American Nuclear Society

Detecting Radiation in Our Radioactive World

6 hour workshop

Teacher Resource Book

American Nuclear Society
555 N. Kensington Ave.
La Grange Park, IL 60526
708-352-6611

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The American Nuclear Society

The American Nuclear Society (ANS) is a not-for-profit, international, scientific and educational organization. It was established by a group of individuals who recognized the need to unify the professional activities within the fields of nuclear science and technology. December 11, 1954 marks the Society's historic beginning at the National Academy of Sciences in Washington, D.C. ANS has a diverse membership composed of engineers, scientists, administrators, and educators. It is governed by three officers and a board of directors elected by this membership.

More than 11,000 individuals employed by corporations, educational institutions, and government agencies belong to ANS. More than 800 students representing 32 universities belong to the Society. Approximately 1,000 members live overseas in 45 countries. ANS currently has 51 U.S. and nine non-U.S. local sections and 24 plant branches, with a membership of nearly 6,000.

The Society's main objective is to "promote the advancement of engineering and science relating to the atomic nucleus, and of allied sciences and arts." Other purposes are to integrate the many nuclear science and technology disciplines, encourage research, establish scholarships, disseminate information, hold meetings for the presentation and discussion of scientific and technical papers, and cooperate with government agencies, educational institutions, and other organizations having similar purposes.

DETECTING RADIATION

Our eyes react to different types of electromagnetic waves that we call visible light in order for us to see something. We can change our extent or field of vision with the aid of glasses, telescopes, or microscopes. We use our senses in order to understand the things around us. However, when it comes to radiation, we cannot see, hear, touch, smell or taste it. We have to rely on scientific instruments in order to detect and measure radiation for us.

When radioactive substances were first discovered, the harmful effects of radiation were not known so detection was not necessary. Many scientists who studied radioactivity were exposed to harmful radiation. When x-rays began to be used by doctors, many reported that patients who were exposed to x-rays suffered burns. In 1896, the physicist Elihu Thompson deliberately exposed his finger to x-rays so that he could accurately report on the phenomenon of x-ray burns. Thomas Edison was experimenting with x-rays in 1896 when one of his assistants became fatally ill from over exposure to radiation. In 1906, Henri Becquerel, the discoverer of radioactivity, was accidentally burned by a radioactive substance he was carrying in his pocket. When Pierre Curie heard of his injury, he taped a radioactive substance to his own arm to observe the injuries it could cause.

Ionizing radiation has high energy capable of knocking off electrons from atoms. Because electrons are negatively charged particles, the atoms that lose these electrons take on a positive charge because the number of positively charged protons left in their centers (nuclei) is greater than the number of remaining electrons. Because the ionizing radiation produces electrically charged particles, we can make instruments that can see these particles, thereby “seeing” radiation.

In using this concept, Geiger counters were designed to sense extremely small electrical impulses caused by ionizing radiation. In a Geiger counter, an electric current is passed along the walls of a tube. A thin wire passes through the center of the tube which is filled with a gas (argon) that easily loses electrons if it is hit with ionizing radiation. When this happens, an electric current can jump through the gas to the wire. This completes an electrical circuit and the resulting electricity causes a loud clicking noise or moves a needle on a dial.

Another instrument often used to detect radiation is a scintillation counter, which takes advantage of the fact that certain substances such as zinc sulfide, give off light when

they are struck by high energy radiation. A photocell senses the flashes of light that occur as the radiation strikes and thus measures the number of decay events per unit of time.

Henri Becquerel discovered a method of detecting radiation as far back as 1896. He found that invisible rays would affect silver emulsions on photographic plates just like light rays would. This is the principle behind the film badge.

Radiation that strikes photographic film affects it much the way light does. The difference is that radiation can penetrate through materials that can stop light. A result, photographic film can be used to test for radioactivity. People who might be exposed to radiation often wear a film badge that contains a small bit of photographic film. This film badge records exposure to ionizing radiation. The photographic film badge is referred to as a dosimeter. The film is covered by a layer of materials such a paper or plastic that prevents light from reaching the film but allows the radiation to pass through. After use, the film is slipped out of the dosimeter and developed. The extent of darkening on the developed film can be translated into a measure of the total amounts of radiation received by the person wearing the dosimeter.

Our skin also can act like photographic film. When we are exposed to even small amounts of radiation from the sun, our skin gets darker. This is called a suntan, or a sunburn if exposure is too great. To avoid overexposure to the sun's radiation, we use clothing, umbrellas, or sun screen lotions.

We cannot detect radiation with our senses and exposure to too much ionizing radiation is harmful; therefore, a symbol has been developed to warn us when radioactive materials are present. The symbol is used on packages of radioactive materials, such as isotopes, and on doors to rooms or areas where radioactive materials are used or stored.

NATURAL RADIATION SOURCES

BACKGROUND RADIATION

Everything in the world is radioactive and always has been. The ocean, the mountains, the air, and our food all expose us to small amounts of natural background radiation. This is because unstable isotopes that give off or emit ionizing radiation are found everywhere. Much of the Earth's natural background radiation is in the form of gamma radiation, which comes from outer space. It also comes, however, from such elements as potassium, thorium, uranium, and radium, which constantly decay and emit radiation. No matter where we go or what we do, we are surrounded by small amounts of radiation.

Radiation amounts differ according to where we are on Earth. Different places on Earth have different amounts and types of rocks and minerals. Deposits of substances such as uranium vary in concentration and location as do other materials like coal, copper or lead. In the U.S., some of the best known deposits or uranium are found in New Mexico, Utah, Wyoming and Colorado. In some parts of India and Brazil there are also high amounts of background radiation from their rocks and minerals. The background radiation in parts of India and Brazil exceeds the safety limit of 5 millirems per year that the U. S. Government has set as a maximum limit just outside of nuclear powerplants.

A person living in Kerala, India receives about 3,000 millirems of natural background radiation each year. In the U. S., Colorado has the highest average at 170 millirems per year. Location is the important factor; living near a granite rock formation can increase the background radiation by as much as 100 millirems per year to an individual.

Many different building materials, such as bricks, wood, and stone also emit natural background radiation. Our homes, schools, businesses and even churches are all sources of natural background radiation.

Cosmic rays from outer space are another large contributor of natural background radiation. Many of the cosmic rays are filtered out by the clouds and atmosphere so there are natural controls for the amount of radiation that people receive. Generally, exposure increases by about 1 millirem per year for every 100 foot increase in altitude a person lives above sea level. People who live at high altitudes get more background radiation than people who live at lower altitudes because of the thinner atmosphere. A ski instructor at a mountain resort will receive more background radiation than a fisherman at sea level. An airplane trip across America will expose a person to about 4

millirems of radiation because of the high altitude flying.

Natural background radiation is also found in plants, animals and people. Living things are made of radioactive elements such as carbon and potassium; therefore, they are made of naturally radiation-emitting materials. Americans get about 25 millirems of radiation from the food and water they eat and drink each year. This can vary depending upon what is eaten, where it is grown and the amount eaten. However, all foods contain some radioactive elements, and certain foods such as bananas and Brazil nuts contain higher proportions than most other foods.
During our lifetimes, our bodies harbor more than 200 billion billion radioactive atoms. About half of the radioactivity in our bodies comes from potassium-40, a natural radioactive form of potassium. Most of the rest of our body's radioactivity is from carbon-14 and tritium, a radioactive form of hydrogen.

Still more radiation is gotten from manmade sources. In the United States, most manmade radiation comes from medical and dental sources, mainly x-rays. We also receive radiation from building materials such as bricks, the nuclear industry, coal-fired power plants, and aboveground testing of nuclear weapons done in the 1950's.

The average exposure/dose each American receives each year is about 360 millirems. This is from all natural sources of background radiation. It is a small amount considering that radiation levels much greater (50,000 millirems) have been demonstrated to not show any evident ill effects. Current standards allow people to work with radiation to receive 5,000 millirems per year, although an x-ray technician or a worker in a nuclear power plant control room generally receives only 50 extra millirems in a year. The average person's medical radiation exposure is 70 millirems per year. Wearing a luminous-dial watch gives you 3 millirems per year. An hour of TV each day gives you 0.15 millirems each day. Each time you run through the airport metal detector you get 0.001 millirem. A smoke detector in your home exposes you to 0.02 millirems. The use of Fiesta Ware adds 2.4 millirems per year. A normally operating nuclear power plant adds less than one millirem per year to your average yearly radiation exposure.

Radon, the hidden hazard, is one of the pollutants that can build up in our energy efficient homes. Radon-222, an isotope of the noble gas family is extremely radioactive, with a half-life of minutes, is found in one of the decay steps of uranium-238. The granite bedrock under much of the United States contains small amounts of this uranium-238. It is a naturally occurring radioactive isotope with a half-life of more than a billion years. It slowly decays in a series that leads to lead-206.

The danger of exposure to radon is considerable to anyone living in a community that is built on granite bedrock. Radon gas can seep into the basement of a house through holes or cracks in the foundation. The half-life of the radon-222 is so short that the danger is beyond the radon. When it is taken into the lungs, some of it will decay before it is exhaled. As radon decays, the products combine with tiny dust particles in the air and stick to the lung tissue. Radiation from the decay products of radon-222 is thereby suspected of playing a significant role in causing lung cancer. The EPA recommends that levels of radon should not exceed 4 picocuries per liter of air. A normal house contains approximately 1.5pCi-L of air, (1pCi/L = 200 mrem/y EDE or 1.6 rem/yr to the lungs).

IONIZING vs NON-IONIZING RADIATION

IONIZING (Can cause cancer)	**NON-IONIZING**
Alpha	Solar (visible light)
Beta	Radio broadcast
Gamma	TV broadcast
X-rays	Microwave
Ultraviolet light	Heat (infrared)
Fast neutrons	Low frequency EMF
Muons	

TYPES OF IONIZING RADIATION

	Alpha	Beta	Gamma
What is it?	Very fast He nucleus	Very fast electron	Very high frequency light
Electric charge	+2	-1	0
Mass (amu)	4	about 0	0
Speed (% of light speed)	3-8	20-99	100
1 layer of paper, plastic wrap, Al foil, cloth	Stops		
1 mm metal, 1cm wood	Stops	Stops	
5 cm metal	Stops	Stops	Stops
Penetration in water or flesh	few .01's mm	0.1mm -10 mm	few m’s
Penetration in air	few cm	10cm-10m	roughly 100m

BASIC TERMS

Radiation (ionizing) - fast, high energy sub-atomic particles which, when they hit matter, knock electrons off atoms and break apart molecules.

Radioactive - containing atoms with unstable nuclei which emit radiation.

Irradiated - matter which has been hit with a significant amount of radiation.

Contaminated - contaminated with radioactive atoms - radioactive atoms where you do not want them to be.

Units of Radiation Measurement

Roentgen (r) - SI and conventional unit used to measure exposure. It can only be used to describe an amount of gamma and x-rays, and only in air. Measures the ability of photons to ionize air.

Rad (radiation absorbed dose) - A unit used to measure the quantity called absorbed dose. This relates to the amount of energy actually absorbed per unit mass in some materials. It is used for any type of radiation and any material. It is the amount of x-ray energy (ergs) absorbed per gram of tissue. Mrad = 10^{-3} rad, urad = 10^{-6} rad, prd = 10^{-12} rad.

Rem (roentgen equivalent man) - A unit used to derive a quantity called equivalent dose. It relates the absorbed dose in human tissue to the effective biological damage of the radiation. Not all radiation has the same biological effect, even for the same amount of absorbed dose.

Curie (Ci) - One curie is that quantity of radioactive material that will have 37,000,000,000 transformations or disintegrations per second. The relationship between Becquerels and curies is: 3.7×10^{10} Bq = 1 Ci.

Gray (Gy) - SI unit used to measure a quantity called absorbed dose. This relates to the amount of energy actually absorbed in some material, and is used for any type of radiation and any material. One gray is equal to one joule of energy deposited in one kg of a material. One gray is equal to 100 rads.

Sievert (Sv) - SI unit used to derive a quantity called absorbed dose. This relates to the absorbed dose in human tissue to the effective biological damage of the radiation. Not all radiation has the same biological effect, even for the same amount of absorbed dose. Equivalent dose is often expressed in terms of millionths of a sievert or microsievert. One Sv is equivalent to 100 rem.

Becquerel (Bq) - SI unit that is that quantity of radioactive material that will have a transformation or disintegration in one second. One Becquerel is equal to one transformation per second. 37 Gbq equals 1 curie or 37 billion Bq equals one curie.

USES AND BENEFITS OF RADIATION
in Medicine, Industry, Space, Agriculture and Research

"We all hoped that with the end of the war, emphasis would be shifted decidedly from the weapon to the peaceful aspects of atomic energy."
- Enrico Fermi

The ground work had already been laid for peaceful aspects of atomic energy in the 1890's. Radioactive thorium was first used in mantles for camping lanterns, because of its bright, light-producing properties when burning. Little was known of the background radiation from Thorium-232 at that time. In 1895, x-rays were discovered by Wilhelm Roentgen. The wide use of x-rays in medicine and industry is phenomenal.

In the early 1900's the first food irradiation patents are issued in the U.S. and Europe. This is a method for processing foods by treating them with radiation. It does not make the food radioactive. By 1911, George de Hevesy is the first person credited with using radioisotope tracers. As a young researcher living in a cheap boarding house, he suspected that his landlady was saving leftovers and serving them to the boarders the next day. He added a tracer to food he left and the next day used a radiation detector to prove he was right. She evicted him, but he later won a Nobel Prize in biology for use of radioisotopes as tracers.

Herman Blumgart, a physician at Thorndike Laboratory, Boston City Hospital, first used radioactive tracers to diagnose heart disease in 1927.

By the early 1930's elements were bombarded with neutrons in an attempt to produce new isotope or elements. Dental laboratories begin blending trace amounts of uranium oxide with porcelain materials to give crowns, bridges and dentures the fluorescent color of natural teeth. In 1935, Irene Joliot-Curie (daughter of Marie and Pierre Curie) and her husband Frederic received the Nobel Prize for creating the first artificial radioactive isotope. In that same year, nuclear medicine came into existence when cyclotron-produced radioisotopes and nuclear radiations become available in the U. S.

The experiments which lead up to the development of the Atomic Bomb slowed down the developments in benefits in medicine and industry. However, those developments escalated in 1946 when reactor-produced radioisotopes for first civilian use were shipped to Banard Cancer Hospital, St. Louis. By 1947 radioactive dating of artifacts using carbon-14 was demonstrated. Research and development was under way on applications of nuclear power for space systems.

In the 1950's early application of radiation technology was concentrated on full-scale

nuclear power plants. By the mid 50's plants were operating in Calder Hall, England and Shippingport, Pennsylvania.

Today tracers are widely used in industry and medicine.

In the 1960's the first radioisotope-powered remote weather station installed by the U.S. on Axel Heiberg Island, 700 miles from the North Pole.

Neutron activation analysis (a lab technique) used in court by the Internal Revenue Service to pinpoint an illegal distillery from mud samples on a truck. NOTE: Crime labs use neutron activation analysis to find gunshot residues.

