evidence of two types of neutrinos.

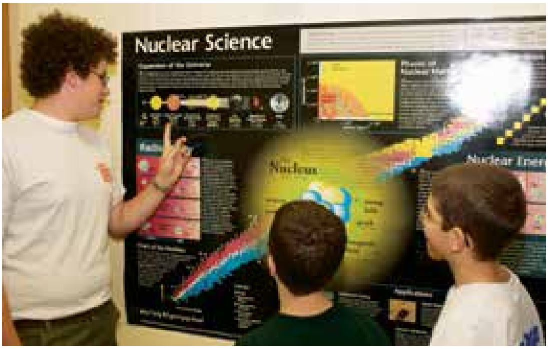
Neutrinos can pass through solid matter with only a slight chance of a collision. A beam of neutrinos can travel completely through Earth without losing intensity. The ability of neutrinos to penetrate matter makes them useful in the study of particles. Using particle accelerators, physicists have learned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

Continuing Discoveries About the Nucleus

Physicists have learned that the nucleus often behaves as if it were a raindrop, moving fluidly, constantly changing shape like a drop of liquid. It can be round like a tennis ball or shaped like a football. It can vibrate or, if football-shaped, spin. James Rainwater, 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.

Some atoms are known to be stable, while other isotopes of the same element can be unstable. *Stability* in an atom means that it does not give off any form of radiation. For example, of the 14 isotopes of carbon, 12 of them undergo radioactive decay and two (carbon-12 and carbon-13) are stable. Maria Goeppert-Mayer and J. Hans D. Jensen (1963 Nobel laureates) created the *nuclear shell* model to explain this. They figured out that protons and neutrons in stable nuclei move like pairs of dancers, spinning together clockwise or counterclockwise. As they spin, they move around in "shells" or defined spaces inside the nucleus. Goeppert-Mayer and Jensen found that a nucleus with its shells exactly filled tends to be stable.

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



The Standard Model: Elementary Particles

In 1964, Murray Gell-Mann and George Zweig of the California Institute of Technology proposed that even protons and neutrons could be broken down into simpler particles.

Quarks

Using particle accelerators, researchers shattered protons and neutrons into pieces that 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.

Quarks determine if proton or neutron.
Protons determine chemical properties.
Ratio of neutrons to protons make a nucleus *stable* or *unstable*.

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.

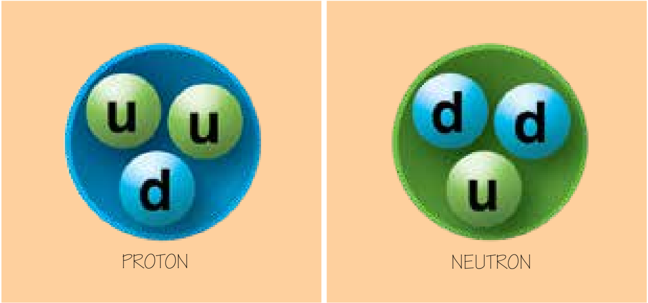
Leptons

Quarks are called *elementary particles* because they have no known smaller parts. There is another type of elementary particle called *leptons.* The best-known lepton is the electron, but physicists have identified five others. The six leptons are divided into three families: (1) the electron and its neutrino; (2) the *muon* and its neutrino; and (3) the *tau* and its neutrino.

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 nuclei together. The work is an important step toward providing a unified (single) description of all the forces of nature, from the tiny distances within the nucleus of an atom to the enormous expanse of the universe.

The electron, the muon, and the tau have electrical charge. The other leptons—the three neutrinos—do not.

Electrons are stable. The muon and the tau are more massive than the electron, and they are unstable. They are short-lived and are not found in ordinary matter at all.



Quarks form the fundamental building blocks of protons and neutrons. Gluons keep the quarks together. Note: The symbols on the Nuclear Science merit badge reflect the quarks' structure of protons and neutrons.

Elementary particles of matter—quarks and leptons—have no measurable size. Physicists describe them as "pointlike."

Force Carriers

The elementary particles interact; that is, they affect one another because of particles called *force carriers*. The gluon that binds quarks together is a force carrier. Another force carrier is the *photon*, which carries the electromagnetic force that acts between electrically charged particles. The force carriers *W boson* and *Z boson* transmit the *weak force* that acts on quarks and leptons but only for distances smaller than an atomic nucleus.

Elementary Particles

Quarks	u	c	t	g	Force Carriers
	d	s	b	γ	
Leptons	ν_e	ν_μ	ν_τ	W	
	e	μ	τ	Z	
3	I	II	III	Generations	

The Standard Model

"The Standard Model" is the current theory of the structure of matter. It says that matter is made up of quarks and leptons that interact by exchanging force-carrying particles. The chart shows the elementary particles that are thought to make up all of the physical world and make matter behave as it does.

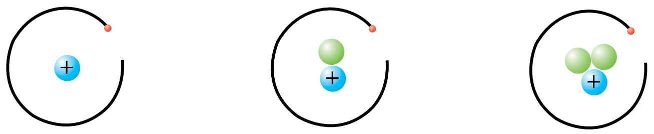
The Higgs boson discovery at the Large Hadron Collider helped scientists understand the nature of the universe and what it's made of.

Make 3-D Models of Isotopes

Models that can be touched are called *physical models.* (The Standard Model is a *mental model*—a model of ideas.) You will make physical models of isotopes to help explain to your merit badge counselor the difference between mass number and atomic number and the difference between the atom, nuclear, and quark structures of isotopes.

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 isotope notation, ordinary hydrogen is ^{1}H. There are two other hydrogen isotopes: deuterium (written in isotope notation as ^{2}D) with 1 proton and 1 neutron, and tritium (^{3}T or ^{3}H) with 1 proton and 2 neutrons.

Now use your imagination (and whatever materials are handy) to make a 3-D model of each isotope. Successful atomic models have been made with pizza or cookies or Styrofoam balls. On the next page is an example to get you thinking about the three isotopes of hydrogen. If you wish, you can make models of three isotopes of an element other than hydrogen, like carbon.



HYDROGEN	DEUTERIUM	TRITIUM
1 PROTON	1 PROTON	1 PROTON
1 ELECTRON	1 ELECTRON	1 ELECTRON
ATOMIC NUMBER = 1	1 NEUTRON	2 NEUTRONS
MASS NUMBER = 1	ATOMIC NUMBER = 1	ATOMIC NUMBER = 1
	MASS NUMBER = 2	MASS NUMBER = 3

How To Build Isotope Models

Materials You Will Need

- ❑ 3 large clear plastic fillable balls or ornaments (label one "Proton" and two "Neutron")
- ❑ 1 small white pompom (the electron)
- ❑ 1 pipe cleaner (the electric attractive force)

Build a Hydrogen Atom

Bend one end of the pipe cleaner around the loop of the proton ball. Bend the other end around the white pompom.

If a hydrogen atom were the size of a football stadium, the proton would be the size of a marble, and the electron and quarks would be too small to see.

Build a Deuterium Atom

Add the neutron ball to the pipe cleaner. The neutron and proton should touch.

The neutron and the proton have about the same mass, but much more mass than the electron. A proton has almost 2,000 times as much mass as an electron.

Build a Tritium Atom

Connect a neutron ball with a pipe cleaner to the deuterium model so that it touches both the other neutron and the proton.

Tritium is radioactive, with a half-life of 12.3 years, changing into Helium-3.

How To Build Quark Models

You could also build a model to represent quarks.

Materials You Will Need

- ❑ 5 medium red pompoms (for the down quarks)
- ❑ 4 medium blue pompoms (for the up quarks).

Build a Proton

Put two red balls and one blue ball in a transparent ball.

Real quarks are not stationary, but are always moving inside their proton. Quark containment means you cannot separate a single quark from a proton.

Build a Neutron

Put one red pompom and two blue pompoms in a transparent ball.

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.