The world's first commercial irradiation plant for food processing was commissioned in Canada. Polyester-cotton fabric (for permanent press uniforms and coveralls) first produced using radiation-induced grafting method. NOTE: In the 1960's, U. S. and European food packaging industries begin using shrinkable plastic wrap, made with irradiation process. And the first Nuclear Reactor operates in space.

In 1973, as a result of the 1970 electricity "brownouts" in the Northeast during a heat wave, utilities order 41 nuclear power plants, a one-year record. (NEI)

By 1973 x-ray scanners first mandated at U. S. airports. Today the baggage inspection devices at airports use a radiation source to detect weapons being carried in luggage.

In the 1980's Low-Level Radioactive Waste Policy Act passed. Makes states responsible for own disposal of low-level waste - medical, industrial, power plants waste. At this time NIMBY was the cry. After realizing the many benefits of radiation, many have given up the cry. Education and understanding are crucial today.

1983 - Eleven years after launch, Pioneer 10, using a nuclear generator, passes beyond Neptune and Pluto and becomes the first human-made object to leave our solar system. NOTE: since the 1960's American astronauts and Russian cosmonauts have eaten radiation sterilized foods in space.

1984 - Nuclear power produces more electricity in U. S. than any other source except coal.
Nuclear medicine procedures performed yearly on one of three people entering U.S. hospital.

1988 - Carbon-14 dating determine the Shroud of Turin could not be the burial cloth of Jesus.

1992 - First U.S. commercial food irradiation plant in Florida ships its first irradiated strawberries to Miami, Seattle, Spokane, Pittsburgh, Rhode Island, Italy and France. Two tons of irradiated mangos sold out in a week in North Miami Beach during a 1986 market test.

1993 - through Today - Use of tracers to detect AIDS related abnormalities in the lungs at an early stage. Use of nuclear imaging of the brain to provide early identification of Alzheimer's disease. Chemical processes removing up to 99.9% of radioactivity from fission products.

Nuclear Energy and Technology Applications

Medicine
- myocardial imaging
- bone & lung scans
- pulmonary embolism
- "Hooking" radio-isotopes to antibodies
- "gamma knife" surgery
- pacemakers
- surgical gloves

Consumer Products
- Antistatic copiers
- shrink wrap
- sterilize cosmetics, contact solution, and bandages
- smoke detectors
- Non-stick pans

Industry
- look for defects in welds
- obtain the proper thickness of tin and aluminum
- locate and quantify oil, natural gas and mineral deposits
- check for flaws in jet engines
- test the quality of steel in vehicles
- gauge the density of road surfaces and sub-surfaces

Agriculture/Food
- insect control
- sterilization
- irradiation of astronaut foods
- study germination
- fertilization
- water desalination

Electric Power/Space
- 435 plants in 30 countries
- 104 plants in US; 20% of nation's electricity
- Sweden 50%, Belgium 60%, France 80%
- Saves world's fossil fuels
- Nuclear power spacecraft
- lower CO2 emissions
- remote weather monitoring stations

Research
- carbon-14 dating of artifacts
- 95% all new drugs tested by radiation
- treatment of AIDS and cancer

Sources:

NEI - Nuclear Energy Institute
IAEA - International Atomic Energy Agency
Schull, William J. Effects of Atomic Radiation "A HALF-CENTURY OF STUDIES FROM HIROSHIMA AND NAGASAKI"

NUCLEAR SCIENCE & TECHNOLOGY MILESTONES (1942 – present)

The 1940's

December 2, 1942 - Dr. Enrico Fermi achieves the first controlled nuclear chain reaction with the first demonstration reactor - the Chicago Pile 1.

August 6, 1945 - The U. S. drops an atomic bomb on Hiroshima, Japan, and three days later drops another bomb on Nagasaki. World War II ends days later.

August 1, 1946 - President Harry S. Truman signs the Atomic Energy Act of 1946, putting the fledgling nuclear energy industry under civilian control, and creating the powerful Joint Congressional Committee on Atomic Energy.

October 6, 1947 - The U. S. Atomic Energy Commission first investigates the possibility of peaceful uses of atomic energy, issuing a report the following year.

The 1950's

December 20, 1951 - An experimental reactor produces the first electric power from the atom, lighting four light bulbs.

June 14, 1952 - Keel for the Navy's first nuclear submarine, Nautilus, laid at Groton, Connecticut.

March 30, 1953 - Nautilus first starts its nuclear power units.

December 8, 1953 - President Dwight D. Eisenhower unveils his "Atoms for Peace" program, proposing an international agency to develop peaceful nuclear technologies.

August 30, 1954 - President Eisenhower signs the Atomic Energy Act of 1954, the first major amendment of the original Atomic Energy Act, giving the civilian nuclear energy program further access to nuclear technology.

January 10, 1955 - The Atomic Energy Commission announces the beginning of a cooperative program between government and industry to develop nuclear power plants.

July 17, 1955 - The first U. S. town is powered by nuclear energy - Arco, Idaho, population 1,000 - by experimental boiling water reactor BORAX III.

August 8-20, 1955 - The first international conference on the peaceful uses of nuclear

energy is held in Geneva, Switzerland, sponsored by the United Nations.
July 12, 1957 - The first power from a civilian nuclear unit is generated by the Sodium Reactor Experiment at Santa Susana, California. The unit provided power until 1966.

September 2, 1957 - President Eisenhower signs into law the Price-Anderson Act; legislation to protect the public, utilities and contractors financially in the event of an accident at a nuclear power plant.

December 2, 1957 - The first full-scale nuclear power plant at Shippingport, Pennsylvania goes into service. Twenty-one days later it reaches full power, generating 60 megawatts of electricity.

May 22, 1958 - Keel is laid for the first nuclear-powered merchant vessel, Savannah, at Camden, New Jersey. She is launched on July 21, 1959, and operates for 12 years, calling at most major ports of the world.

October 15, 1959 - Dresden-1 Nuclear Power Station in Illinois, the first U. S. plant built entirely without government funding, achieves a self-sustaining nuclear reaction.

The 1960's

February 16, 1960 - The Atomic Energy Commission publishes its 10-year plan for nuclear energy.

August 19, 1960 - The third U.S. nuclear power plant Yankee Rowe Nuclear Power Station achieves a self-sustaining nuclear reaction.

Early 1960s - Small nuclear-power generators are first used in remote areas to power weather stations and to light buoys for sea navigation.

March 17, 1962 - President John F. Kennedy asks the Atomic Energy Commission to report on the role of nuclear energy in the economy.

December 12, 1963 - Jersey Central Power and Light Company announces its commitment for the Oyster Creek nuclear power plant, the first time a nuclear plant is ordered as an economical alternative to a fossil fuel plant.

August 26, 1964 - President Lyndon B. Johnson signs the Private Ownership of Special Nuclear Materials Act, which allows the nuclear energy industry to own the fuel for its units. After June 30, 1973, private ownership of the uranium fuel is mandatory.

October, 1964 - Three surface ships powered by the atom - Enterprise, Long Beach and Bainbridge - complete a round-the-world cruise without any logistical support.

December 16, 1964 - The Atomic Energy Commission issues Oyster Creek nuclear power plant's construction permit.

April 3, 1965 - First nuclear reactor operates in space.

November, 1965 - The Atomic Energy Commission gives the Liquid Metal Fast Breeder reactor highest priority and decides to build the Fast Flux Test Facility. The facility begins operation in April, 1982.

November 9, 1965 - The first major power blackout occurs in the northeast United States.

The 1970's

April 20, 1970 - The first Earth Day is celebrated.

September 23, 1970 - Electricity “brownouts” hit the northeast during a heat wave.

June 4, 1971 - President Richard M. Nixon announces a national goal of completing the Liquid Metal Fast Breeder unit by 1980.

June 29, 1973 - President Nixon proposes to replace the Atomic Energy Commission with the Energy Research and Development Administration and the Nuclear Regulator Commission.

October 17, 1973 - The Organization of Petroleum Exporting Countries (OPEC) agrees to use oil as a foreign policy weapon, cutting exports 5 percent until Israel withdraws from Arab territory occupied during the Yom Kippur War. Days later Saudi Arabia cuts oil production by 25 percent and joins many other oil-producing nations in embargoing oil shipments to the United States.

1973 - U. S. utilities order 41 nuclear power plants, a one-year record.

1974 - The first 1,000 Mwe nuclear plant goes into service - Commonwealth Edison’s Zion 1 plant.

October 11, 1974 - President Gerald Ford abolishes the Atomic Energy Commission and creates in its place the Energy Research and Development Administration and the Nuclear Regulatory Commission to begin regulating the nuclear industry. The Joint Congressional Committee on Atomic Energy is also abolished.

January 19, 1975 - Energy Research and Development Administration begins operating.

April 7, 1977 - President Jimmy Carter announces a new policy banning reprocessing of used nuclear fuel.

August 4, 1977 - President Carter combines the Energy Research and Development Administration with the Federal Energy Administration creating the Department of

Energy.

March 28, 1979 - A major accident occurs at Unit 2 of the Three Mile Island nuclear plant near Harrisburg, Pennsylvania. Damage is limited to inside the reactor, and no one is injured.
October, 1979 - The U. S. nuclear energy industry creates the Institute of Nuclear Power Operations to address issues of safety and performance.

The 1980's

1980 - Nuclear energy generates more electricity than oil.

October 8, 1981 - President Ronald Reagan's administration lifts the ban on reprocessing used nuclear fuel and announces a policy that anticipates the need for a high-level radioactive waste storage facility.

January 7, 1983 - President Reagan signs into law the Nuclear Waste Policy Act.

October 26, 1983 - Funding for the Clinch River Breeder Reactor project is killed by Congress.

1983 - Nuclear energy generates more electricity than natural gas.

1984 - The atom overtakes hydro power to become the second largest source of electricity after coal.

1985 - The Institute of Nuclear Power Operations forms a national academy - the National Academy for Nuclear Training - to accredit every nuclear power plant's training program.

1986 - The Perry power plant in Ohio becomes the 100th U.S. nuclear power plant in operation.

1988 - U. S. electricity demand is 50 percent higher than in 1973.

1989 - America's nuclear power plants provide 19 percent of the electricity used in the United States; 46 units have entered service during the decade.

The 1990's

1991 - America's nuclear power plants set record for amount of electricity generated, surpassing the 1956 level for all fuel sources combined.

1992 - Nuclear power plants account for about 20 percent of all electricity used in the United States.

August, 1992 - The fourth and final standardized nuclear power plant design is submitted to the Nuclear Regulatory Commission (NRC) for certification and approval. Getting the plant designs approved by the NRC is a step toward building uniform nuclear power plants in the United States.

October 24, 1992 - President George Bush signs into law the Energy Policy Act, which sets the U. S. on course for planning its energy needs, and reforms the licensing process for advanced, standardized nuclear power plants. The updated process affords the public more timely opportunities to participate in decisions to build new nuclear power plants. The updated process affords the public more timely opportunities to participate in decisions to build new nuclear plants and is expected to create a more stable financial environment for investors.

March, 1993 - The nuclear energy industry positions itself for the future when 16 nuclear utilities sign the first of two contracts with U. S. nuclear plant manufacturers - each agreeing to develop first-of-a-kind engineering on two advanced plant designs. General Electric signs in March and Westinghouse signs in June.

April 6, 1993 - Another nuclear power plant - the Comanche Peak Unit 2 in Glen Rose, Texas - goes on line, providing 1,150 megawatts of electricity to U. S. consumers.

December, 1993 - In 1993, two decades after the first Arab oil embargo, the 109 nuclear power plants operating in the United State generate 610 billion kilowatt-hours of net electricity, providing about one-fifth of the nation's electricity.

January 14, 1994 - More than a half century after President Eisenhower stood before the United Nations and urged the countries of the world to take nuclear materials "out of the hands of soldiers...[and place them] into the hands of those who will... adapt [them] to the arts of peace," the U. S. again leads the world in promoting the peaceful uses of nuclear technology by signing a contract to buy uranium from the Russian Federation that could be blended down into power plant fuel, ensuring it will never again be used for warheads.

July, 1994 - The Nuclear Regulatory Commission issues final design approval for the first two of four advanced nuclear power plant designs - General Electric's Advanced Boiling Water Reactor (ABWR) and ABB Combustion Engineering's System 80+. The approval means that all major design and safety issues have been resolved to the satisfaction of the NRC staff and the Advisory Committee on Reactor Safeguards. The two plants are the first to obtain final design approval under the NRC's new regulations for licensing standardized plant designs. The NRC will now prepare a rulemaking, which will include public comment, to codify the designs.

April 7, 1995 - The NRC publishes proposed design certification rules for General Electric's advanced Boiling Water Reactor (ABWR) and ABB Combustion Engineering's System 80+ plant designs. These rulemakings will codify the ABWR and System 80+ final design approvals issued in 1994. Certification is expected in 1996.

1995 - Discovery of the top (t) quark, the last undiscovered quark belonging to the 3rd generation at Fermilab using the proton-antiproton collider Tevatron. It was announced as a simultaneous result of the efforts of several hundred scientists working in two competing teams represented by P. Grannis and H. Montgomery (DO Collaboration), and B. Carithers and G. Bellettini (CDF Collaboration). The t quark is a very massive particle, it "weighs" a little more than 10 H2O molecules.

The 2000's

2002 – Raymond Davis and Mastoshi Koshiba receive the Nobel Prize for their contributions to the understanding of cosmic neutrinos.

2005 - The Energy Policy Act provided incentives for establishing new-generation power reactors in the U.S.

2006 - A Princeton-led group reported discovery of bacteria 2.8 km underground (Mponeng Gold Mine, South Africa) deriving energy from the radioactivity of rocks rather than from sunlight. The life of these sulfate reducers (related to *Desulfotomaculum*) depends on the hydrogen produced by the radiolysis of water.

2008 - The 27 km long Large Hadron Collider (LHC) at CERN starts test runs in preparation for p-p collision experiments to study the conditions right after the Big Bang. The final collision energy is planned to be 14 TeV. To achieve this, proton beams moving in the opposite direction have to be accelerated to 7 TeV before head-on collision takes place between them.

The 2010's

August 6, 2012 – Curiosity, a car-sized robotic rover aboard the Mars Science Laboratory (MSL) spacecraft, successfully landed on Aeolis Palus in Gale Crater on Mars. This large and highly mobile robot derives its electrical power from a Multi-Mission Radioisotope Thermoelectric Generator (MMRTG).

July, 2012 – CERN Higgs Boson Discovery**.** The discovery of a particle consistent with the Higgs boson opens the way to more detailed studies, requiring larger statistics, which will pin down the new particle's properties, and is likely to shed light on other mysteries of our universe."

October, 2013 - National Ignition Facility (NIF) achieved the first step towards harnessing the power of the sun here on earth -- they got more energy out of a fuel burn than was put into it.