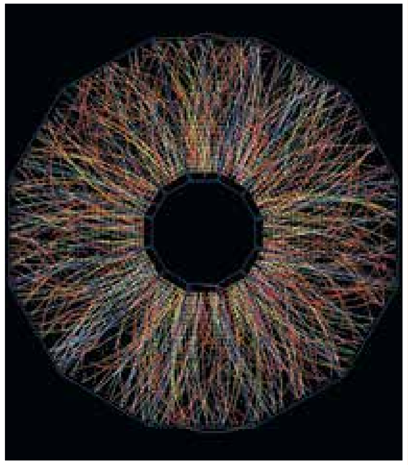
Learn About Particle Accelerators

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 **Large Hadron Collider (LHC)** in Geneva, Switzerland, is the world's largest and highest-energy particle accelerator. Scientists use the LHC's 17-mile-long underground ring to smash beams of protons or heavy ions into one another. Physicists are using the collider to help explain the interactions and forces among the elementary particles and to test theories about the structure of the universe.

The **Relativistic Heavy Ion Collider** at Brookhaven National Laboratory in Upton, New York, accelerates ions to *relativistic* (near-light) speeds and smashes them together. The goal is to re-create a *quark-gluon* plasma—the super-hot, ultra-dense, soup-like form of matter that existed in the universe's first microseconds, beginning the formation of the universe as we know it.

The **Thomas Jefferson National Accelerator Facility** in Newport News, Virginia, is a *fixed-target accelerator* that creates a continuous stream of high-energy electrons. The machine steers the electrons into stationary nuclei, which shatter into smaller particles.



A high-energy collision of gold nuclei by the STAR experiment at Brookhaven National Laboratory produced the pattern shown in this picture.

Scientists analyze these fragments to measure and study the quark content of the nucleus.

The **Facility for Rare Isotope Beams** at Michigan State University is the most powerful heavy-ion accelerator where scientists study the structure of atomic nuclei.

The **Advanced Light Source,** a division of Lawrence Berkeley National Laboratory in Berkeley, California, produces light—mainly X-rays—with special qualities. Scientists use these X-rays to probe the structure of atoms and molecules, explore the properties of materials, investigate chemical reactions, analyze samples for trace elements, and even manufacture microscopic machines.

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

One example is the: **Center for Accelerator Mass Spectrometry (CAMS)**, at Lawrence Livermore National Laboratory in Livermore, California. CAMS is used for a broad range of scientific missions such as climate change, forensics, radiocarbon-dating, and public health.

Linear accelerators can be used for medicine, too. For instance, using a beam of protons or particles to destroy hard-to-reach tumors or tumors resistant to other forms of treatment.

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

- How does the accelerator work? Is it a *linac* (linear accelerator) 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 it designed to do? What questions does the research seek to answer?
- 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 position here?
- Are there radiation hazards around this machine? Why or why not? How are people protected from potential hazards?

You too can build cloud chamber, a vessel that shows the paths or tracks of electrically charged particles passing through. **See instructions on page 32.**

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.

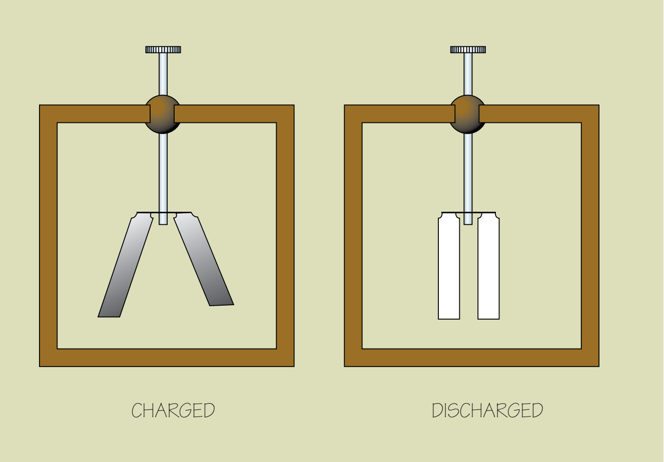
X-rays proved to be important not only in medicine, but also in giving scientists new insights into the nature of radiation and the structure of the atom. Scientists soon found that X-rays made ions of the atoms in air. Because of this, we call X-rays *ionizing radiation.*

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.

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

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.

Build an Electroscope

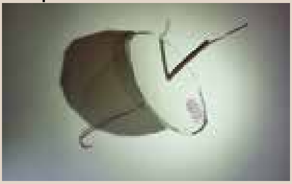
Materials You Will Need

- ❑ Balloon
- ❑ 5-inch copper wire
- ❑ Plastic coffee stirrer
- ❑ Pop-Tart® wrapper
- ❑ Pushpin
- ❑ 5-inch square aluminum foil
- ❑ Wide-mouth glass canning jar
- ❑ Styrofoam plate
- ❑ Masking tape
- ❑ Permanent marker
- ❑ Scissors
- ❑ 1 teaspoon of salt or desiccant
- ❑ Gas lantern mantle containing thorium or a small rock containing autunite or uranium (Adults must handle these radioactive materials!)

Step 1—Clean and dry the canning jar.

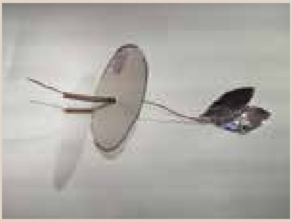
Step 2—Trace around the lid of the jar onto the Styrofoam plate with a pen and cut out the circle. This will be the lid of the jar.

Step 3—Use the pushpin to poke a small hole in the center of Styrofoam. Cut a 1½-inch piece of the plastic coffee stirrer and place into the hole in the Styrofoam circle.



Step 4—Make a small hook on one end of copper wire. Thread wire through the plastic coffee stirrer and place through the hole in the Styrofoam lid.

If you need a source for the thorium gas lantern mantle for building an electroscope, visit Gas-Lights.com with your parent or guardian's permission and look for Coleman lantern mantles containing thorium. Thorium makes a bright white light.



Step 5—Cut two small leaves about an inch long from the Pop-Tart® wrapper. With the pushpin, punch a small hole in the pointy end. Carefully thread both leaves through wire.

Step 6—Heat a spoonful of table salt in an oven at 350 degrees, then drop the salt into the dry bottle or use desiccant. This will absorb moisture from the air in the bottle.

Place lid with leaves onto jar, tape around jar to make airtight. The leaves should not touch the bottom of the jar. Crumble up a 1-inch ball of aluminum foil and place on top of the wire outside the jar.

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 or small rock containing uranium or autunite. All three materials are radioactive.

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 the thorium radiation discharge the electroscope?

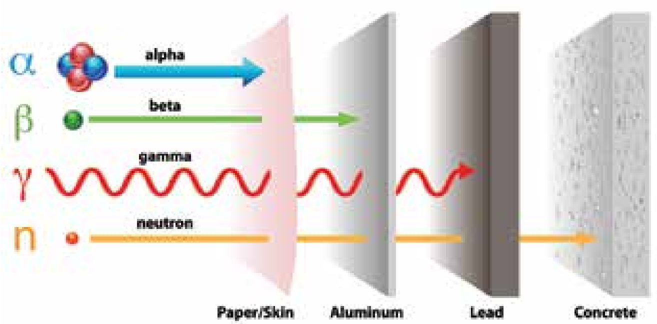
Hint: If you ionize the air, the charge will leak faster. Radiation will ionize air.

Types of Radiation

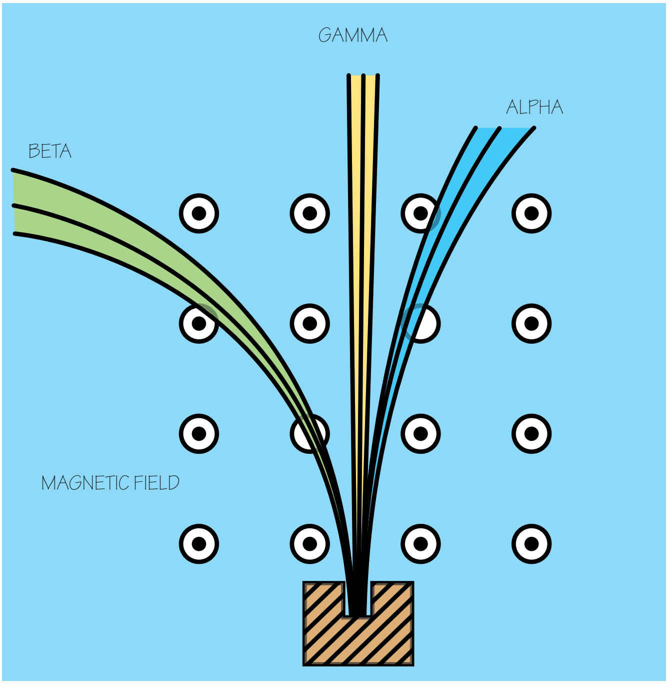
Ernest Rutherford found that uranium had two types of radiations. One type, which he named *alpha rays,* would not go through a sheet of paper. The second kind, *beta rays,* was more penetrating. One sheet of paper would stop an alpha ray, but it took a hundred sheets to stop beta rays.