Nuclear Quiz

Answer True or False for each statement

1. Radiation could mutate you, giving you deformities. _____

2. Sleeping next to someone most nights for a year results in a radiation dose of about the same as that from an X-ray of your hand. _____

3. A recent shipment of 1.5 tons of plutonium from France to Japan had the energy equivalent of about 1000 oil tanker shipments. _____

4. Some TVs and computer screens emit radiation that can cause cancer. _____

5. Many dentures are radioactive. _____

6. Irradiation of strawberries to retard spoilage causes the strawberries to be slightly radioactive. _____

7. Living one mile from the Chernobyl nuclear reactor during the accident would be more likely to cause your early death than being five pounds overweight. _____

8. Organically grown tomatoes are not radioactive. _____

9. Radioactive waste with a half-life of one trillion years is even more dangerous and difficult to store or dispose of safely than is otherwise-similar waste with a half-life of 24,000 years. _____

10. The Chernobyl accident has resulted in deformed farm animals being born. _____

11. Transportation of fruits and vegetables will cause more deaths over the next 20 years than the transportation of nuclear waste. _____

12. A pound of plutonium dust dispersed over a city would likely cause over 100,000 deaths. _____

13. The Three-Mile Island nuclear reactor accident will ultimately result in over a thousand people dying of cancer. _____

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Nuclear Quiz

TEACHER KEY

1. Radiation could mutate you, giving you deformities. **FALSE**

2. Sleeping next to someone most nights for a year results in a radiation dose of about the same as that from an X-ray of your hand. **TRUE**

3. A recent shipment of 1.5 tons of plutonium from France to Japan had the energy equivalent of about 1000 oil tanker shipments. **TRUE**

4. Some TVs and computer screens emit radiation that can cause cancer. **TRUE**

5. Many dentures are radioactive. **TRUE**

6. Irradiation of strawberries to retard spoilage causes the strawberries to be slightly radioactive. **FALSE**

7. Living one mile from the Chernobyl nuclear reactor during the accident would be more likely to cause your early death than being five pounds overweight. **FALSE**

8. Organically grown tomatoes are not radioactive. **FALSE**

9. Radioactive waste with a half-life of one trillion years is even more dangerous and difficult to store or dispose of safely than is otherwise-similar waste with a half-life of 24,000 years. **FALSE**

10. The Chernobyl accident has resulted in deformed farm animals being born. **FALSE**

11. Transportation of fruits and vegetables will cause more deaths over the next 20 years than the transportation of nuclear waste. **TRUE**

12. A pound of plutonium dust dispersed over a city would likely cause over 100,000 deaths. **TRUE**

13. The Three-Mile Island nuclear reactor accident will ultimately result in over a thousand people dying of cancer. **FALSE**

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Radiation Around You

Radiation is around us all the time. It is as much a part of our everyday environment as the light and heat of the sun's rays. Scientists call this background radiation and measure it in units called millirems.

Earth has always been radioactive. In fact, the natural radioactivity in the environment is just about the same today as it was at the beginning of the Neolithic Age, more than 10,000 years ago.

The water we drink, the food we eat, the air we breathe - all contain radioactive elements that occur naturally and always have been on Earth.

People living in Denver (high elevations) get more cosmic radiation from the sun than people in Dallas (low elevations).

Television depends on radiation to form the picture, yet modern sets give off a barely detectable level of radiation.

There are many different kinds of radiation that can be both beneficial and harmful under some circumstances. For example, while none of us would be alive without radiant energy from the sun, excessive exposure can cause skin cancer.

A person traveling on a transcontinental flight at an altitude above 33,000 feet receives about 3 to 5 millirems of radiation per trip. This is more than you would receive if you spent 24 hours a day at the gate house of a nuclear power plant for an entire year.

For most people, the biggest single source of man-made radiation exposure is medical tests.

Mother Nature's Reactor! In 1972, scientists found the remains of a natural nuclear reactor located in a uranium mine in Oklo, Gabon, Africa. Evidence shows that a nuclear chain reaction occurred in the mine 1.5 billion years ago.

A portion of each person's annual dose of radiation, about 40 mrems, comes from inside the human body. This results from the decay of naturally occurring radioactive atoms found in such elements as potassium contained in our bodies.

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American Nuclear Society

Radiation

is a part of our world

Estimate Your Personal Annual Radiation Dose

Estimate Your Personal Annual Radiation Dose

Factors	Common Sources of Radiation	Your Annual Dose (mrems)
Where You Live	**Cosmic Radiation** (from outer space) Exposure depends on your elevation (how much air is above you to block radiation). Amounts are listed in mrem (per year). At sea level..... 26 mrem; 0-1000 ft..... 28; 1-2000 ft..... 31; 2-3000 ft .....35 mrem; 3-4000 ft .....41; 4-5000 ft .....47; 5-6000 ft .....52; 6-7000 ft .....66 mrem; 7-8000 ft .....79; 8-9000 ft .....96 (Elevation of cities (in feet): Atlanta 1050; Chicago 595; Dallas 435; Denver 5280; las Vegas 2000; Minneapolis 815; Pittsburg 1200; St.louis 455; Salt lake City 4400; Spokane 1890.)	_____ mrem
	Terrestrial (from the ground) If you live in a state that borders the Gulf or Atlantic Coasts, add 16 mrem If you live in the Colorado Plateau area, add 63 mrem If you live anywhere else in the continental US, add 30 mrem	_____ mrem
	House Construction If you live in a stone, adobe, brick or concrete building, add 7 mrem	_____ mrem
	Power Plants If you live within 50 miles of a nuclear power plant, add 0.01 mrem	_____ mrem
	If you live within 50 miles of a coal-fired power plant, add 0.03 mrem	_____ mrem
Food, Water, Air	**Internal Radiation**[2] From food (Carbon-14 and Potassium-40) & from water (radon dissolved in water)	40 mrem
	From air (radon)	228 mrem
How You Live	Jet Plane Travel .....0.5 mrem per hour in the air	_____ mrem
	If you have porcelain crowns or false teeth[3] .....0.07 mrem	_____ mrem
	If you go past luggage x-ray inspection at airport.....0.002 mrem	_____ mrem
	If you view a TV or computer screen which uses CRT technology[4].....1 mrem	_____ mrem
	If you smoke 1/2 pack of cigarettes every day of the year .....add 18 mrem	_____ mrem
	If you have a smoke detector.....0.008 mrem	_____ mrem
Medical Tests	**Medical Diagnostic Tests** – Number of millirems per procedure[5] X-Rays: Chest-10 mrem, Mammography (2 views)-72, Skull-10, Cervical Spine-20, Lumbar Spine-600, Upper GI-600, Abdomen (kidney/bladder)-700, Barium Enema-800, Pelvis-60, Hip-70, Dental Bitewing/Image-0.5, Extremity (hand/foot)-0.5	_____ mrem
	CT Scans: Head-200 mrem, Chest-700, Abdomen/Pelvis-1000, Extremity-10, Angiography (heart)-2000, Angiography (head)-500, Spine-1000, Whole Body-1000, Cardiac-2000	_____ mrem
	Your Estimated Annual Radiation Dose	_____ mrem

We live in a radioactive world - humans always have. Radiation is part of our natural environment. We are exposed to radiation from materials in the earth itself, from naturally occurring radon in the air, from outer space, and from inside our own bodies (as a result of the food and water we consume). This radiation is measured in units called millirems (mrems). The average dose per person from all sources is about 620 mrems per year. It is not, however, uncommon for any of us to receive less or more than that in a given year (largely due to medical procedures we may undergo). Standards allow exposure to as much as 5,000 mrems a year for those who work with and around radioactive material.[1]

1. See http://www.nrc.gov/about-nrc/radiation/health-effects/info.html
2. Average values.
3. Some of the radiation sources listed in this chart result in an exposure to only part of the body. For example, false teeth or crowns result in a radiation dose to the mouth. The annual dose numbers given here represent the "effective dose" to the whole body.
4. The value is less than 1, but adding a value of 1 would be reasonable.
5. Exposures for medical tests vary depending upon equipment and the patient. The doses listed are an average for an actual exposure.

Primary sources for this information are National Council on Radiation Protection and Measurements Reports: #92 Public Radiation Exposure from Nuclear Power Generation in the United States (1987); #93 Ionizing Radiation Exposure of the Population of the United States (1987); #94 Exposure of the Population in the United States and Canada from Natural Background Radiation (1987); #95 Radiation Exposure of the U.S. Population from Consumer Products and Miscellaneous Sources (1987); #100 Exposure of the U.S. Population from Diagnostic Medical Radiation (1989); and #160 Ionizing Radiation Exposure of the Population of the United States (2009).

ANS

Comparing the Effects of Where You Live and How You Live

Objectives: **Build student's ability to read and interpret information on the worksheet. Develop understanding of natural background radiation vs. man-made radiation. Facilitate discussion of how we assess what is acceptable radiation exposure.**

As you review answers to these questions and discuss the worksheet (Estimate Your Personal Radiation Dose), point out to students that:

- natural background radiation exists wherever you live
- the amount of natural background radiation varies from place to place (see the worksheet for examples)
- radiation comes from man-made sources, too (TV, false teeth, smoke detectors, etc.); most exposures from these sources are smaller
- than what people get from natural background radiation
- medical diagnostic procedures are the largest single source of man-made radiation to which most people are ever exposed

1. **A family moves from a wood-frame home in Dallas to a brick home in Denver.** ***How will this change affect each person's annual radiation dose?'***

   Dallas (cosmic 28, terrestrial 16, frame home 0 = 44) Denver (cosmic 52, terrestrial 63, brick house 7 = 122)

   Moving to Denver results in an annual radiation dose increase of 78 mrem.

2. **Lucinda moves from a wood-frame home in Chicago to a wood frame home in Dallas.** ***How does her annual radiation dose change?***

   Chicago (cosmic 28, terrestrial 30 = 58) Dallas (cosmic 28, terrestrial 16 = 44)

   Moving to Dallas reduces her annual radiation dose by 14 mrem.

3. **John likes to watch TV and play video games on his computer. After realizing that these activities expose him to radiation, he gives up both.** ***How much has he reduced his annual radiation dose?***

   (TV +1, video display terminal +1 = 2.0 mrem)

   How does this compare to the average annual dose?

   (It is only a fraction of the average annual dose. Remember the average annual dose for most people in the U.S. is about 620 mrem, so this is about 2/620 = 1/360 th of the average annual dose OR less than 0.3 % of the average.)

4. **Sam lives in a suburb of a large city. His house is 55 miles from a nuclear power plant and 20 miles from a coal-fired electrical plant. His family buys a new house in another suburb on the other side of the same city. It is 20 miles from a nuclear plant and 60 miles from a coal-fired electric plant.** ***What is the change in his annual radiation exposure?***

   First house (coal plant +0.03) Second house (nuclear plant +0.01) His annual exposure is REDUCED by 0.02 mrem.

   Do you think this is a significant amount?

   (Answers will vary. Remind students that the average annual dose for most people in the U.S. is about 620 mrem.The change is much less than 1 mrem, so the change is less than 1/620 th of the average. It is actually, 0.02 mrem/620 mrem = 0.003%)

5. **Mary and her mother were in a serious automobile accident that resulted in broken bones and internal injuries. Mary's mother had a cervical spine x-ray, a CAT scan of her head, and an x-ray of her pelvis. A week later doctors needed to conduct an x-ray of her upper GI tract.** ***How much radiation did Mary's mother receive from medical tests, as a result of the accident?***

   Cervical spine x-ray 20 CAT scan of head 200 pelvis x-ray 60 upper GI x-ray 600 = 880 mrem

   How did this radiation compare to her average annual dose?

   (The radiation from medical exams accounted for more than the average annual dose, which is about 620 mrem.)

   Why is this acceptable?

   (Answers may vary. Several points are worth noting: (1) the benefits obtained from the medical diagnostics may outweigh the perceived risk, (2) people who work with or around radioactive material are allowed up to 5,000 mrems per year according to accepted standards, (3) some people who have been seriously injured or ill have required many x-rays, been exposed to fairly large quantities of radiation, and still lived long lives.)

The Units Used to Measure Radiation

Objectives: **Students learn that many units can be used for measuring radiation. Students learn how to convert mrems to mSv.**

Present the following information to students, using whatever concrete examples are available (12 inch rulers, meter sticks, yard sticks, measures for liquid volume, etc.)

Variety of Units. More than one type of unit is used for measuring most things. The choice of measurement units depends upon many factors, including:

- what standard system is used in a particular location
- the "scale" of the object or event being measured
- convenience in expressing or understanding the resulting measurements
- how meaningful a particular measurement is to a specific situation

Most people in the U.S. are accustomed to measuring distance in inches, feet, yards, or miles depending on the circumstance. They also use fractions of an inch [½, 1/4, 1/8/ 1/16, or thousandths of an inch (0.001 inch), in some applications such as making precision machinery]. However, people in most parts of the world are accustomed to measuring distance using the basic unit of distance for the metric system, the meter. They also use kilometers (1000 meters), centimeters (1/100 meter) and millimeters (1/1000 meter).

It is possible to convert measurements from one unit of measurement to another using known equivalents, such as:

1 inch = 2.54 centimeters ***1 kilometer = 0.62138 mile*** ***1 meter = 39.37 inches*** ***1 yard = 36 inches***

Units for Radiation. Radiation, too, is measured in a variety of units (Curie, bequerel, rad, rem, sieverts, etc.)

In the U.S., it is common to measure radiation dose in rems or millirems (mrem). In certain scientific disciplines and in other parts of the world, it is common to measure radiation dose in sieverts (Sv) or millisieverts (mSv) or even microsieverts (µSv).

Measurements of radiation doses can be converted from one measuring unit to another using conversion factors, such as:

1 rem = 1000 mrem ***1 sievert (Sv) = 1000 millisieverts (mSv)*** ***1 Sv = 10,000 microSv (µSv)***

1 rem = 1/100 Sv ***1 rem = 10 mSv*** ***1000 mrem = 10 mSv***

1 mrem = 0.01 mSv ***1 mrem = 10 µSv***

Classroom Activity: Converting Radiation Dose Estimates from one unit to another

You can help students be aware of commonly-used units and integrate a bit of math into your science content by teaching them how to convert mrem to mSv. You could apply one of two approaches:

1) Using a conversion formula x mrem x 0.01 mSv/mrem = **?** mSv

For example, an average annual dose of 620 mrem 620 mrem x 0.01 mSv/mrem = **6.2 mSv**

2) Using ratios

$$\frac{1000 \text{ mrem}}{10 \text{ mSv}} = \frac{\textbf{known} \text{ mrem}}{\textbf{?} \text{ mSv}}$$

For example, the average annual radiation dose of 620 mrem can be converted, as follows:

$$\frac{1000 \text{ mrem}}{10 \text{ mSv}} = \frac{620 \text{ mrem}}{\textbf{x} \text{ mSv}}$$

(1000 mrem) **(x** mSv) = (10 mSv) (620 mrem)

x = 6.2 mSv

You can provide students with a variety of radiation doses and have them convert them to other units, including mSv and Sv. OR, you could have them convert numbers from the worksheet (exposure from TV, exposure from smoke detector, etc.) into other units (Sv and mSv).

Question for Discussion:

What is one reason we might choose mSv instead of Sv as a unit for expressing a person's average annual radiation dose?

(For most people, the average annual dose is relatively small. If you measure in Sv, the value will be a decimal value. Sometimes people get confused by decimals. For example, which is a greater amount of radiation, 0.02 mSv or 0.0006 mSv? At first glance, the value with the "6" looks greater. But, because it has more decimal places, 0.006 mSv is actually a smaller radiation dose.)

Totally Rad Scenario: The Flying Salesman (a simulation)

William is excited that his position as a Health Food Salesperson of some excellent Herbal Products manufactured here in the United States allows him to travel to London, Spain, and South Africa. Bill's home base in Pittsburgh, Pennsylvania. He lives in a quiet community of brick homes with tree-lined streets. He enjoys taking photographs, especially of nature for about 24 days a year with his telephoto lens.

In the past year, Bill has traveled 300 hours at 39,000 feet altitude to and from these three countries to set up businesses. To satisfy his passport requirements, he had to have a chest x-ray. First, he was given the Tuberculosis Saline Test. It gave a positive reaction. His doctor, a good one, had him take a chest x-ray as a follow-up. The x-ray photos were negative. He was really happy about his news. Bill found out that he has an allergic reaction to the chemicals in the Saline Test. His doctor advised never to let anyone inject him with the chemical again.

What dose of radiation has Bill been exposed to this past year?

Use the information from the Radiation Dose Chart to help you solve the problem.

Cosmic radiation	_____
High altitude flight	_____
Terrestrial radiation	_____
Radon (basements)	_____
Buildings (stone/concrete/brick)	_____
Internal radiation (food/water)	_____
Medical exposure (dental/chest x-ray)	_____
False teeth or crowns	_____
Smoke detector	_____
Television/PC	_____
Smoker	_____
Gas lantern mantle	_____
Camera lens	_____
Luminous wrist watch	_____
Total	_____

Totally Rad Scenario: The Twins Compete (a simulation)

The twins, Gina and George are very sports oriented. They live in a brick mansion in Salt Lake City, Utah. Gina is on the girls' basketball team and George is on the boys' team. In fact, they are good competitors on the swim and baseball teams during the spring and summer.

In the winter, things change a bit. George and Mom love to ski. It is not unusual for the two of them to spend at least five long weekends during the winter months on the slopes in Colorado. Oh! I forgot to tell you the family is very rich. However, Gina is not too keen on heights, so she does not ski. When her brother and mom go off to ski, she becomes a couch potato and watches television, then plays with her IPad non-stop until her twin returns home. On these skiing trips and other flights, George spends 20 hours at 39,000 feet each year, while Gina does not fly at all.

Dad provides well for his family. He makes certain that there is a check for radon in the basement so that it does not exceed about 200 mrem/yr. and checks to see that the smoke detectors are in good operating condition. He made sure that Gina kept her appointment with the dentist after she complained of pain from her lower braces. The dentist did an x-ray to make sure the braces were not cutting into her gums. It was the second one she had during that year. George did not have this problem with his braces. The family is exposed to what any average family is exposed to in background radiation.

How does the twins' exposure to radiation compare for the year?

Use the information from the Radiation Dose Chart to help you solve the problem.

Cosmic radiation	_____
High altitude flight	_____
Terrestrial radiation	_____
Radon (basements)	_____
Buildings (stone/concrete/brick)	_____
Internal radiation (food/water)	_____
Medical exposure (dental/chest x-ray)	_____
False teeth or crowns	_____
Smoke detector	_____
Television/PC	_____
Smoker	_____
Gas lantern mantle	_____
Camera lens	_____
Luminous wrist watch	_____
Total	_____

Measuring Background Radiation

Teacher Instructions

Introductory Information

We live in a radioactive world, as did our earliest ancestors. The radiation in our world comes from many sources – cosmic radiation (outer space), terrestrial sources (the earth), radon in the air, etc. In addition, we live and work in buildings made from materials (stone, adobe, brick, concrete) which contain elements that are naturally radioactive. The amount of naturally occurring background radiation we experience varies, depending upon location.

Background Radiation.

Geiger counters will register the presence of some radiation even if you have not placed them near a known radiation source. This is a measure of the background radiation that is always present at a given location.

In order to make meaningful measurements of the radioactive nature of specific objects or materials, we will need to know how much radiation is naturally present in the environment. The difference between background radiation and the radiation measured near a specific object will give us the level of radiation due to the object.

Although background radiation is quite steady on average, you would never conclude that by listening to or watching a Geiger counter. The amount of radiation will appear to vary, depending upon the specific time at which you take a measurement.

An Analogy.

Suppose that someone sets up a water sprinkler and maintains a steady flow of water to the sprinkler. If one quantifies the rate at which the sprinkler puts water on the ground by how many drops of water fall on a sheet of notebook paper in a short time, one will not get the same result every time or in every location under the sprinkler. This is because the water falls onto the ground in discrete units (drops). Similarly, radiation (alpha and beta particles, gamma photons, etc.) strikes a given location in discrete units or amounts.

If the *average* number of water drops that fall on a piece of paper in one minute is 25 drops, you may **not** get exactly 25 drops in a one-minute measurement. Results ranging between 20 and 30 drops are likely, and counts as low as 15 and as high as 35 might occur, though that is less likely.

This same variation in measurements may occur with radiation.

Objective

- Familiarize students with the concept of background radiation.
- Determine the amount of background radiation present at a specific location.

☞ The **key ideas** for students to understand upon completing this lab are:

- there is background radiation wherever they are
- level of background radiation varies somewhat from one location to another
- there are some small variations in the level of background radiation from one moment to the next.
- when measuring the radiation from an object, we must take into account the contribution made by background radiation
- although uncalibrated Geiger counters may give *slightly* different counts in identical situations; however, they are useful for
    - determining that radiation is present
    - comparing radiation levels for locations or objects

Materials

Use as many Geiger counters as you have available. *We will assume for this experiment that you are using Geiger counters which are **not** calibrated* (they may not provide the same readings under the same circumstances). So, you may want to label each Geiger counter with a code number or letter; then, each group can record the code of the Geiger counter being used and use it for future activities.

Advance Preparations

Clear the room of any unnatural radioactive sources.
Create identifiable "locations" within the room – to correspond to the number of lab groups you will have. Code each of these locations in some way for easy reference.

Procedure

Before beginning, make sure students have some familiarity with the Geiger counter and how it will be used. Predetermine whether measurements are to be made with the "window" on the Geiger tube open or closed. Give students an overview of how and where to set the sensitivity level, etc.

1. Have the students measure background counts for one minute.
   This is done by counting the number of "clicks" from the Geiger counter. It is **not** practical to make this measurement by reading the counts/min scale on the Geiger counter.
2. Have each lab group enter the results of all the groups into the proper space on the table you provide. (See TABLE 1, example below.)

TABLE 1

Measurement time (sec)	Count Rate (expressed in "counts per minute")					
	Lab Group or Student Name and "location" code					Range
60 (1st trial)						
60 (2nd trial)						
60 (3rd trial)						
Range for group						

➔ Ask students to examine the results. Do the results vary? If so, what is the lowest value and the highest value? What is the "range" of results? What are some possible reasons why the results might be different?

Results **will** vary. Possible reasons include: inaccurate counting, inaccurate timing, slight variations in background radiation from location to location within the room, differences between Geiger counters, some students might be wearing a watch or other jewelry which affects the results. There may be other suggestions from students -- which you must evaluate.

➔ Ask students how they could try to eliminate some sources of error.

They may suggest repeating the measurements to rule out inaccurate timing and counting. They may suggest removing any jewelry, etc.

3. Have students run a second and third trial and *enter **only** the data **for their own group** into the table*.

➔ Ask the class: Do the results **for your lab group** vary from one trial to another? If so, why? What is the range for your own measurements?

At this stage, students may have discovered that the results for their own group vary slightly in each trial. Discuss this variation. Consider the possibility that errors were made during every measurement and discuss whether this is likely.

Also, discuss the idea that the amount of background radiation present may actually be slightly different from one moment to the next -- even though it has an "average" value. Refer to the water sprinkler analogy mentioned in the introduction.

Have each group enter the "range" for their own measurements in the bottom row of the table.

➔ Regarding the counts they took, ask, “Were the clicks always evenly spaced? OR, did the clicks sometimes cluster together with pauses between them?”

Clicks are usually NOT evenly spaced. There are usually some “clusters” of clicks and some pauses.

Discuss the possibility that this variation or “clustering” of clicks may have some impact on how long a time period we use for measuring radioactivity levels. For example, using a really short time period might make measurements more prone to error than a longer time, especially if you did the “short period” measurement during a “pause” or during a “cluster” of clicks.

To illustrate, draw a clock face and let it represent a 60 second measurement. Then, make marks around the perimeter to represent when clicks are heard. This will give you clusters of marks and some empty spaces. If someone takes a measurement in a specific period of 5 seconds, it can easily affect the count they get.

4. Then, have the students enter the data for all of the groups into the table.

➔ Ask the students: Are there variations from group to group? If so, what are some possible reasons?

Discuss possibilities: variations in Geiger counters, variations due to “location” in the room, etc.

➔ How could we determine if these differences are due to our Geiger counters being different or to differences within the room?

You should realize when you begin this activity that these “uncalibrated” instruments are likely to give slightly different results under identical conditions and at the same time. However, it IS possible for there to be slight variations within the room. Proximity to a particular building material or exposure to some other radiation source, for example, may produce higher “background” readings in a specific location.

There are several experimental approaches you and your students could use in resolving this issue.

You could have each group make measurements at the same location and compare them. OR, each group could move to each of the identified locations and make readings for comparison purposes. Students may come up with other suggested solutions. Depending upon the time you want to allow and the sophistication level of your students, you can structure another set of measurements to provide an answer to the question above.

Other possible extensions of this activity:

Students could measure levels of background radiation in other areas of the school (indoors, outdoors, on a higher floor, in the basement, etc.). Each group could prepare a table to summarize its findings for use in comparing them to the results of other groups. They could compare to see if there are differences between clear, sunny days and cloudy days, etc.

Questions for discussion

1. What is background radiation? What are its sources?
2. Can you eliminate background radiation?
3. Why would we take a measurement of background radiation levels before starting a radiation experiment?
4. In measuring background radiation, would it be better to take a 5 second reading or a 1 minute reading? Why would this time period be a better choice?
5. When making measurements of radiation, would it be better to make one measurement or three measurements? Why?

Note: This lab exercise is loosely adapted from one developed and copyrighted by Jay W. Shelton. His lab assumed that you have "calibrated" or matching Geiger counters. It also requires a bit more mathematical skill from the students. It involves using different time periods (1 sec, 2, sec, 10 sec, 30 sec, 60 sec, and 300 sec.) for the background count and then converting those counts to "counts per minute."

Measuring Background Radiation

Student Worksheet

Your teacher will give you specific instructions about what measurements to make, when to make them, and what data to enter into the table.

TABLE 1

Measurement time (sec)	Count Rate (expressed in "counts per minute")					
	Lab Group or Student Name and "location" code					Range
60 (1st trial)						
60 (2nd trial)						
60 (3rd trial)						
Range for group						

Is It Radioactive?

Teacher Notes

Introduction

The covert theme of this lab is dealing with ambiguity.

Because there is background radiation always giving a background signal, and a non-constant signal at that, measuring a sample for a minute or two (with ordinary Geiger counters) just cannot determine with certainty if the sample is weakly radioactive or not.

Because of the randomness of radiation, if the true long-term average background count rate were 16 counts per minute, then by chance alone, a single one-minute measurement of background has about a 17% chance of being more than 20[1]. Similarly there is about a 1% chance of getting a one-minute count rate of 25 or higher[2]. Since in a typical class period, each of the six objects can be measured for only one or two minutes, unless the measured count rate is above about 25 counts, the honest and scientifically correct answer to whether the object is radioactive, is, “I do not know.”

Repeating the measurement and again getting 25 or higher increases the chance the object is really radioactive, as opposed to background just happening to be very high twice.

Materials

Geiger counters
An assortment of objects with varying radioactivity, including some in each of three categories:

1. not detectably radioactive
2. just barely radioactive (“Vaseline glass”, thoriated welding rods, “depression green” glass, some fossils)
3. unambiguously radioactive (orange/red Fiestaware, certain lantern mantles, some uranium ore and minerals)

To avoid confusion, each item should be labeled as a 1, 2, or 3, and in addition, I put all the 1's in their own labeled box and the same for the 2's and 3's.

The students love testing the “hotter” items, but having the three categories of objects assures that everyone tests at least two each of clearly radioactive, marginally radioactive (would really need more counting time than available during lab to be sure),

---

[1] $16 \pm \sqrt{16}$

[2] $16 \pm 2\sqrt{16}$

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and essentially non-radioactive. The point is to have the students struggle with and face the uncertainty concerning whether or not items are radioactive.

Suggestions

If you are doing this activity in a one-period time slot, it is difficult to include measurement of background. Thus, most teachers use an average value for background, measured on a previous day. (Background varies little over time.)

If your Geiger counters have analog as opposed to digital (total counts) meters, fear not, you have many options. With earphones or an amplifier/speaker connected to the counter, your students can still count the number of clicks in a minute.

A reasonably accurate count can also be obtained for low count rates by counting every time the needle jumps up a little (and counting as two if the needle jumps up significantly more than average). All of this will keep you class very busy and quiet.

Post-Activity discussion

Reasons for negative source rate:

- Assumed average background too high
- Measured rate anomalously low
- Background low during measurement
- Each source shields out some of background (e.g., lead or brick)
- Source activity low during measurement (it also is not steady)

“Non-Reasons” for negative source rate:

- Object not radioactive
- Object less radioactive than background
- Geiger next to less-radioactive-side of object
- Bag or box stopped alpha and beta radiation from reaching detector

Use a rain (background) and sprinkler (source) analogy. Even though each may be steady on average, you do not get the same number of drops landing each second on a sheet of paper on the ground. The drops are analogous to the radiation, and the paper is analogous to the Geiger counter.

Other ideas from students for more reliably determining if objects are radioactive:

- Find lower background environment [lower altitude, underground (except uranium mines), under water, lead shield, ...]

Measure background simultaneously (good idea, but not really possible – background measurements over one minute will not be the same at two very close locations – rain drop analogue)

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Technically, every macroscopic object and material is radioactive. E.g., every object made of or contaminated with carbon is radioactive because of the naturally radioactive isotope C-14 which is part of all modern carbon.

Similarly, K-40 is present in all objects containing potassium, and in this case it does not matter how old the object is; K-40's 1.3 billion year half-life is so long that K-40 is still around from when the earth formed.

And, there are many more naturally radioactive isotopes, and many mostly-man-made isotopes such as Pu-239 and some isotopes of strontium and cesium. And, since no macroscopic object is perfectly pure, all such objects contain radioactive atoms. The radioactivity is too small or the radiation is too weak to be detected with an ordinary Geiger counter, but with sophisticated chemical preparation and with much more sophisticated instrumentation, the radioactivity in most objects can be proven.

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Is It Radioactive?

Student Worksheet

Define “measured rate”:

_____

_____

Define “background rate”:

_____

_____

Define “count rate due to object”:

_____

_____

Define “radioactive”:

_____

_____

Select two objects each from each of the three categories. Measure them in any order, but put the data on the appropriate line.

Object Category	**Object Description**	**Measured Count Rate (c/min)**	**Background Count Rate (c/min)**	**Count Rate Due to Object (c/min)**	**Is Object detectably radioactive as packaged?** Yes, No, Probably, Probably Not, or Not Sure
1					
2					
3					
1					
2					
3					

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1. If you get a negative object count rate for one of the objects, what does this mean? What are all the explanations you can think of? (Answer this even if you got no negative object rates.)