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.

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.



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.



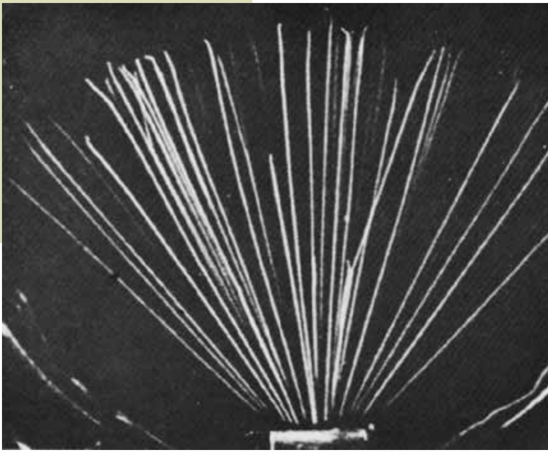
In 1903, Marie Curie pictured how radiation is bent by magnets. The paths of alpha particles (positively charged) are bent one way, and the paths of beta particles (negatively charged) are bent the opposite way.

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. In SI units, you may see 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.

Charles Thomson Rees Wilson (1869–1959) received the Nobel Prize in physics in 1927 "for his method of making the paths of electrically charged particles visible by condensation of vapour"—the expansion cloud chamber. He was a meteorological observer in Scotland where he tried to reproduce clouds in his lab by expanding and cooling air. In 1896, he fired some newly discovered radium through a cloud and saw it left a trail of water droplets in the gas. Wilson's cloud chamber was used for many years in nuclear physics.



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

Build a Cloud Chamber

Although ionizing particles are invisible, you can use a cloud chamber to see the tracks the particles leave behind. You can build a cloud chamber with household items, or you can buy a kit from an educational supply store.

Materials You Will Need

- ❑ Clear polystyrene petri dish* (available from biological supply companies)
- ❑ Methanol or HEET™ (methyl alcohol, available from automobile parts stores) or propanol-2*
- ❑ Black felt strip
- ❑ Flashlight
- ❑ Tweezers
- ❑ Dry ice** (available from some grocery or ice cream stores. Buy dry ice the morning of the demonstration in order to minimize the sublimation losses of the dry ice. If you must buy the evening before, store in a sealed cooler that allows the CO_2 gas to vent as it sublimes from the solid form. The loss rate of dry ice is somewhere between 5-10 pounds in 24 hours.)
- ❑ Thick leather Gloves
- ❑ Scuba-mask defogger
- ❑ Gas lantern mantle containing thorium or a small rock containing autunite or uranium (Adults must handle these radioactive materials!)

Step 1—Spray the outside of the bottom of the petri dish black. Place a strip of felt on the inside of the bottom rim.

Step 2—With an eye dropper, carefully add about 3 ml of methanol to petri dish around felt rim.

*Methanol is flammable and poisonous. Keep it away from heat and open flame. Use it in a well-ventilated area, wear plastic gloves to protect your skin, and never drink it.

Step 3—Using tweezers and with adult supervision, place small radioactive source or rock in center of petri dish. Close dish.

You can get a small radioactive source at a rock or hobby shop or an educational supply store to place in the jar and increase the radiation, rather than depend on natural cosmic rays.

Step 4—Wearing thick leather gloves, place the petri dish on a cake of dry ice. Seal the chamber and wait 10-15 minutes to allow the supersaturated zone of alcohol to form a layer near the bottom of the dish. Be sure the petri dish is in good contact with the dry ice.

**Dry ice can severely damage your skin. Never handle it bare-handed; always wear thick gloves and eye protection. Set the dry ice in a box or on a tray to protect your tabletop or work surface. Dry ice changes to carbon dioxide gas, so operate your cloud chamber in a well-ventilated area.

Step 5—Expect to observe particle tracks within 10-15 minutes, though there are cases where the tracks may appear within a few minutes, and others where it takes longer. In some rare cases, if the saturated zone does not form, the chamber might have to be adjusted: perhaps a little more alcohol, a new piece of felt, and then resealed. Use a strong flashlight well placed to shine at an angle to the petri dish. If you see only a very thick mist and no tracks, open the petri dish and let some of the vapor escape.

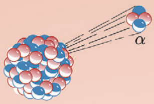
What Is Happening?
An electrically charged cosmic particle that passes through the cloud chamber ionizes the alcohol vapor—that is, it strips electrons from some of the atoms along its path. Removing electrons (which are negatively charged) leaves the atoms positively charged. This triggers condensation that reveals the path the particle took through the chamber. The condensed droplets of alcohol make the particle's trail visible. Short and fat trails are from alpha particles; fine, curly trails are beta particles; and long, straight trails are from muons (cosmic rays). Forked tracks are from a particle decay.

Visualize Radioactive Decay

Can you spot these different types of radioactive decay?

LOOKS LIKE THIS IN THE CLOUD CHAMBER

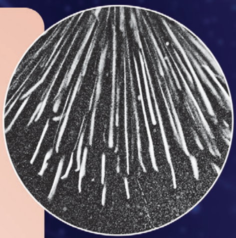
α-decay
(alpha decay)



The nucleus emits two protons and two neutrons bound together in a particle identical to a helium nucleus. Alpha particles are heavy and only travel very short distances.

USES FOR ALPHA DECAY

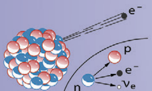
Alpha "seeds" inserted in tumors | Electricity and mineral testing in space vehicles | Power for drones



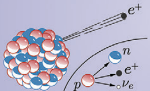
Short and fat trails

β-decay
(beta decay)

There are two types of beta decay. In both, the nucleus emits a positive or negative particle. Beta can travel farther and penetrate about ½ inch into the body.

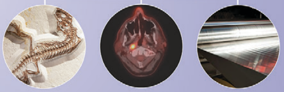


β− decay
Neutron becomes a proton and emits a tiny, negatively charged particle like an electron

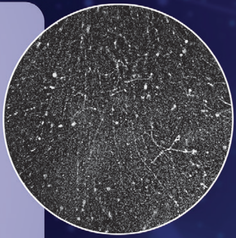


β+ decay
A proton becomes a neutron, and a positron, a tiny particle with positive charge, is emitted

USES FOR BETA DECAY

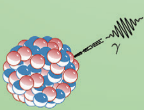


Carbon dating of artifacts | Positron Emission Tomography (PET) scan image | Measuring aluminum foil thickness



Fine, squiggly trails

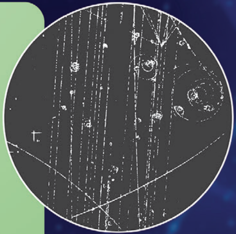
γ-decay
(gamma decay)



Gamma radiation is a ray of pure energy. The rays travel great distances at the speed of light and can penetrate many materials.

USES FOR GAMMA DECAY

Deep Space Telescopes | Detecting flaws and cracks in materials | Sterilizing medical instruments



Leaves no trail, but affects other particles that leave trails

American Nuclear Society ans.org

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.*

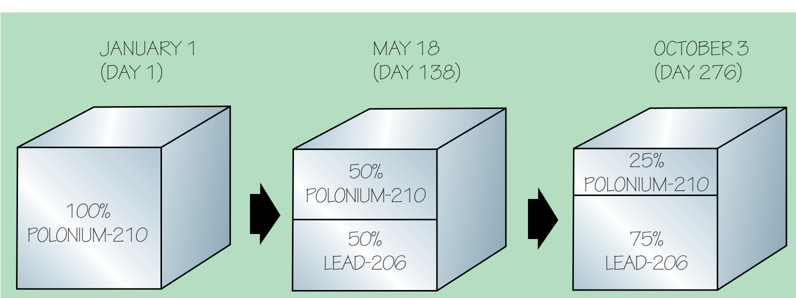
Rutherford found that radioactive materials get less radioactive as they get older. The radioactive nuclei change into stable (nonradioactive) nuclei as they give off radiation, a process called *radioactive decay.*

> *Decay time*—the time it takes for a radioactive element to transform into a different element by giving off particles. This decay leads to a less energetic, more stable nucleus.