2. Which object was not radioactive?

    a) Can you be absolutely sure it (they) were not radioactive? Why? (Answer even if you did not measure such an object.)

3. Which object might have been radioactive, but you are not certain?

    a) What could you do to become more certain? (Answer in any case.)

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Totally Rad - Radiation from a Source

Objective: To learn how to calculate the radiation exposure from a radioactive source.

Suggested Grade Level: 8 - 12

Skills: Mathematics, problem solving

Duration: 45 minutes

Materials: Calculator

Background:
Now that we have learned about the background radiation that is part of our everyday life, we need to know about how much radiation dose we could receive from a radioactive source that is near us.

The basic formula is very simple.

Formula:
Radiation Dose Rate at location = Effective Area of body / (4π r²) X Radiation Dose at surface of source

To find the Radiation Dose Rate at Location -

We need:

1. The effective area of our body that is exposed to the radiation. If an outline of your body was drawn on a flat sheet of paper, it would approximately form a rectangle which includes the **width of your shoulders** and your total height as the length of your body. The effective area is approximately the product of the width of your body and the height, giving the area in square meters. **(Area of a rectangle = Length X width)**

   For example, if an elephant is two meters wide and two meters tall, then the effective area is **(2 meters x 2 meters = 4 square meters).**

2. Because the radiation for the source goes equally in all directions, the fraction of the radiation that we receive is the area or our body divided by the area of a sphere **($4\pi r^2 = 12.6 r^2$)** whose radius is the distance of our body from the radioactive source. This ratio gives the fraction of all of the radiation that is intercepted by our body.

How far are we from the center of the source **(distance) is (r)** the radius. We must square the radius.

(r^2) **or** (r X r) **or** (r) X (r)

(Remember the factors for reducing radiation exposure - time, distance, shielding, and quantity.)

3. How much radiation per hour (Dose Rate) is being emitted from the surface of the source (millirem per hour).

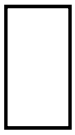
(Remember our millirem chart - the **source** is the radioactive material.)

Source = 1 mrem/hr
Distance (r) = 10 meters
Height (length) = 1.4 meters
Width - .25 meter

Example:
The effective area of our body must be in the same units as we used to measure the distance from the source to our location (for example, meters and square meters).

A small source emitting 1 millirem per hour is 10 meters away from us. Assume that we are about 1.4 meters tall and about .25 meter wide at the shoulders. We can approximate our effective areas as a rectangle.

Height = 1.4 meters



Width = 0.25 meter

1.4 X .25 = 0.35 square meters of area

Using the formula we get :

Radiation dose rate = 0.35 / (12.6) (100) X (1 mrem per hour) = 0.0003 mrem/hr
at our location

which is really a small amount per hour.

What if we are close to a dangerous source? Let us consider a source of 150 millirem per hour. This dose rate is not good. If we stay here for 15 minutes, we will have as much radiation as a dental x-ray. Let us now move a whole football field (100 meters) away from the source.

Then:

$$\textbf{Radiation dose rate at our location} = \frac{0.35}{(12.6)(100)(100)} \times (150 \text{ mrem/hr}) = 0.0004 \text{ mrem/hr}$$

This is **very** small! So, getting a large distance away from even a dangerous source will decrease the dose to very low values.

Another way to decrease the danger of a radioactive source is to put it <u>behind</u> or <u>inside</u> **shielding**.

For each source there is a thickness that reduces the dose rate by 1/2. This thickness is called a <u>half-value layer</u>.

If we put one half-value layer around our source, the dose rate would be 1/2 (150 millirem per hour) or 75 millirem per hour.

If we put 2 half-value layers around our source, it would be reduced by 2 again, and the dose rate would be 1/2 (75 mrem/hr) or 37.5 mrem/hr.

Let us now put 7 half-value layers around the source. Now the dose rate will be

$$\begin{aligned}
&(1/2) \times (1/2) \times (1/2) \times (1/2) \times (1/2) \times (1/2) \times (1/2) \times (150 \text{ mrem/hr}) \\
&= (1/128) \times (150 \text{ mrem/hr}) \\
&= (150/128) \\
&= 1.171875 \\
&= 1.2 \text{ mrem/hr.} \quad \textbf{rounded to the nearest significant number.}
\end{aligned}$$

Shielding can make a dangerous source so much less dangerous.

Is it possible, with shielding, to make the dose rate exactly zero?

Trucks carrying radioactive cargo usually have shielding so the radiation dose rate at the truck's surface is about 1 millirem per hour.

If such a truck is parked 10 meters from our pet elephant who is 2 meters tall and 2 meters wide, and if the dose rate at the truck is 1 mrem/hr, what is the dose rate for our elephant?

Answer:
Source = 1 mrem/hr
Distance = 10 meters
Height = 2 meters
Width – 2 meters

Radiation dose rate = at the elephant $\frac{2 \times 2}{(12.6)\ (10 \times 10)}$ **X (1 mrem/hr) = 0.0003 mrem/hr.**

It would take 1000 hours for our elephant to get a dose of 3 millirem at this distance.
The following table is taken from a reference called BEIR V, which stands for the "Biological Effects of Ionizing Radiation 5." This reference summarizes the experience of the world's scientific community with the immediate effects of radiation. It does not indicate the small effects on the possible state of cancer later in life. The effects of low levels of radiation for causing cancer in a lifetime are given by a small number for each millirem of exposure. This number is about 1.2 per 10 million for every millirem. We will not be using this number here, but have included it for completeness.

According to BEIR V

Biological Effects of Ionizing Radiation	
Amount of exposure	Effect
5000 mrem (5 rem)	No detectable injury or symptoms
100,000 mrem (100 rem)	May cause nausea and vomiting for 1-2 days and temporary drop in production of new blood cells
350,000 mrem (350 rem)	Nausea and vomiting initially, followed by a period of apparent wellness. At 3-4 weeks there is a potential for infections and bleeding due to a profusion of white blood cells and platelets. Medical care is required.
Higher levels of exposure can be fatal.	

Procedure:

1. Read the sample problem below and identify all information needed to solve the problem. Use the example below as a guide.

   A person who is 1.5 meters tall and 1/3 meter wide is standing 20 meters away from a source with a dose rate of 5 millirem per hour. What is the dose rate absorbed by this person?

   Answer:

   Dose rate at this location = $\frac{(1.5)\ (1/3)}{(12.6)\ (20)\ (20)}$ x (5 mrem/hr)

1.5 x (1/3) The effective area of our body	**divided by the product of**	(12.6) (20) (20) Area of a sphere ($4\pi r^2$) (r squared is the distance squared)	**multiplied by**	5 millirem per hour Radiation dose at the source

The dose rate at this location = .0005 millirem per hour

The same person is now standing only 1 meter away from the 5 millirem per hour source. What is the dose rate now?

The dose rate = $\frac{(1.5)\ (1/3)}{(12.6)\ (1)\ (1)}$ x (5 mrem/hr) = 0.2 mrem/hr

2. Use the formula for finding radiation dose from a source to solve the three problems below.

   (1) A person who is 2 meters tall and 1/2 meter wide stands 15 meters away from a radioactive source with a dose rate of 10 millirems per hour. What is the dose rate absorbed by this person?

   (2) If the person in problem #1 moves to a distance of 30 meters from the source, what is the dose rate absorbed?

   (3) Joe is 1.5 meters tall and 1/2 meter wide. He stands 30 meters from a radioactive source with a dose rate of 8 millirems per hour. Mary is 2 meters tall and 1/3 meter wide. She stands 20 meters from a radioactive source with a dose rate of 5 millirems per hour. Who absorbs radiation at a higher rate?

Answers:
(1) 0.0035 mrem/hr
(2) 0.00088 mrem/hr
(3) Joe = 0.00052 mrem/hr
Mary = 0.00066 mrem/hr
Mary absorbs radiation at a higher dose in this situation

Discussion Questions:

1. How does increasing the distance away from a radioactive source change the dose rate?

2. If the distance to a source is increased by a factor of 10, how much does the dose rate change?

3. Can any number of half-value layer of shielding make the dose rate of a source equal to zero?

4. What are the three things a person can change to decrease the amount of radiation absorbed by our body because of a source?

Assessment Evaluation:

Students' performances could be assessed based on each student's calculations and understanding of the problem solving. Participation in class or group discussion may also be assessed.

Extensions:

Students may be interested in collecting some actual data and creating their own problems to be solved. Perhaps getting some information from a local scientist could be a resource for creating a set of problems for the class to work on.

Resources:

Berger M., Byrd, Bill, West, C. M. (HAP), Ricks, R. C., Transport of Radioactive Materials Q&A About Incident Response Reacts Medical Sciences Division, Oak Ridge Associated Universities, 1992

Environmental Restoration and Waste Management (EM) Fact Sheets U.S. Department of Energy, November 1991

CLOUD CHAMBER

Introduction

Radioactive elements continually undergo a process of radioactive decay during which their nuclei emit high-speed particles and rays. These are much too small to be seen under a microscope. The Cloud Chamber is an instrument designed for the study of the trails of these radioactive emissions. The investigation is accomplished in the following way. First, the air must be saturated with water or alcohol vapor. When the high-energy particles plow through the air, electrons are knocked loose from some of the atoms and form ions. Ions act as excellent centers for condensation. This condensation, however, must be stimulated by cooling the air. The water vapor or alcohol condenses on the ions, leaving a vapor tail which clearly reveals the path of the ray.

Cloud chambers detect the paths taken by ionizing radiation. Much like the vapor trail of a jet airplane, the tracks in a cloud chamber mark where ionizing radiation has been traveling. The radiation itself is not visible. Radioactive materials are one source of ionizing radiation. The easiest tracks to see are made by alpha radiation. When first formed they are nearly straight lines, 1 to 5 cm long, but they quickly drift, become crooked and evaporate (or condense on the bottom of the can).

Materials

- Plastic cloud chamber kit, 3 1/4" diameter
- (Petrie dish with band of black construction paper around the sides and bottom painted black or lined with black construction paper)
- Alcohol - 95% ethyl
- Dry Ice
- Source - uranium ore, lantern mantle, Fiestaware piece
- Lamp - flashlight
- Magnet - optional
- Photographic film, unexposed roll

Investigations - Time: 30 minutes

Part 1 - Observing radioactive decay

Pre-lab activity

Several days before the investigation, place a tightly-bound, unexposed roll of photographic film in a drawer next to the uranium ore sample (uraninite) from the kit. It should be left there for at least 24 hours. Then, have the film developed and begin the discussion on the day of the investigation with an examination of the film.

Procedure

Discuss the partial exposure which resulted on the roll of photographic film. The students should speculate on how this phenomenon occurred. From the basis of the results of this experiment, begin the investigation with the Cloud Chamber.

Provide the students with a Cloud Chamber Kit and the background information provided in the Introduction. Three types of rays are given off by a radioactive element. They are alpha particles (positive nuclei of helium atoms traveling at high speed), beta particles (high-speed, negative electrons), and gamma rays (electromagnetic waves similar to X-rays).

- Saturate the felt band on the inside of the Cloud Chamber with alcohol.
- Quickly place the radioactive source (uranium ore) on the bottom of the chamber and cover the entire chamber.
- Place a slab of dry ice in a tinfoil or paper dish and then set the Cloud Chamber on its surface. Wait until the air becomes saturated.
- Viewing will be much better if the lights are turned off and each student is provided with a flashlight. The lamp should be directed from above down onto the black surface of the Cloud Chamber.
- Observe the tracks of the particles and answer the following questions:

What you will see:

The tracks formed by the radiation appear to be white lines in the cloud. As the radiation passes through, it knocks electrons out of the atoms in the air. The alcohol vapor then condenses on the charged particles, forming little storms along the path. These tracks disappear almost immediately.

You may be able to find three kinds of tracks:

a. Most of the tracks will be about one-half inch long and quite sharp. These are made by alpha radiation.
b. Sometimes you will see longer, thinner tracks. These are made by beta radiation.
c. Occasionally you will see some twisting, circling tracks that are so faint that they are difficult to see. These are caused by gamma radiation.

After awhile the tracks will become faint because the radiation has affected so many of the atoms in the chamber. When this happens, rub the top of the chamber briskly with a cotton or silk cloth. The static electricity that is produced will clear the chamber and cause the tracks to become visible again.

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More things to do with your Cloud Chamber

Experiment A: How far can radiation travel?

Carefully mark the top of the chamber at the point where the alpha tracks disappear. Measure how far the radiation traveled from the radioactive source. Then measure the beta tracks. Which type of radiation travels the farthest from the source?

Experiment B: Does a magnet affect radiation?

Hold the north end of a strong magnet next to the chamber. Do you see any effect on the alpha tracks? On the beta?

Experiment C: Radiation Detection

Count the number of tracks that you can see in ten seconds. If your school has a Geiger counter, use it to count radiation from the source for ten seconds. Which type of count is more accurate?

Experiment D: Shielding

Wrap the source in a sheet of paper. Which types of radiation are still visible?

Wrap the sample in a sheet of aluminum foil. Is the effect the same? Use as many different materials as you can find, including plastic, cloth, etc. Which types of radiation are stopped by each type of material?

Experiment E: Different Source

Remove the source from the cloud chamber. Replace the cover. Allow the chamber to cool off again before continuing.

Hold a wrist watch or clock with a luminous dial (containing radium) close to the side of the chamber. Do you see any radiation tracks? What type?

Experiment F: Natural Radiation

Are any tracks visible when no source of radiation is near the chamber?

What type of radiation is found in our environment?

MAKING RADIATION PHOTOGRAPHS

Supplies List

Polaroid Type 57 (3000 speed) 4x5 packet film (sometimes photo stores sell outdated film for much less than the full price, which is about $2 per sheet in boxes of 20).

radiation sources:

- lantern mantles can be found at hardware and sports stores;
- Fiestaware at flea markets and some antique stores;
- old radium-dial watches
- smoke-detector part
- assortment of rocks (e.g., samarskite) from science materials suppliers such as Fisher.

rubber or Plexiglas photo developing roller or sturdy wooden or plastic ruler.

sheet of aluminum foil, lead

The Polaroid film packets should be exposed to various common radioactive items by placing the item on top of the film packets (on “this side toward lens” side) for about a week. The items are displayed here.

Background for making radiation photographs

In autoradiography, an image is produced in a photographic emulsion by the radiation from some substance. Henri Becquerel first did this experiment in 1896. This principle is the basis of film badge monitoring. Film badges are worm by many radiation workers to measure personal radiation doses received over a period of time.

The recommended radiation sources below can be matched to the image appearing on the film. For example:

- radiation discs give off beta and gamma radiation;
- samarskite rock (contains uranium and thorium, which give off alpha, beta, and gamma radiation; found in North Carolina and California in the United States);
- some camping lantern mantles (mesh bag dipped in thorium oxide) can give off alpha, beta, and gamma radiation;
- a piece of orange Fiesta Ware (colored using uranium to get a bright look) gives off beta radiation;
- a radium-dial watch face gives off alpha and gamma radiation.

Since a sheet of paper can block alpha radiation and the film is covered by paper, this film will only detect beta and gamma radiations, <u>not</u> alpha.

By placing aluminum or lead between the radiation source and the film packets, you will

also block beta, or gamma radiation. Therefore, you can identify the type of radiation coming from the source according to whether or not you get a “picture” of the source when various “shielding” items are used.

Question 1

Choose a film packet. Using the roller or ruler, place it behind the raised area containing developer (marked to show “do not press here”). Push the roller or ruler firmly over the developer area and straight back to the metal clip at the end of the film packet. Go back and forth a few times to spread the developer evenly. Wait about 25 seconds. Peel open the film packet (avoid getting the developer on your hands). The area exposed to a radiation source will be shaded lighter than the rest of the photograph. Match the radiation sources to your photograph and identify the source used.

Question 2

There are three (3) types of radiation:

Alpha a sheet of paper blocks this radiation
Beta a sheet of lead or a foot of concrete is needed to block this
Gamma several inches of lead or a foot of concrete is needed to block this

Which type(s) or radiation <u>will</u> be detected by this film?

Question 3

If you placed metal (like a paper clip, aluminum, or lead) between the radioactive item and the film packet, what could you tell about the radiation source after several days?

Engineering Design Project

The purpose of this project is to investigate the detection, shielding, and storage considerations needed when handling radioactive sources.

Shielding Type
Determine which shielding materials seem to provide the "best" overall shielding for the given source, using the following materials. (Rate: good, better, best)

Method: Using a qualitative assessment, use a radiation detector to observe which materials can be used as an effective shield for your source.

Material	Alpha Source	Beta Source	Gamma Source	Unknown Source
lead				
plastic				
aluminum				
water				
paper				
concrete				

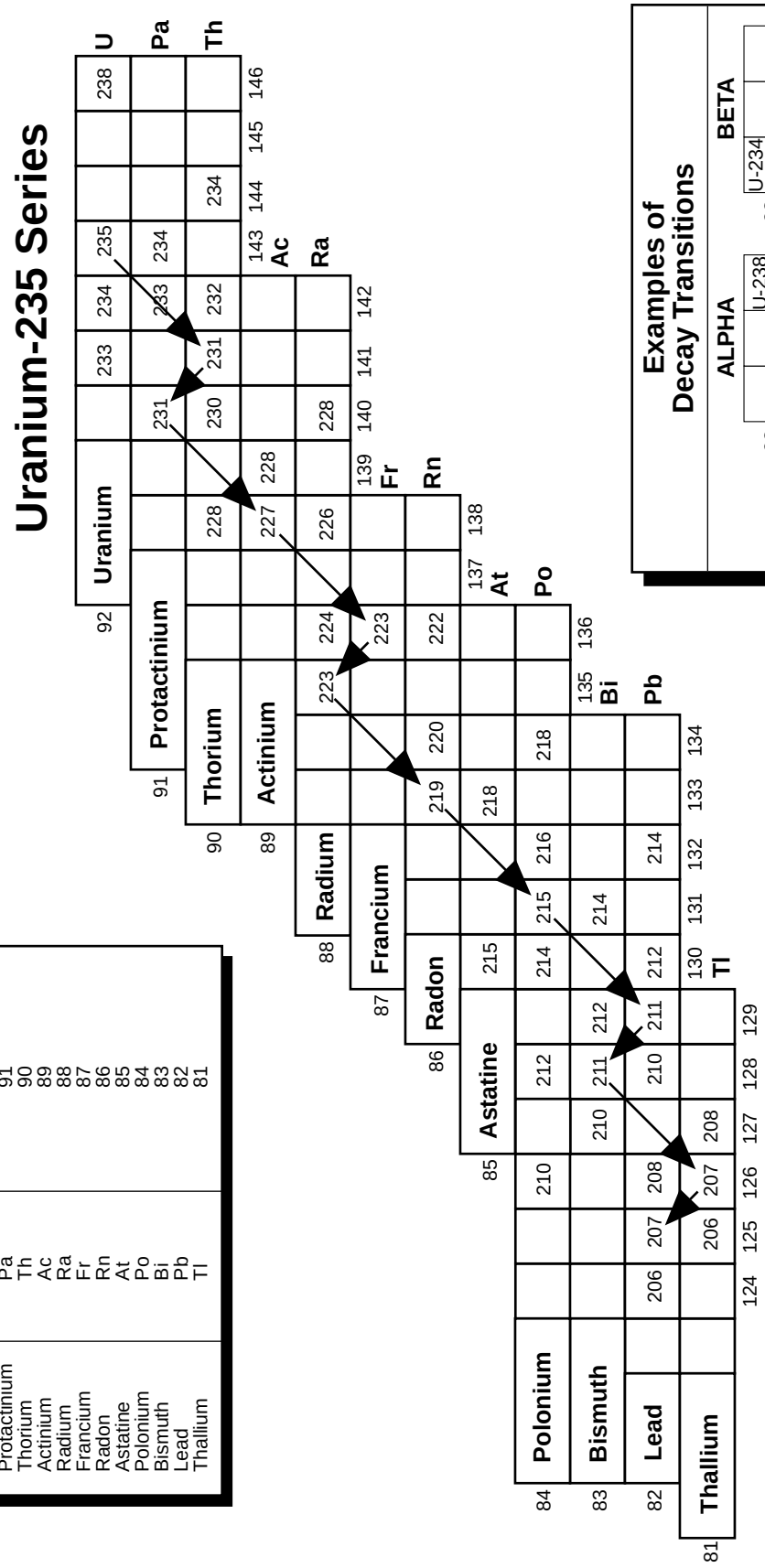
Distance
What distance (cm) is needed to reduce the source strength to one-half of its initial strength?

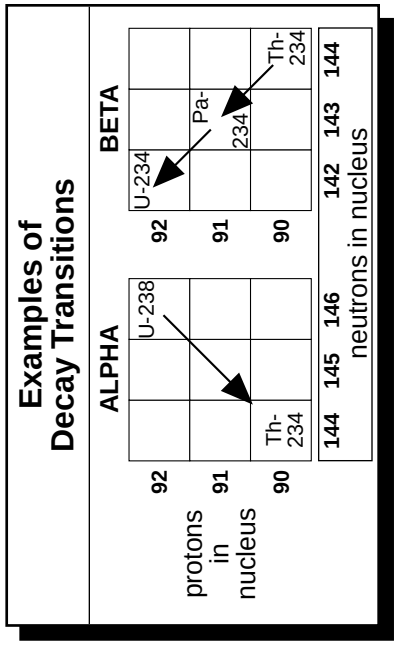
Method: By a quantitative assessment, use a radiation detector to determine what distance is needed to reduce the count-rate seen by the detector to one-half of the initial strength. Place the detector at variable positions away from the source (in increments of about 1-5 cm) and then keep increasing the distance between the detector and the source until the source strength is about one-half of the initial value. Then, record the distance.

Distance	Alpha	Beta	Gamma	Unknown

CHART OF THE ISOTOPES IN THE U-238, U-235, and Th-232 DECAY SERIES ANSWERS

Element	Symbol	Number of Protons in Nucleus (Atomic Number)
Uranium	U	92
Protactinium	Pa	91
Thorium	Th	90
Actinium	Ac	89
Radium	Ra	88
Francium	Fr	87
Radon	Rn	86
Astatine	At	85
Polonium	Po	84
Bismuth	Bi	83
Lead	Pb	82
Thallium	Tl	81





ATOMIC TRANSITIONS IN THE NATURAL RADIOACTIVE DECAY SERIES

Directions:

1. Using the table of atomic transitions, trace the thorium-232 decay series on the chart of the isotopes.
2. Using the information provided in the table of atomic transitions, plot the transitions in the uranium-235 decay series on the chart of the isotopes.
3. Using the plot of the transitions in the uranium-238 series given on the chart of the isotopes, fill in the blanks on the table of atomic transitions.

Thorium-232			Uranium-235			Uranium-238		
Number of Protons in Nucleus (Atomic Number)	**Isotope**	**Decay**	**Number of Protons in Nucleus (Atomic Number)**	**Isotope**	**Decay**	**Number of Protons in Nucleus (Atomic Number)**	**Isotope**	**Decay**
90	Th-232	Alpha	92	U-235	Alpha	92	U-238	Alpha
88	Ra-228	Beta	90	Th-231	Beta	_____	_____	_____
89	Ac-228	Beta	91	Pa-231	Alpha	_____	_____	_____
90	Th-228	Alpha	89	Ac-227	Alpha	_____	_____	_____
88	Ra-224	Alpha	87	Fr-223	Beta	_____	_____	_____
86	Rn-220	Alpha	88	Ra-223	Alpha	_____	_____	_____
84	Po-216	Alpha	86	Rn-219	Alpha	_____	_____	_____
82	Pb-212	Beta	84	Po-215	Alpha	_____	_____	_____
83	Bi-212	{ 33.7% Alpha	82	Pb-211	Beta	_____	_____	_____
		{ 66.3% Beta	83	Bi-211	Alpha	_____	_____	_____
84	Po-212	Alpha	81	Tl-207	Beta	_____	_____	_____
81	Tl-208	Beta	82	Pb-207	Stable	_____	_____	_____
82	Pb-208	Stable				_____	_____	_____
						_____	_____	_____
						82	Pb-206	Stable

ATOMIC TRANSITIONS IN THE NATURAL RADIOACTIVE DECAY SERIES

Thorium-232

Number of Protons in Nucleus (Atomic Number)	Isotope	Decay
90	Th-232	Alpha
88	Ra-228	Beta
89	Ac-228	Beta
90	Th-228	Alpha
88	Ra-224	Alpha
86	Rn-220	Alpha
84	Po-216	Alpha
82	Pb-212	Beta
83	Bi-212	33.7% Alpha 66.3% Beta
84	Po-212	Alpha
81	Tl-208	Beta
82	Pb-208	Stable

Uranium-235

Number of Protons in Nucleus (Atomic Number)	Isotope	Decay
92	U-235	Alpha
90	Th-231	Beta
91	Pa-231	Alpha
89	Ac-227	Alpha
87	Fr-223	Beta
88	Ra-223	Alpha
86	Rn-219	Alpha
84	Po-215	Alpha
82	Pb-211	Beta
83	Bi-211	Alpha
81	Tl-207	Beta
82	Pb-207	Stable

Uranium-238

Number of Protons in Nucleus (Atomic Number)	Isotope	Decay
92	U-238	Alpha
90	*Th-234*	*Beta*
91	*Pa-234*	*Beta*
92	*U-234*	*Alpha*
90	*Th-230*	*Alpha*
88	*Ra-226*	*Alpha*
86	*Rn-222*	*Alpha*
84	*Po-218*	*Alpha*
82	*Pb-214*	*Beta*
83	*Bi-214*	*Beta*
84	*Po-214*	*Alpha*
82	*Pb-210*	*Beta*
83	*Bi-210*	*Beta*
84	*Po-210*	*Alpha*
82	Pb-206	Stable

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THE RADIATION CHECK SOURCES ATTACHED TO THE CIVIL DEFENSE RADIATION MONITORS HAVE THE FOLLOWING CHARACTERISTICS:

Radioactive Material: Ra-D and RA-E (PB-210 and Bi-210)

These are beta emitters with low gamma emission

Activity: Nominally about 0.1 micro Curie

Since these radioactive materials are naturally occurring isotopes of natural uranium, they are unregulated and not controlled by any Federal or State Regulatory Agency. Furthermore, the very low activity posts no risk to teachers or students or other persons as long as the sources are not ingested.

INSTRUMENT NOT CALIBRATED

Please note that this instrument has not been calibrated, so no true value for the radiation dose rate should be inferred from its use. The instrument - without calibration - may be used validly only for relative measurements, for example the degree of attenuation by absorbers placed between a radiation source and the Geiger tube.

How Your Geiger Counter Works

Basics of Radiation Detection

The most common detectors (which employ the Geiger-Muller tube) utilize ionization to detect radiation.

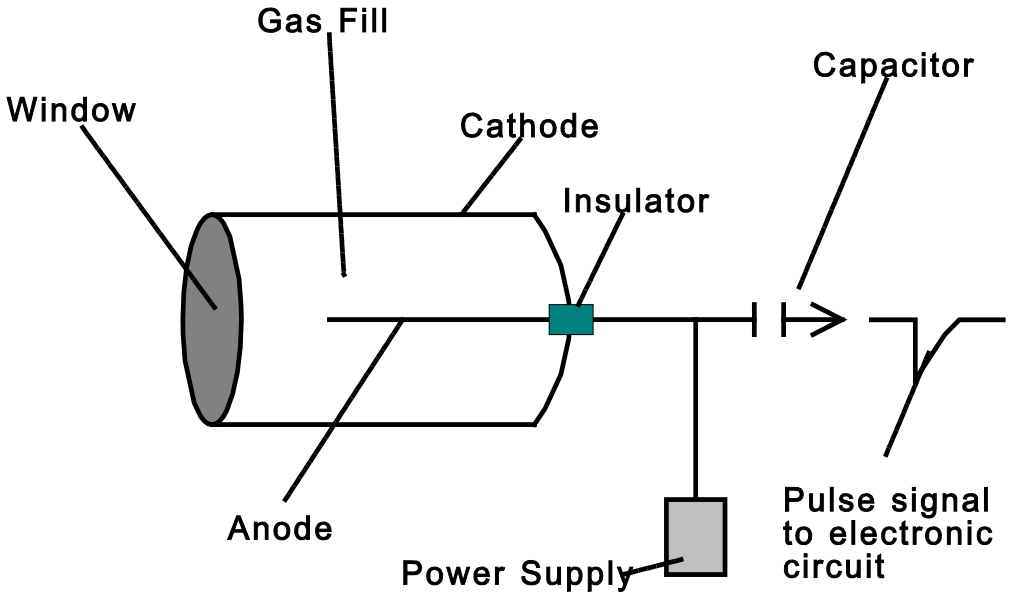
Certain types of radiation (alpha, beta, gamma, and x-rays) are said to be ionizing radiation. These types of radiation can provide enough energy to remove an electron from an atom. The result is formation of a positively charged particle, or ion (the nucleus of the atom and some of the electrons), and the release of an electron, which is a negatively charged particle.

Typical structure of ionization detector

The detector (Geiger-Muller tube) consists of a gas-tight housing which contains a noble gas such as argon, neon, or xenon, with small amounts of other gases.

The detector tube has a “window” through which radiation may enter. The tube has an anode (positively charged) and cathode (negatively charged) with a high-resistance insulator between them.

A power supply (30 - 1500 volts) charges the tube.



What happens when ionizing radiation is present:

- Ionizing radiation enters the detector tube.
- Energy from the radiation is absorbed by an atom of gas.
- An electron or electrons are removed from an atom of gas.
- The electrons, which are negatively charged, move toward the positively-charged anode.
- The anode attracts the electrons because of the charge from the power supply.
- As a result, the electrons rush toward the anode at great speed.
- A large number of electrons arrives in a burst (less than a millisecond) at the anode. This pulse can be used to cause a “beep” in a speaker.
- This flow of electrons through the tube is also an electrical current.
- The current flow is measured and interpreted in radiation units.

Other factors:

- Window material and thickness determine what types of radiation can be detected by a specific instrument.

  Consider, for example, alpha particles, which are relatively large and slow moving. They are stopped by a thin sheet of paper. They may be unable to get through the window of some detectors.