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.

Rutherford called the amount of time it takes an element to lose one-half of its radioactivity its *half-life.* Half-life is the time required for half of the unstable atoms to decay.

You can't judge how much radiation is being produced based on the physical size of the source. Radioactive material with long half-lives, meaning it decays away slowly, will not give off a lot of radiation per unit mass. This is referred to as the isotope's *specific activity*. For isotopes like cobalt-60, which only has a half life of a few years, a gram of cobalt-60 has the same activity (number of decays per minute) as 1800 tons of uranium. 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.



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

Half-Life Activity

Half-life is the statistical time it takes for an isotope to reduce its starting quantity by half.

Start with 100 coins in a resealable bag. Each coin represents a nucleus.

Step 1—Shake the bag and carefully put the coins on the table. What is the chance of a flipped coin landing on heads? (Statistically a quarter has a 50% chance of landing on heads or tails.)

Step 2—Separate heads and tails. Count the number of heads and write the number down.

Step 3—Set aside the tails. Put the heads back in the bag.

Repeat all steps until there are no more coins to put back in the bag.

Look at the numbers you wrote down. You can make a graph on graph paper or with the coins in stacks. What does your graph look like? Is it a straight line or is it another shape?

Repeat this activity a few more times and compare results.

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. Most X-ray techniques for imaging are known as transmission techniques that are good for anatomical imaging. Anatomical imaging refers to the fact that the imaging technique is primarily intended to reveal differences in the structure of anatomy.

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. X-rays are sensitive to different densities of material so they are well suited for imaging solid structures. X-rays come from electron's binding energy and any other excess energy that was imparted to the electron while being removed from its bound state.

Visit an X-ray Room

Make arrangements with your counselor to visit an X-ray room. Talk with the operator about their 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).

Try this experiment: Ask the technician if they would take an X-ray of objects like a penny, a Lego® brick, a small wooden object like a Pinewood derby car, and a gummy bear or similar soft candy. Note the differences in the brightness of each and write down your findings. Discuss why the different parts of the image have different levels of brightness.

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.

Nuclear medicine can be confusing to describe since it refers to both imaging using nuclear emissions of rays of particles and therapy that uses the same or similar rays and particles. By *therapy* we mean that the intention of nuclear medicine is to destroy diseased tissues such as cancerous tissues or to eliminate hyperactive thyroid.

Nuclear medicine techniques can use gamma rays to image. Gamma rays do not come from electron binding energies exchange but rather initiate from energy changes inside of the atom's nucleus. As nucleons change their energetic state, gamma rays can be directly emitted from the nucleus or other particles will be emitted from the nucleus.

Try this experiment: Ask a nuclear medicine technologist about how much activity they inject for kidney imaging and what the name, isotope and half-life is of the radionuclide that is injected.

• Repeat the same questions, but this time ask for thyroid ablation (removal of the thyroid).

• Compare the answers. Why do you think one is higher than the other?

• Background activity in some parts of Washington, D.C., can be 0.3 microCuries. How many half-lives would it take for the radionuclides above at the stated injected activity before the activity would be the same or slightly lower as the stated background activity in Washington?

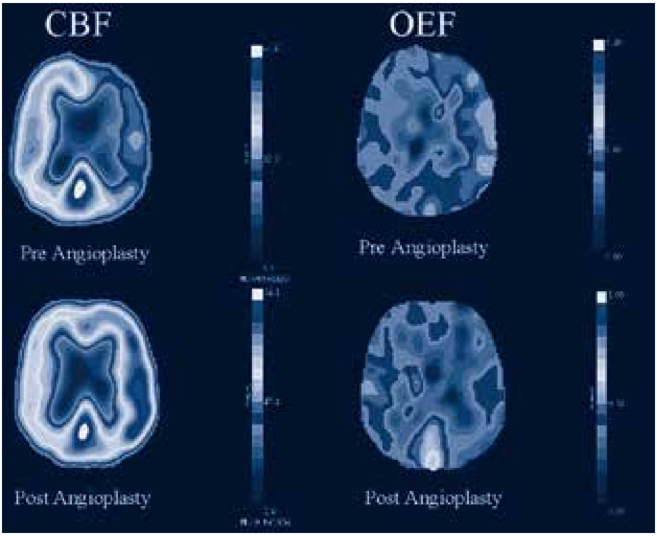
For thyroid disorders, such as Graves' disease, treatment with radioactive iodine is so successful that it has virtually replaced thyroid surgery.

Radiation Therapy

Radiation therapy takes on several forms. Radiation therapy, as stated above can be from nuclear medicine approaches with injectable isotopes or from X-ray emitting machinery.

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 is minimized. Types of cancer that often are treated with radiation therapy include cancer of the larynx (the voice box) and prostate cancer.

Rosalyn Yalow (1921–2011) earned a doctorate in nuclear physics and, while working at the Bronx (NY) 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.



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

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

Modern radiation therapy can use a collimated beam of neutrons or accelerated charged particles such as electrons or protons. It has been only in this century that accelerated protons are commercially available and can be found in some hospitals. The benefit of using accelerated charged particles is that as they traverse tissue on their way to a tumor, the

If you break your arm and get an X-ray at the doctor's office, does your arm become radioactive? Maybe just for a few minutes? Objects (and people) do not become radioactive when exposed to X-rays. Although some of the energy of the X-ray beam is deposited in your bones and tissues, this energy does not make your body radioactive.

particles deposit only a small amount of energy to the healthy tissue however, almost as if by magic, they deposit a large amount of energy at the end of their path thus selectively destroying tissues at the end of the path that can be several centimeters below the surface of the human body.

Try this experiment: Ask the technologist or medical physicist to show you how a radiation therapy treatment using high-energy X-ray beams or accelerated charged particle beams is performed using computer software. Ask what types of medical images are used to help in the planning process. Ask if, besides anatomical referencing what other information from the medical images is used in the treatment plan.

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.

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

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.

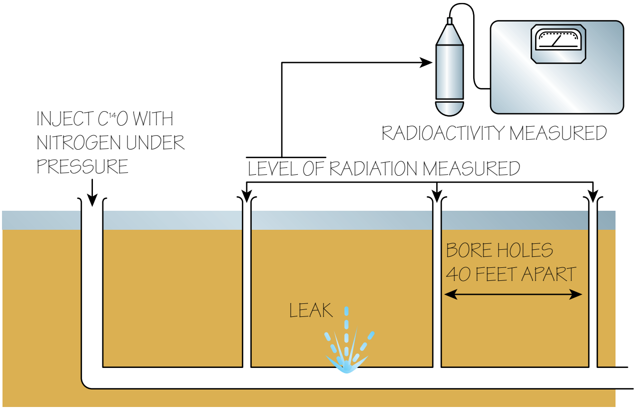
Irradiated foods are labeled with a symbol called the radura—simple green petals in a broken circle. The symbol is used worldwide to identify food that has been irradiated. The package also will have the words "treated by irradiation."

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.

Nuclear techniques have been used to sterilize insects to eradicate agricultural pests, like the tsetse fly in Ethiopia and the Mediterranean fruit fly in Jordan. Another nuclear technique, isotopy hydrology, can desalinate sea water, making more freshwater available for human use.

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.

Radiography lets us take a picture of the inside of things without cutting them open. Note the broken finger in this radiograph.

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.

Vaseline glass made with uranium fluoresces in ultraviolet light.

Radiation in Art History

Art historians use radiation techniques for detailed analysis and preservation for paintings. They use photon, X-ray and neutron beams produced by particle accelerators and research reactors to scan paint samples or entire paintings to learn more about their composition, manufacturing methods and history.

In 2022, a conservator at the National Gallery of Scotland was preparing for an exhibition and X-rayed a

Vincent Van Gogh painting, *Head of a Peasant Woman*. Visible on the X-ray was a hidden self-portrait on the back of the painting. Artists at the time sometimes reused canvases to save money, but this was a significant discovery.

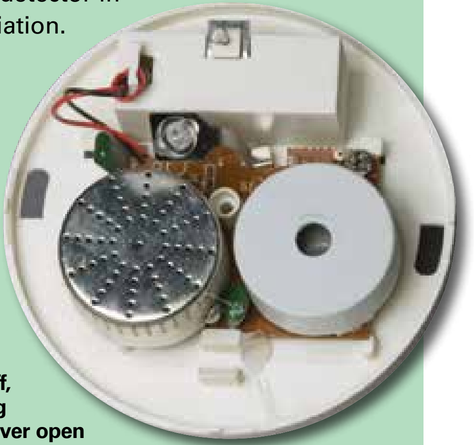
Typically yellow, topaz becomes blue after irradiation.

Irradiated Gemstones

Some gemstones are exposed to radiation to change their color. In the early 1900s scientists like Bordas and Crookes used radium salts to change blue sapphires and diamonds green. Now scientists use gamma rays from cobalt and put the gems in a closed, heavily shielded container and leave them there until they change color or they use a research reactor or particle accelerator. The radiation causes electrons to be knocked off some atoms, leaving them free to be absorbed by others. They call this creating a "color center" which changes how light is absorbed into the gem. The resulting gemstones are not radioactive and they are safe to wear.

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. (Note: Never open the radioactive source container in a smoke detector.)

Radiation in Science

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

Radiocarbon Dating

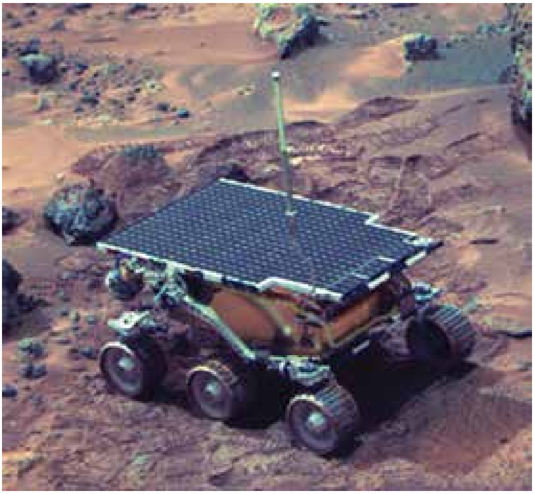
All living things have some radioactive carbon-14 in them. Because living things no longer take in carbon-14 when they die, we can measure the amount left in substances that once were living, such as wood, and figure out when the living thing died. Archaeologists and paleontologists use this measurement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

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.



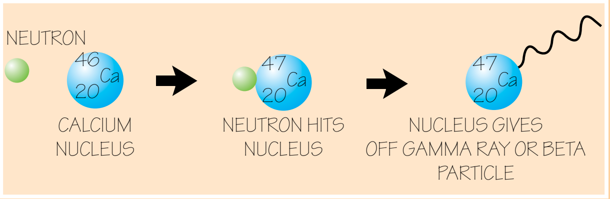
NASA's Mars rover *Sojourner* spent 83 days of a planned seven-day mission exploring the Martian terrain in 1997, acquiring images, and taking chemical, atmospheric, and other measurements.

Radiation exposure during spaceflight is a serious threat to an astronaut's health. The radiation environment outside of Earth's protective atmosphere is comprised of energetic protons and heavy nuclei that pose a hazard to living organisms. NASA's Space Radiation Element is working to characterize health outcomes associated with space radiation exposure so that they can protect astronaut health and ensure safe human spaceflight.

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.



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 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 to prevent releasing pollutants into our environment. Ecologists can follow the movement of tiny amounts of insecticides in the environment.

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.

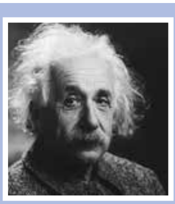
Neutron activation allows scientists to measure the pollution that was in the air decades ago, when this tree was alive and growing.

Fission and Fusion: Nuclear Energy

A *joule* is an energy unit. A burning match will produce 1,100 joules.

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).

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.



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.

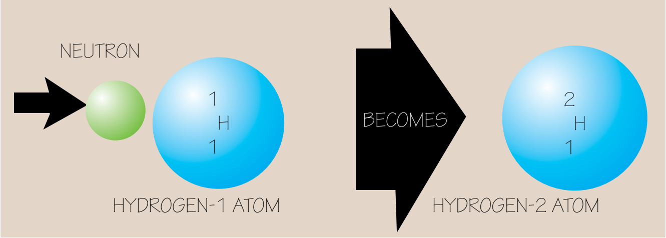
Neutrons as Atomic Bullets

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.

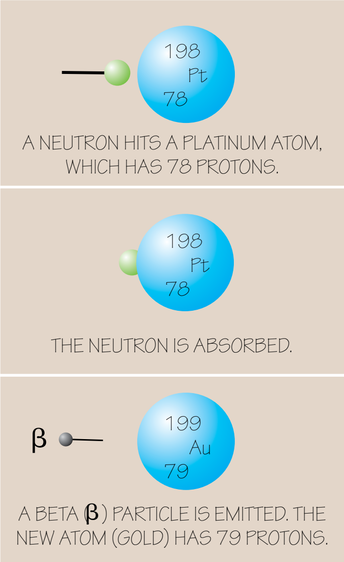
Two things can happen to an atom hit by a neutron. One possibility is that it will add one unit to the atom's mass number. When a neutron is added to the nucleus, the atomic number stays the same; only the mass number is changed.

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



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



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.

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.

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?

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.

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.

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 radio-actinium. 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. Element 105 was named hahnium in his honor.

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. Element 103 was named lawrencium in his honor.

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.

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 co-wrote 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.

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.

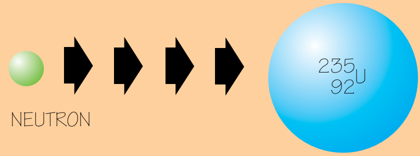
In December 1942, Fermi and a group of other scientists completed the first atomic *pile.* This was a stack of blocks of graphite containing uranium in carefully spaced lumps. The graphite was the moderator. Rods of cadmium in the pile soaked up neutrons before they could hit the uranium. These *control 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.

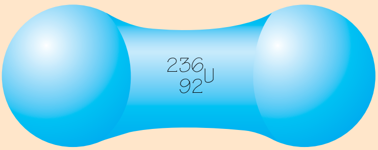
The stack of blocks Fermi used was called a nuclear pile. Modern devices for hosting chain reactions are called *nuclear reactors.* A *critical mass* of nuclear fuel is necessary to sustain a chain reaction. Too little fuel produces too few neutrons to keep the fissions going.

How Fission Works

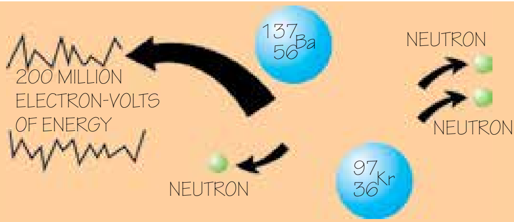
1. A neutron hits a uranium nucleus.



2. The nucleus stretches and bends.



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



Fission creates many different combinations of fission products. Barium and krypton are shown as possible examples.

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.

The fission process changes mass to energy consistent with Einstein's equation (page 48). The neutron and the target nucleus have more mass than the fission fragments and free neutrons. Fission converts about 3 millionths of an attogram (0.000 0000 000 000 000 000 000 000 03 grams) to energy. The lost mass is also called the mass defect.

Working with mousetraps can be tricky. Some mousetraps are sensitive and can snap on your fingers. Gloves may help. Set the traps carefully.

Make a Mousetrap Reactor

In this fun experiment, you can watch a demonstration of a chain reaction to show how nuclear fission works.

Materials You Will Need

- ❑ Transparent plastic box
- ❑ Knife or scissors
- ❑ 20 (or more) spring mousetraps
- ❑ 20 (or more) pingpong balls
- ❑ Gloves

Step 1—Carefully cut a small hole in one edge of the bottom of the plastic box, large enough for a pingpong ball to fit through easily.

Step 2—Place the lid of the box on a flat surface. Put all mousetraps in lines, covering the entire lid with traps. Ask an adult to carefully set the traps.