- Signal output (current flow) increases as radiation intensity increases.

  When radiation intensity is higher, more atoms are affected by the ionizing radiation. This results in the formation of more ions and the movement of more electrons toward the anode. That means a higher radiation reading or more “clicks” of your Geiger counter per minute.

The CD V-700 Radiological Survey Meter

This instrument is a rather simple device for measuring radiation dose rates at low intensities. It is capable of measuring dose rates from both beta and gamma radiation. Although knowledge of how the instrument works is not necessary for its use, some understanding may be helpful.

The basic principle is that radiation impinging on the detection device. The Geiger tube causes ions - which are charged atoms - to form in the gas within the tube. Under the effect of a high-voltage field, more ions are formed producing a pulse which is measured by the electrical circuit. The number of pulses is proportional to the strength of the radiation field and they are reflected by movement of the needle in the meter. This meter is simply a sensitive volt meter that is calibrated to read in milliroentgen per hour (mr/hr) and counts per minute (c/m).

The instrument has three settings permitting measurement of dose rates over a hundredfold range. Settings X1, X10, and X100 correspond respectively to full-scale readings of 0.5, 5, and 50 mr/hr.

In addition to the visual scale, the instrument is provided with an audible output so that an idea of the intensity of the radiation can be obtained by use of a headphone without having to look at the meter.
This audible output is a series of “clicks.” The frequency of the clicks is proportional to the intensity of the radiation field.

The Geiger tube is surrounded by two concentric metal tubes, one with a “window” allowing direct access of the radiation to the Geiger tube. With the window open, beta radiation is measured. With the window closed (by twisting the outermost tube) the penetrating gamma radiation - but not the beta radiation - is measured.

Use of the Survey Meter

Be sure the instrument has batteries. If batteries are needed, open the case by releasing the clamps. Lift up on the lid to which is attached all the operating circuitry. Disengage the battery clamps by squeezing them and lifting them out. Install the battery’s negative end first, then slide the positive terminal firmly into position. Replace the battery clamps and the lid assembly.

To operate the Survey Meter, switch the instrument to the X10 position with the beta window closed. Wait 30 seconds - the meter will read about zero. Open the window and expose the open Geiger tube to the check radiation (beta) source

which is on the side of the unit. According to the vendor's Instruction Manual, the meter should read between 0.5 and 0.8 mr/hr (after correcting for the 34-year decay of the source which has a half-life of 22 years). Obviously some deterioration of the instrument over this time interval would not be surprising and it could possibly affect the accuracy of the readings.

PRECAUTIONS

1. **Precautions**

Although this instrument is operated from four "D" cells, the high voltage power supply operates at voltages in excess of 900 volts which constitutes a shock hazard if not handled carefully. The power supply high-voltage components are located near the high voltage transformer at the rear of the circuit board. These components should not be touched, even when the instrument is "OFF," until the high-voltage capacitors are discharged. The method of discharging these capacitors is to short-circuit the two leads of the corona regulator tube V2 with a screwdriver which has an insulated handle.

GENERAL DESCRIPTION

1. **Introduction**

This instrument is a portable survey meter using a Geiger tube as the detector. The Geiger tube is mounted in a probe on the end of a 36-inch cable. The entire instrument and its accessories comprise a circuit box, a probe, a headphone, and a carrying strap; a radioactive sample is mounted on the side of the case.

2. **The Probe**

The probe comprises a nickel-plated brass shield with a window which may be opened in order to admit beta radiation. Within the probe is mounted a plug-in type Geiger tube which is sensitive to moderate- and high-energy beta radiation and to gamma radiation down to low energies. Because the Geiger tube is fragile, shock mounts are proved on both ends of the tube. In addition, rubber gasketing is used to seal against moisture.

3. **The Circuit Box**

The circuit box consists of the supply batteries, an electronic high-voltage supply, and electronic pulse shaping and metering circuit and a radioactive sample. The system is shockproof and waterproof, and is secured with rapid take-down clamps in order to make access very simple. The entire electronic circuit is mounted on a single card with connections going to the probe, the phone connector, and to the meter. The batteries are housed in a high-impact resistant plastic case which cannot be corroded by leaking battery fluids. The battery contacts are readily replaceable without tools to facilitate cleaning or replacement. The battery box is designed to be mechanically selective so that batteries cannot be inserted backwards.

OPERATION

1. Operating the Circuit the First Time

Clamp the circuit box back together and turn the switch to the X10 position. Make certain that the siding beta window of the probe is closed. Wait 30 seconds for the system to reach stability. The indicator should remain substantially at zero.

Open the window on the probe and present it to the center of the calibration source which is a beta radiation sample. The indicator should fall between 1.5 mr/hr and 2.5 mr.hr, averaging about 2 mr/hr.

2. Calibration

NOTE: The beta source must constitute the sole source of radiation when calibration is performed. Calibration must not be undertaken when the background is above normal or when the probe is in a radiation field other than that produced by the known beta source supplied with the instrument.

If the indication falls above or below this range, it may be corrected by screw-driver adjustment inside the box which is marked “CAL.” Advance the adjustment clockwise, increasing the reading.

3. Scale Ranges

There is only one control on this instrument for the operator to use. It is range control, comprising an “OFF” position and three ranges label “X100, X10, and X1. These respectively are both 100 times and time the scale reading in milliroentgens per house and counts per minutes shown on the meter. This scale is 0.5 milliroentgens per hour and three counts per minutes respectively with the major divisions all indicated on 50-division scale.

4. Using the Headphones

If the operator chooses to use a headphone with the instrument, it is screwed into the connector provided immediately to the left of the handle. The yellow plastic protective cap is removed. In using the headphone, the operator will note that each pulse arriving at the instrument is indicated by a distinctive audible “click” in the headphones.

5. Normal Background

Since normal background of radioactivity is of the order of 0.01 to 0.010 milliroentgens per hour, little activity will normally be observed. Under background conditions, only about 20 per minute of these clicks that occur are randomly spaced so that one may wait for several seconds before a click is observed and then there may be two or three in rapid succession. Very accurate measurements of background and other low-level radiation can be made by counting headphone clicks and timing with a watch which has a second hand.

The procedure is to count a given number of counts and observe the time required to obtain these counts. The radiation rate in counts per minute is the number of counts divided by the time in minutes. Table 1 gives the number of counts that are required to provide a given percentage error where percent standard error is defined as that error for which in 68 cases out of 100 the true error will not exceed the given percentage error. The nine-tenths error is that error for which the true reading is no different from the observed reading within the percentage limits for 90 cases out of 100.

TABLE 1

Percent Error	Number of Counts Required for Standard Error	Number of Counts Required for Nine-Tenths Error
1%	10,000 Counts	27,000 Counts
3%	1,100 Counts	3,000 Counts
10%	100 Counts	271 Counts

6. Checking Calibration

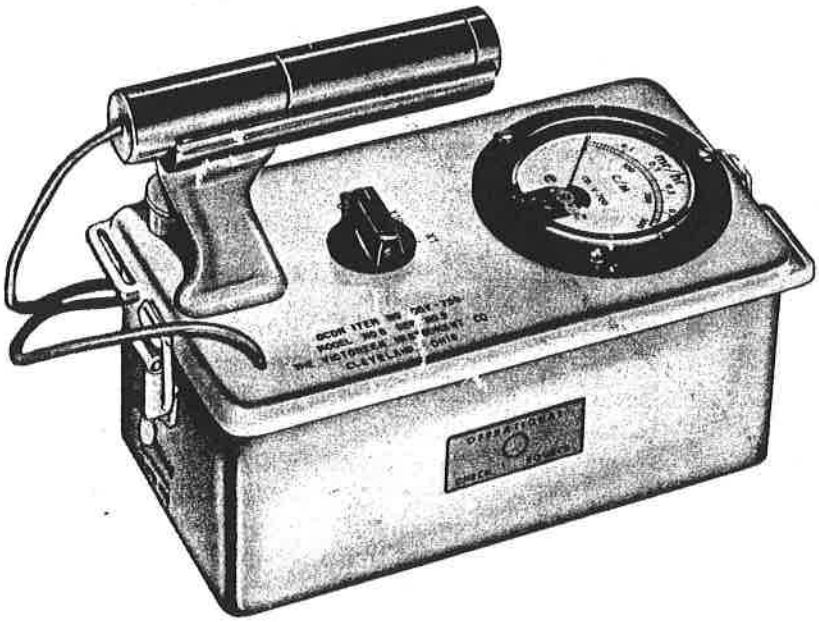
The operator should periodically check the calibration of the instrument to verify that it is correct. This operation is described in item 2.

Instruction and Maintenance Manual

RADIOLOGICAL SURVEY METER

OCDM Item No. CD V-700, Model No. 6 And Model No. 6A

Manufactured 1961



Note:

The next four pages (bearing the numbers 2&3, 4&5, 6&7, 8&9, were taken from a manual originally created by the manufacturer of one brand of Geiger counter (Victoreen) now being distributed at ANS Teacher Workshops.

Some instruments distributed by ANS are from other manufacturers. However, the original instruction manuals were similar.

Lionel brand requires only 2 batteries; Anton brand requires 5 batteries; ElectroNeutronics brand requires 4 batteries.

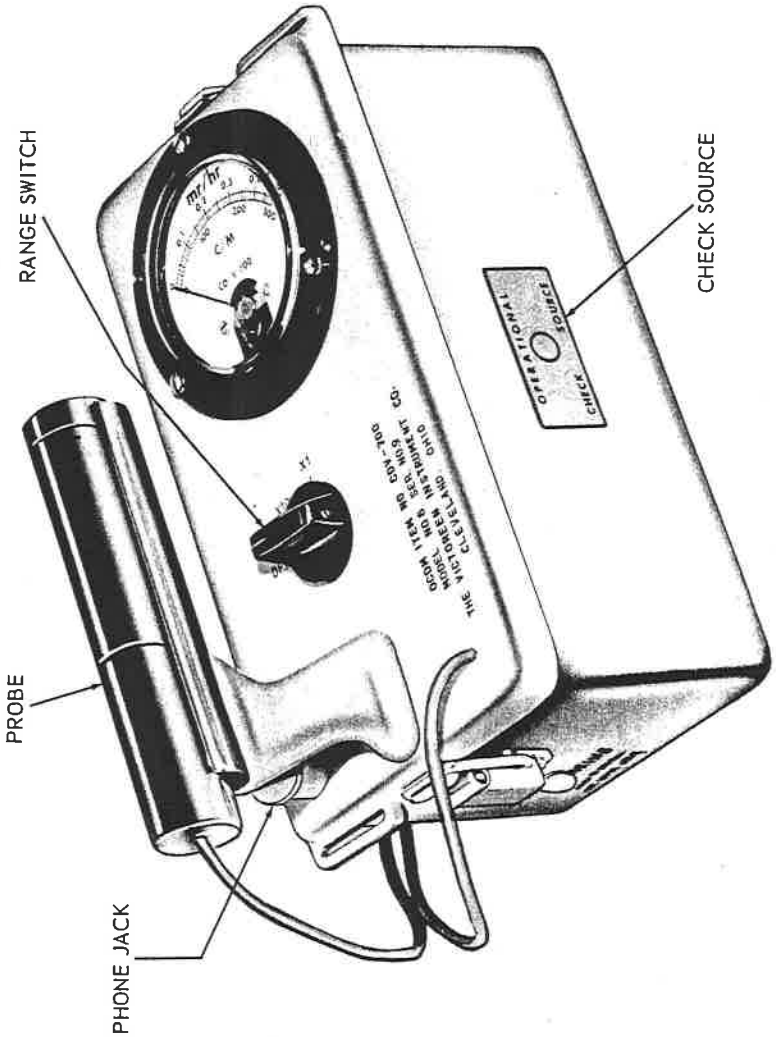


Figure 1. View of CD V-700, Model No. 6, Showing Operating Controls

1. PRECAUTIONS

1.1 PRECAUTIONS:

Although this instrument is operated from four "D" cells, the high voltage power supply operates at voltages in excess of 900 volts which constitutes a shock hazard if not handled carefully. The power supply high voltage components are located near the high voltage transformer at the rear of the circuit board. These components should not be touched, even when the instrument is "OFF", until the high voltage capacitors are discharged. The method of discharging these capacitors is to short-circuit the two leads of the corona regulator tube V2 with a screwdriver which has an insulated handle.

2. GENERAL DESCRIPTION

2.1 INTRODUCTION:

This instrument is a portable survey meter using a geiger tube as the detector. The geiger tube is mounted in a probe on the end of a thirty-six inch cable. The entire instrument and its accessories comprise a circuit box, a probe, a headphone and a carrying strap; a radioactive sample is mounted on the side of the case.

2.2 THE PROBE:

The probe comprises a nickel-plated brass shield with a window which may be opened in order to admit beta radiation. Within the probe is mounted a plug-in type geiger tube which is sensitive to moderate and high energy beta radiation and to gamma radiation down to low energies. Because the geiger tube is fragile, shock mounts are provided on both ends of the tube. In addition, rubber gasketing is used to seal against moisture.

2.3 THE CIRCUIT BOX:

The circuit box consists of the supply batteries, an electronic high voltage supply, an electronic pulse shaping and metering circuit and a radioactive sample. The system is shockproof and waterproof and is secured with rapid take-down clamps in order to make access very simple. The entire electronic circuit is mounted on a single card with connections going to the probe, the phone connector and to the meter. The batteries are housed in a high-impact resistant plastic case which cannot be corroded by leaking battery fluids. The battery contacts are readily replaceable without tools to facilitate cleaning or replacement. The battery box is designed to be mechanically selective so that batteries cannot be inserted backwards.

2.4 THE HEAD PHONE:

The head phone is a single piece magnetic type device with a connector suitable for the sealed jack mounted on the circuit box.

2.5 THE CARRYING STRAP:

The carrying strap, made of vinyl for easy decontamination, is provided with easily operated spring clips.

3. THEORY OF OPERATION

3.1 INTRODUCTION:

Operationally this instrument consists of a geiger tube radiation detector, a regulated high voltage supply, a pulse shaping and metering circuit, an indicating meter and headphone for audible detection of activity.

3.2 THE GEIGER TUBE:

The geiger tube is a gas filled device which detects the presence of ionization within its gaseous volume. The ionization results from the passage of ionizing type radiation through the gas. The primary type of radiation it detects is beta rays (high speed electrons). These are produced as a primary breakdown product of radioactive substances and in addition are produced within the geiger tube and within the walls of the probe by gamma radiation. A shield is provided which stops external beta radiation, thus making the detector sensitive to gamma radiation only, but a window in the probe may be opened to make the system sensitive to beta radiation also. The geiger tube operates at 900 volts which is essentially the center of a plateau extending from about 850 volts to about 920 volts.