Step 3—Have an adult gently place a pingpong ball on each mousetrap. Don't set off any traps! *See the photo in the upper left corner of the cover of this pamphlet.*

Step 4—The adult can then place the box bottom on top of the lid. This contains the reaction and protects anyone from being hit by a ball.

Step 5—Drop a pingpong ball into the box through the top hole of the reactor chamber. Watch quickly! It lasts only a few seconds.

How It Works

Critical System—Each mousetrap represents a nucleus of U-235. A free neutron (the additional pingpong ball put into the box) initiates a chain reaction and fissions a U-235 nucleus by triggering a mousetrap. More neutrons (pingpong balls) are released and they fission other neutrons.

Subcritical System—Place a few mousetraps with pingpong balls far apart in the box. One mousetrap should be directly beneath the hole, so at least one mousetrap will set off. It may take some experimentation to figure out what the critical mass for mousetraps is for your reactor.

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.

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 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.

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.

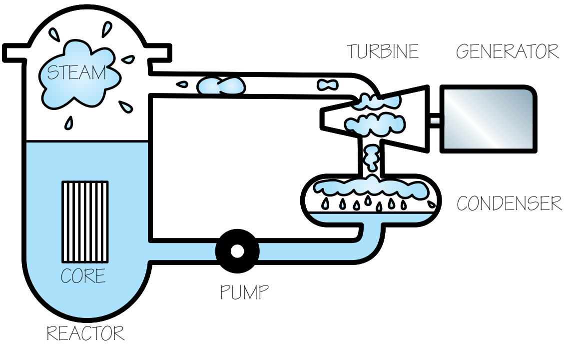
Nuclear energy is energy released when the nucleus of an atom splits (fission), joins with another nucleus (fusion), or disintegrates (radiation). "Nuclear energy" rather than "atomic energy" is the most exact name for the energy produced in a nuclear reactor.

Kinds of Reactors

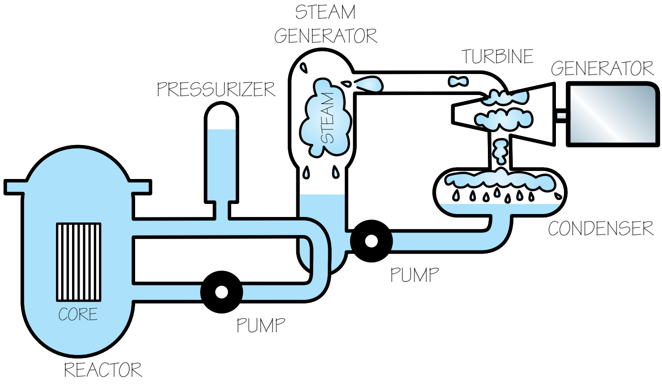
All commercial power reactors in the United States are *light water reactors*. They use light (ordinary) water as the moderator and coolant. Canadian reactors are *heavy water reactors*. They use heavy water, which has deuterium in place of ordinary hydrogen.

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.

Most nuclear plants in the United States use pressurized water reactors (PWRs). This type makes steam outside the



Boiling water reactor



Pressurized water reactor (PWR)

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.

Advanced Nuclear Reactors

New reactor technologies are in development that could offer safer, cheaper, emission-free electricity and heat for industrial processes. There are three types:

Advanced water-cooled reactors are similar to traditional reactors, but are designed to be simpler and much smaller. The smaller size and power could be used in rural areas as an emergency backup. One example are small modular reactors (SMRs), which use a modular assembly for more efficient construction. The power capacity is up to 300 MW per unit, about a third of a typical power reactor. Microreactors are tiny SMRs designed to generate electrical power up to 10 MW.

Non water-cooled reactors generate energy from fission using coolants other than water to control the reactor temperature. Molten salt reactors (MSRs) use a molten fluoride salt. Other coolants being studied use liquid sodium, molten lead or helium gas.

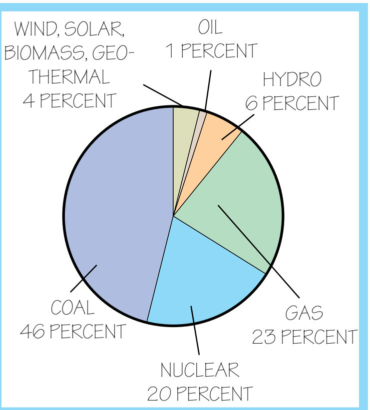
Fusion reactors use nuclear fusion instead of fission. Coolants may include water and helium.

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.

Nuclear power supplies about 20 percent (one-fifth) of the electricity used in the United States. 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

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.

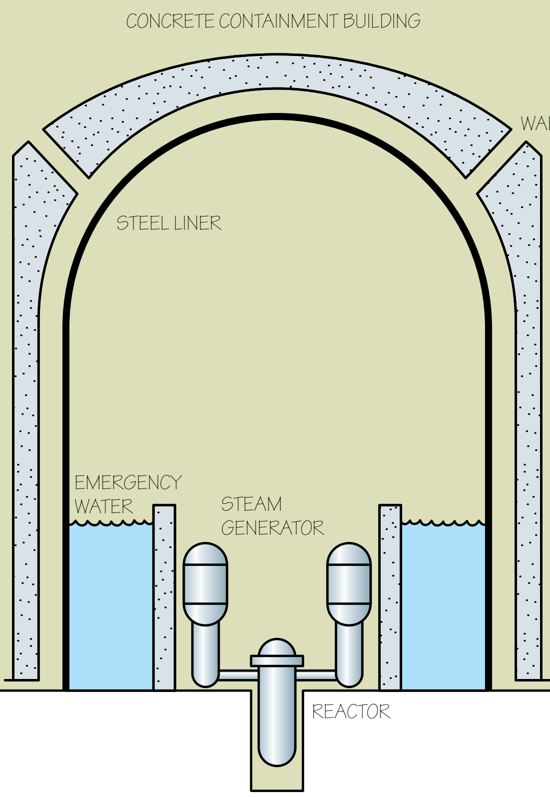
Plants have physical barriers to keep radiation from escaping into the environment. Most of the radioactive by-products of the fission process remain locked inside the nuclear fuel pellets. The pellets are sealed inside strong metal rods. The fuel rod assemblies are enclosed in a steel reactor vessel 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.

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.

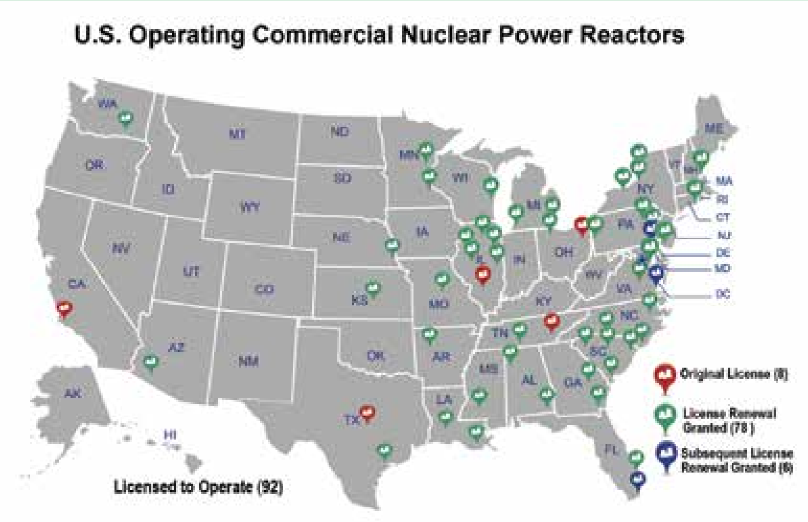
Nuclear Reactors as Factories

Besides generating electric power, a nuclear reactor also can be a kind of factory 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.



As of February 2023, the United States had 92 nuclear power plants with 95 operating nuclear reactors. (Some plants have more than one reactor in operation.)
Source: U.S. Nuclear Regulatory Commission

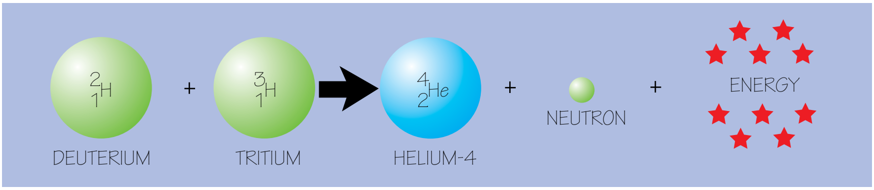
Fusion Research

Fission splits nuclei; *fusion* combines them. This process releases tremendous amounts of energy. While fission reactors split heavy elements like uranium, fusion reactors join light elements (typically deuterium and tritium, isotopes of hydrogen). When fusion occurs, the mass of the particles after the reaction is less than the mass before the reaction. As with fission, this mass lost in the reaction is converted to energy according to Einstein's equation (see pages 48 and 49).

For fusion to happen, a reactor system must create and hold plasma, a very hot body of gas. Atoms in a plasma move so fast they ionize, separating the electrons from the nuclei. Creating a plasma and starting fusion requires putting a lot of energy into the system. Because nuclei are all positively charged, there must be enough particle energy to overcome their tendency to repel each other. This resistance is called the coulomb barrier.

There are three conditions for fusion to occur:

1. The plasma must be hot enough;
2. The plasma must be held in a confined space; and
3. The plasma must be held for a sufficient period of time.



The deuterium-tritium fusion reaction produces helium.

Several projects around the world are trying to make fusion possible. These include the *National Ignition Facility (NIF)* in Livermore, Calif. To become a useful technology, these projects are trying to create systems that reach ignition, producing more energy than they use.

The NIF uses an approach called *inertial confinement*, a process in which 192 powerful lasers compress a tiny fuel pellet about the size of a grain of sand. The mighty blast of the lasers crushes the fuel to achieve fusion. In 2022, the NIF achieved fusion ignition—creating more energy from fusion reactions than the energy used to start the process—for the first time anywhere.

Fusion power plants could produce a tremendous amount of usable energy with little impact on the environment. However, going from scientific experiments to building fusion power plants will take additional engineering and construction.

Below: The NIF Target Bay served as the set for the engine room of the Starship Enterprise in the 2013 movie *Star Trek: Into Darkness*. The NIF's 192 laser beams converge at the center of this giant sphere to make a tiny hydrogen fuel pellet implode.

Health Physics

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.

The effects of radiation on human health fall into two general categories: *chronic* and *acute*.

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.

Chronic Health Effects

Exposure to low levels of radiation over a long time can cause chronic effects, which are difficult to measure and can appear to be unpredictable. Because radiation affects different people differently, some effects of exposure occur randomly and do not always depend on the size of a dose. Typical low-level exposure (from background radiation and medical diagnostics) appears to produce few or no adverse effects. 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.

How can radiation both cure cancer and cause cancer?

Radiation affects the body by depositing energy into cells and into molecules that make up cells. If a lot of energy (a high-radiation dose) is deposited, the cell is killed and cannot go on to reproduce a cancerous group of cells. If a smaller (sub-lethal) dose is deposited, the cell might just be damaged and might eventually cause cancer. (The cell might also be able to repair itself, in which case no damage or cancer will occur.) Thus, a very large dose may be used to destroy most or all of the cells in a tumor. A much smaller dose may just damage cells, and these might later become cancerous.

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 (see "Radiation Units" later in this chapter), in small doses over a lifetime, we would expect five or six more people to die of cancer than would otherwise. The overall age-adjusted mortality rate of cancer in the U.S. was 161 per 100,000, based on a 2012–2016 study by the National Cancer Institute. A 2014–2016 study by the institute found that approximately 39.3 percent of men and women will be diagnosed with cancer in their lifetime.

In the same group of 10,000 people, we would expect

- 40 to die from falling
- 40 to die in an auto accident
- 16 to die from being hit by a car
- 9 to die by drowning
- 9 to die in fires
- 2–3 to die in plane crashes
- 425 to die from some type of injury

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

Acute Health Effects

An *acute* exposure—that is, getting a big dose of radiation in a short time—produces *acute* 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.*

Radiation sickness (or radiation poisoning) can be fatal. The symptoms include nausea, vomiting, weakness, hair loss, skin burns, and bleeding. 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.

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

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 2 months*
600	Death probable within 1 to 2 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.

Our Bodies are Resilient

The cells in our body live in a continuing barrage of damaging events. About every 10 seconds, each cell in our body "takes a hit." The vast majority of these assaults is not from radiation but from inescapable byproducts of the chemical processes in our bodies that enable us to live. Behind that is the natural or man-made toxins that we take into our body.

Way below those effects are the five or so DNA breaks per cell each year that happen because of background radiation. (out of the tens of millions total). Our bodies have extremely efficient DNA repair mechanisms.

When cells are dividing (undergoing *mitosis*) they are more susceptible to radiation damage because the cells don't have all their repair mechanisms. Because of this, cells that are often dividing—like the cells that create our blood or line our intestine, hair follicles, and fetal cells—are more susceptible to radiation damage. Specialized or slowly dividing cells, like brain cells, are radio-insensitive.

At low doses, no physical effects have been observed. Although somewhat controversial, this increased risk of cancer is presumed to be proportional to the dose (no matter how small). While radiation is a carcinogen and a mutagen, radiation is a very weak carcinogen and a mutagen.

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.

Radiation Contamination

A person exposed to radiation does not become radioactive. When you get an X-ray at the doctor's office, it does not make you radioactive.

Getting radiation exposure is just like going to the beach and being exposed to sunshine. The light rays may deposit enough energy into your body to cause an effect, like a sunburn, but when you turn off the lights that night you will not be glowing.

Radiation is a type of energy. **Contamination** is material where you don't want it.

Contamination is radioactive material spilled somewhere you don't want it. For example it can be the spilled vial of a radioactive liquid of radiopharmaceutical pictured above, or it can be dust or even chunks of radioactive material wherever it is not wanted.

Even when spread around the radioactive material, the contamination still emits radiation.

- Contamination can get on you.
- If you walk through it, touch it, or breath airborne contamination; it may get on, or inside of you.
- The contamination might be too small to be visible.

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 more than 60 miles overhead), so for requirement 1(b) 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 difficult and expensive. 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 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, a thorium-containing incandescent lantern mantle, or a piece of vintage red-orange dinnerware. Almost any antique ceramic in a deep orange or red color is likely to be slightly radioactive because manufacturers once used uranium to produce ceramic glazes. 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.

Natural Background Radiation and NORM

Technically, everyone is a little radioactive because of the potassium-40 in our bodies. Each of us emits several hundred gamma rays every second!

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.

We call these Naturally Occurring Radioactive Material, or NORM. Although almost all materials have very small quantities of naturally occurring radioactive materials, they are not usually considered to be "radioactive." The quantity of radioactivity is so small that you would need a special sensitive radiation detector in order to measure it. Bananas are high in potassium and contain potassium-40, a radioactive isotope. Other common foods containing potassium include carrots and white potatoes and lima beans (which also contain radon-224). Radioactive carbon-14 is in all the food we eat. The most radioactive food item is the Brazil nut, containing radium. In all these foods, the amount of radiation levels are extremely low, and almost none of the radioactive material is retained in the body. Most Americans get about 300 millirem (mrem) each year from natural radiation sources. The ingested dose for an average banana is about 0.01 mrem.

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. Earth's atmosphere provides a good deal of shielding from 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, one of the higher cities in the United States, may get 50 mrem each year. Airliners fly at high altitudes; flight crews might receive an additional dose of from 100-200 mrem per 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 U.S. 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. Many kinds of low-cost, do-it-yourself radon test kits are available through the mail and in hardware stores and other kinds of stores. Find information (with your parent or guardian's permission) online at epa.gov/radon, or call the National Radon Hotline toll-free at 800-SOS-RADON (800-767-7236) to order by phone. To speak with an information specialist, call the National Radon Helpline toll-free at 1-800-55RADON (800-557-2366).

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 or guardian 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.

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.

Cosmic rays fall on us from space. Another major source of background radiation is from Earth itself. Earth contains potassium-40, uranium-238, and thorium-232, which have long half-lives. Shorter half-lived species from the decay of the radioactive ores in the earth can cause a hazard, like radon-222 gas.

Since the human body is made up of the same elements as the environment around us, a small percentage of those atoms are radioactive. The most common are carbon-14 and potassium-40. Living organisms like trees, plants, people, and animals contain carbon-14. Potassium is a key part of DNA.

Scientists use the presence of carbon-14 to do radiocarbon dating. When a living organism dies, the amount of carbon in a carcass matches that of the atmosphere at the time of death. By measuring the carbon-14 decays, scientists can calculate the age of the plant or animal. The age of a sample up to around 60,000 years can be fairly accurately determined. The method now uses a particle accelerator technique called an accelerator mass spectrometer. Carbon dating has been used in archaeology, history and geology.

Exposures From Manufactured Radiation

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

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 often seen in black 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.

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.

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.

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.

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		
up to 1,000 feet	28		
1,000 to 2,000 feet	31		
2,000 to 3,000 feet	35		
3,000 to 4,000 feet	41		
4,000 to 5,000 feet	47		
5,000 to 6,000 feet	52		
6,000 to 7,000 feet	66		
7,000 to 8,000 feet	79		
8,000 to 9,000 feet	96		
Food and water (U.S. average)			40
Air (from radon, U.S. average)			228
Soil			_____
Colorado Plateau (around Denver)		75	
Atlantic or Gulf Coast		16	
Elsewhere in the continental United States		35	
Manufactured Sources:			
Medical X-rays/nuclear medicine			_____
Arm, leg, hand, or foot X-ray		0.1	
Dental X-ray		0.5	
Chest X-ray		10	
Skull X-ray		10	
Pelvis X-ray		60	
Upper GI X-ray		600	
CT scan (whole body)		1,275	
Home (7 mrem from brick, concrete, stone, or adobe)			_____
Jet travel (0.5 mrem per hour in the air)			_____
TV or computer (1 mrem if the screen uses CRT technology)			_____
Total			_____ mrem

How does your approximate annual dose compare to the U.S. average of about 620 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 "Radiation and You", American Nuclear Society, 2022, ans.org/nuclear/dosechart/

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

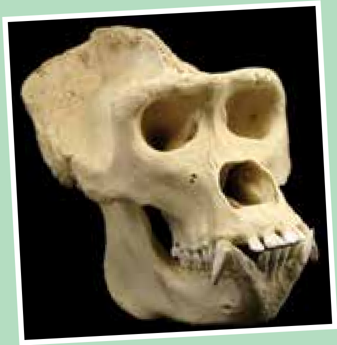
Nuclear energy can help to meet the growing demand for electricity worldwide while not emitting the large amounts of greenhouse gases produced by power plants that burn fossil fuels. Nuclear energy also powers ships, submarines, and satellites, and provides electricity for some spacecraft and space laboratories.

- 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.
- Engineers, technicians, and sailors design, build, maintain, and operate reactor plants for navy ships and submarines.
- Scientists and engineers work at the International Atomic Energy Agency working in safeguards to promote the safe, secure and peaceful use of nuclear technologies.

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

Nuclear Science Resources

Scouting Materials

Archaeology, Astronomy, Chemistry, Dentistry, Electricity, Energy, Engineering, Environmental Science, Geology, Medicine, Plant Science, and *Space Exploration* merit badge pamphlets

With your parent or guardian's permission, visit Scouting America's official retail site, **scoutshop.org**, for a complete list of merit badge pamphlets and other helpful Scouting materials and supplies.

Books

Chapman, Kit, *Superheavy: Making and Breaking the Periodic Table*, Bloomsbury Sigma, 2019.

Conkling, Winifred. *Radioactive! How Irène Curie and Lise Meitner Revolutionized Science and Changed the World.* Algonquin Young Readers, 2018.

Fox, Karen. *The Chain Reaction: Pioneers of Nuclear Science*. Franklin Watts, 1998.

Gallant, Roy A. *The Ever-Changing Atom*. Benchmark Books, 2000.

Goldstein, Natalie. *How Do We Know the Nature of the Atom?* Rosen Publishing Group, 2001.

Halpern, Paul. *Collider: The Search for the World's Smallest Particles*. John Wiley & Sons, 2009.

Lavender, Gemma. *Large Hadron Collider Owners' Workshop Manual: 2008 onwards—An insight into the engineering, operation and discoveries made by the world's most powerful particle accelerator*, Haynes Publishing, 2018.

Oxlade, Chris. *Atoms*. Heinemann Library, 2007.

Pasachoff, Naomi. *Niels Bohr: Physicist and Humanitarian*. Enslow Publishing, 2003.

Richardson, Hazel. *How to Split the Atom.* Franklin Watts, 2001.

Stux, Erica. *Enrico Fermi: Trailblazer in Nuclear Physics*. Enslow Publishing, 2004.

Organizations and Websites

ABCs of Nuclear Science
Lawrence Berkeley National Laboratory
www2.lbl.gov/abc

Advanced Light Source
Brookhaven National Laboratory
als.lbl.gov

Atomic Heritage Museum
ahf.nuclearmuseum.org

American Nuclear Society
555 N. Kensington Ave.
La Grange Park, IL 60526
800-323-3044
ans.org
Virtual field trips: ans.org/nuclear/navigatingnuclear/virtualfieldtrips

American Physical Society
1 Physics Ellipse
College Park, MD 20740
301-209-3200
aps.org

Australia's Nuclear Science and Technology Organisation (ANSTO)
ansto.gov.au/education/resources/apps

Bradbury Science Museum
Los Alamos National Laboratory
lanl.gov/museum

Center for Accelerator Mass Spectrometry
Lawrence Livermore National Lab
cams.llnl.gov

Centers for Disease Control and Prevention
Radiation and Your Health
cdc.gov/radiation-health

Comprehensive Test Ban Treaty Preparative Organization
ctbto.org

Contemporary Physics Education Project
The Nuclear Wall Chart
cpepphysics.org/the-nuclear-wall-chart

EPA Radiation Education
epa.gov/radtown

EPA Radiation Protection
epa.gov/radiation

Facility for Rare Isotope Beams
Michigan State University
frib.msu.edu

Health Physics Society
950 Herndon Parkway, Suite 450
Herndon, VA 20170
703-790-1745
hps.org

Institute of Nuclear Materials Management
inmm.org

International Atomic Energy Agency
1 United Nations Plaza, Room DC-1-1155
New York, NY 10017
212-963-6010
iaea.org
IAEA Learning Management System:
elearning.iaea.org/m2

Large Hadron Collider
CERN, European Organization for Nuclear Research
Geneva, Switzerland
home.cern

Manhattan Project National History Park
National Park Service
Hanford, WA; Oak Ridge, TN;
and Los Alamos, NM
nps.gov/mapr/index.htm

National Council on Radiation Protection and Measurements
910 Woodmont Avenue, Suite 905
Bethesda, MD 20814-3046
(301) 657-2652
ncrponline.org

National Ignition Facility
Lawrence Livermore National Lab
Livermore, CA
lasers.llnl.gov/about/what-is-nif

National Museum of Nuclear Science & History
601 Eubank Blvd SE
Albuquerque, NM 87123
505-245-2137
nuclearmuseum.org

Nuclear Energy Institute
1201 F St. NW, Suite 1100
Washington, DC 20004-1218
nei.org

Nuclear Science Week
nuclearscienceweek.org

The Nuclear Security and Safeguards Education Portal
Center for Nuclear Security Science and Policy Initiatives (NSSPI)
Texas A&M / M312 AI Engineering
College Station, TX 77843
nsspi.tamu.edu/nssep

Oak Ridge Associated Universities Museum of Radiation and Radioactivity
Oak Ridge, TN
orau.org/health-physics-museum

Relativistic Heavy Ion Collider (RHIC)
Brookhaven National Laboratory
Upton, NY
bnl.gov/rhic

Texas Tech Natural Science Research Lab
Radioactive Collection
depts.ttu.edu/nsrl/collections/radioactive.php

Thomas Jefferson National Accelerator Facility
Newport News, VA
jlab.org

Trinity Site, White Sands National Park
National Park Service
nps.gov/whsa/learn/historyculture/trinity-site.htm

U.S. Department of Energy National Nuclear Security Administration
1000 Independence Ave., S.W.
Washington, DC 20585
202-586-5000
energy.gov/nnsa/national-nuclear-security-administration

U.S. Department of Energy Office of Nuclear Energy
1000 Independence Ave. SW
Washington, DC 20585
energy.gov/ne/office-nuclear-energy

U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001
800-368-5642
nrc.gov
Student Corner: nrc.gov/reading-rm/basic-ref/students.html

U.S. Women in Nuclear
winus.org

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