3.3 THE HIGH VOLTAGE SUPPLY:

The high voltage power supply is a blocking oscillator driven "fly-back" type circuit. The blocking oscillator portion of the circuit consists of Q_2, R7B, transformer windings 3-4 and 5-6, and batteries BT1-2. When the instrument is turned "ON", Q_2 conducts and an increasing current flows through winding 3-4. This increasing collector current induces a voltage in winding 5-6 which maintains conduction of Q_2. The collector current increases until Q_2 has insufficient current gain to remain saturated when the circuit rapidly turns "OFF" due to the regenerative action of the transformer. During the "turn-off" action, large "fly-back" voltages appear across all transformer windings. A voltage peak of about 1100 volts appears across winding 1-2 because of the large number of turns in the winding. This voltage "fly-back" is rectified by components CR5 and C5, in the conventional manner and components R12 and C4 form a filter to smooth the pulsations of voltage across C5. V2 is a corona-discharge type regulator tube which regulates the high voltage to about 900 volts throughout the battery life. R11 is the geiger tube load resistor.

3.4 THE PULSE SHAPING AND METERING CIRCUIT:

The pulse shaping circuit is a blocking oscillator similar to the power supply with some exceptions. The circuit is held "cut-off" by the bias formed by

resistors R9 and R10 and the power supply battery. The blocking oscillator consists of components Q_1, T1, L1, CR1 and C1. Coupling capacitor C1 couples negative pulses from the geiger tube to the base circuit of Q_1. Inductance L1 forms a high impedance for the geiger tube pulses while it is a low resistance to direct current. CR1 prevents oscillations from occurring across L1. When Q_1 is turned "ON" by a GM tube trigger, Q_1 saturates and nearly all of the battery voltage of BT3-4 appears across winding 3-4. The winding current increases and a voltage is induced in winding 1-2. The induced voltage is in a direction such that conduction of Q_2 is maintained. Winding 3-4 current increases linearly until the transformer core saturates. At this time the circuit rapidly turns "OFF" and an inductive "fly-back" appears across both windings.

The metering circuit consists of an integrating capacitor C2, and range multiplier resistors R1 through R4. The multipliers determine the amount of charge that is placed on C2 during the pulse period of the blocking oscillator. The charge on the capacitor is discharged by the meter and R5. R6 and R7A are used for calibration.

3.5 SCALE RANGES:

Three ranges of operation are provided. The first range X1, requires 300 pulses per minute for full scale indication; the second range X10, 3000 pulses per minute; and the third range X100, 30,000 pulses per minute. These correspond respectively to 0.5 milliroentgens per hour, 5 milliroentgens per hour and 50 milliroentgens per hour of radium-equivalent radiation. Scale changing is effected by switching meter range resistors.

3.6 THE HEADPHONE CIRCUIT:

The voltage pulse for the headphone is taken from the "fly-back" of winding 3-4 via diode CR3. C3 is an integrating capacitor to "stretch" the "fly-back" pulse. R8 is an isolating resistor and CR4 damps "ringing" of the headphones.

4. INSTALLATION

4.1 INSTALLING THE BATTERIES:

The instruments are shipped with the batteries removed. In order to put the instrument into operation, the following procedure should be observed: Access to the interior of the instrument is accomplished by snapping open the pull catch at each end of the case and separating the top from the case bottom. This exposes the two battery boxes and two battery retainer clips. Remove each retainer clip by squeezing its ends until it can be pulled out of the slots in the battery box. Insert the batteries in the battery boxes observing the indicated polarity. (Each battery box is designed to be mechanically selective so that the batteries cannot be inserted with reversed polarity). Replace the battery retainer clips. Align the top with the case bottom and squeeze together gently. Snap the pull catches closed.

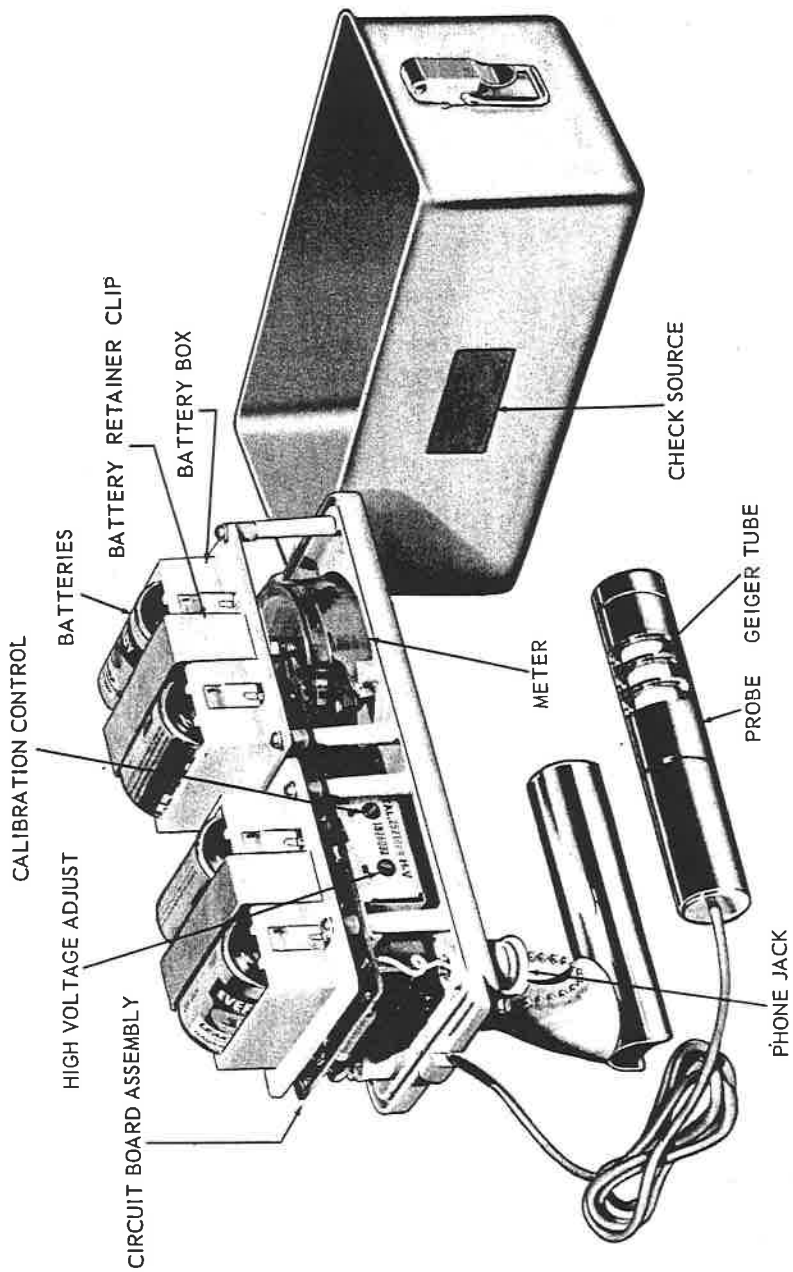


Figure 2. View of CD V-700, Model No. 6, Showing Major Components

NOTE: Due to the half-life of the check source and age of the meters, readings will be lower than suggested here. Refer to the page titled, the **CD V-700 Radiological Survey Meter**, and found earlier in this section (see the final paragraph under "Use of the Survey Meter" for details).

5. OPERATION

5.1 OPERATING THE CIRCUIT THE FIRST TIME:

Clamp the circuit box back together and turn the switch to the X10 scale. Make certain that the sliding beta window of the probe is closed. Wait thirty seconds for the system to reach stability. The indicator should remain substantially at zero.

Open the window on the probe and present it to the center of the calibration source which is a beta radiation sample. The indicator should fall between 1.5 mr/hr and 2.5 mr/hr, averaging about 2 mr/hr.

5.2 CALIBRATION:

NOTE: The beta source must constitute the sole source of radiation when calibration is performed. Calibration must not be undertaken when the background is above normal or when the probe is in a radiation field other than that produced by the known beta source supplied with the instrument.

If the indication falls above or below this range, it may be corrected by the screw-driver adjustment inside the box which is marked "CAL". Advancing the adjustment clockwise increases the reading.

5.3 SCALE RANGES:

There is only one control on this instrument for the operator to use. It is the range control, comprising an "OFF" position and three ranges labeled, "X100, X10, and X1". These respectively are both 100 times, 10 times and 1 time the scale reading in milliroentgens per hour and counts per minute shown on the meter. This scale is 0.5 milliroentgens per hour and 300 counts per minute respectively with the major divisions all indicated on a 50-division scale.

5.4 USING THE HEADPHONES:

If the operator chooses to use a headphone with the instrument, it is screwed into the connector provided immediately to the left of the handle. The yellow plastic protective cap is removed. In using the headphone, the operator will note that each pulse arriving at the instrument is indicated by a distinctively audible "click" in the headphones.

5.5 NORMAL BACKGROUND:

Since normal background of radioactivity is of the order of 0.01 to 0.02 milliroentgens per hour, little activity will normally be observed. Under background conditions only about 20 per minute of these clicks occur and they are randomly spaced so that one may wait for several seconds before any

click is observed and then there may be two or three in rapid succession. Very accurate measurements of background and other low level radiation can be made by counting headphone clicks and timing with a watch which has a second hand. The procedure is to count a given number of counts and observe the time required to obtain these counts. The radiation rate in counts per minute is the number of counts divided by the time in minutes. Table 1 gives the number of counts that are required to provide a given percentage error where percent standard error is defined as that error for which in 68 cases out of 100 the true error will not exceed the given percentage error. The nine-tenths error is that error for which the true reading is no different from the observed reading within the given percentage limits for 90 cases out of 100.

TABLE I

Percent Error	Number of Counts Required For: Standard Error	Nine-Tenths Error
1%	10,000 Counts	27,000 Counts
3%	1,100 Counts	3,000 Counts
10%	100 Counts	271 Counts

5.6 CHECKING CALIBRATION:

The operator should periodically check the calibration of the instrument to verify that it is correct. This operation is described in paragraph 5.2.

5.7 USING THE CARRYING STRAP:

The instrument may be carried in the hand or by a strap over the shoulder. The strap anchors are arranged in such a way that the meter is visible when carried over the right shoulder.

6. OPERATOR'S MAINTENANCE

6.1 BATTERY REPLACEMENT:

Battery replacement is easily accomplished by removing the circuit box bottom and the battery retaining clips on the two battery boxes. The old cells may be pulled out without tools and the new ones inserted.

7. PREVENTIVE MAINTENANCE

7.1 BATTERY LIFE:

CAUTION: Make certain the instrument is turned off at all times when not in use, otherwise the batteries will certainly be depleted and the instrument rendered ineffective. The life of the batteries in the rear battery box is about 100 hours under continuous operation and about 175 hours when operated four hours a day. The life of the other two cells is considerably longer but it is recommended that all batteries be replaced at one time. It is also recommended that the operator become accustomed to noting that the operating switch is in the "OFF" position when the instrument is set aside.

7.2 STORAGE:

For storage purposes it is best, wherever possible, to keep the instrument in a moderately cool area as this will provide greater shelf life for the batteries. At all times one should attempt to prevent radiological contamination of the instrument and particularly of the probe.

8. CORRECTIVE MAINTENANCE

8.1 REPLACING THE BATTERIES:

Battery replacement is accomplished as outlined in paragraph 6.1. The end point of the cells in the rear battery box is 1 volt per cell. The end point of the other cells is 2.5 volts for proper accuracy of the counting circuit. However, it is recommended that all batteries be replaced at one time in order that the shelf life of the counting circuit batteries is not exceeded.

8.2 REPLACING THE GEIGER TUBE:

The chief maintenance on this instrument is replacing the batteries. However, the geiger tube also expends itself with use and must be replaced occasionally but one cannot predict precisely the life of a geiger tube since the total number of counts it has accumulated and the operating conditions of temperature, voltage and load characteristics are very important. Whenever fresh batteries are installed into the instrument and the instrument does not work correctly, it is wise first to try replacing the geiger tube before making any further attempts at circuit checking.

8.3 CHECKING THE HIGH VOLTAGE SUPPLY:

When the power supply is operating, a buzz of about 100 cps. in frequency can be heard due to the oscillations of the power transformer laminations. If the buzz is not audible, the oscillator section is probably not operating

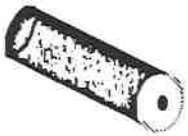
If you DID RECEIVE headphones with your Geiger Counter.
If you received headphones with your Geiger counter, there will be a special screw-on connector which mates with the "phone" connection on the Geiger counter.
The instrument should be audible for one or two people, using the earphone.

If you wish, it is easy to make the instrument audible for classroom demonstrations.
Here's how:

Obtain: a two-conductor 1/8" mono phone PLUG (Radio Shack, Catalog No. 274-286A) **and** a battery powered amplifier/speaker (Radio Shack, Cat. No. 277-1008C).
On your earphone wire, cut the wire near the earpiece and discard the earpiece.
Strip insulation off about ½" of the two wires. Unscrew the PLUG and slip the plastic portion over the wire; connect each wire to one of the two posts of the PLUG and solder in place. Screw the plug back together.
The PLUG inserts into an input jack on the amplifier/speaker. (Some people have reported being able to plug into an audio input on a "boom box" radio.)
Adjust the volume on the amplifier to minimize "hum" and optimize the "clicks."

ELECTRONICS MADE EASY

"INNIE"



RADIO SHACK
Cat. No. 274-333A
Two-Conductor
1/8" Mono Phone Jack
$1.99 Pkg. of 2

(for headphones)

"OUTIE"

RADIO SHACK
Cat. No. 274-286A
Two-Conductor
1/8" Mono Phone Plug
$1.99 Pkg. of 2

(for amplifier / speaker)

low-voltage speaker wire

amplifier / speaker

RADIO SHACK
Cat. No. 277-1008C
Audio
Amplifier / Speaker
$11.99

Requires 1 - 9 volt battery

If you DID NOT RECEIVE Headphones with your Geiger Counter.
If you did NOT receive headphones with your Geiger Counter, it is ***still easy*** to make it audible for classroom use.

Obtain some light weight, low-voltage speaker wire (or earphone wire).
Obtain: a two-conductor 1/8" mono phone PLUG (Radio Shack, Catalog No. 274-286A) **and** a battery powered amplifier/speaker (Radio Shack, Cat. No. 277-1008C).

Follow the instructions at http://www.ans.org/pi/teachers/reactions/2001-04-02.html
The instructions will show you how to use the yellow plastic cap from your Geiger counter to hold the wires in place on the Geiger counter's "phone" connection.

Alternate, *for attaching personal earphones*: Obtain from Radio Shack a two-conductor 1/8" mono phone JACK (Catalog No. 274-333A). Today's popular and inexpensive headphones plug into this JACK. Refer to the instructions on the web site (listed above), substituting the Jack in place of the PLUG shown. Then, plug earphones into the jack.

Atoms and Radiation

Your Name Here
Your Institution Here
Date

What is an Atom?

- Atoms are made up of protons, neutrons & electrons
  - Protons: + charge
  - Neutrons: no charge
  - Electrons: - charge
- Atoms want to have no net charge
  - # protons = # electrons

Mass of an Atom

- Masses
  - Proton: 1 amu
  - Neutron: 1 amu
  - Electron: .000549 amu
- So mass of atom ~
  - # neutrons + # protons

What is the mass of:

- Helium?
  - 2 protons, 2 neutrons, 2 electrons
- Oxygen
  - 8 protons, 8 neutrons, 8 electrons
- Fissile Uranium
  - 92 protons, 143 neutrons, 92 electrons
- Alpha particle
  - 2 protons, 2 neutrons

Isotopes

- Isotopes are similar elements with different amounts of neutrons
- There have similar properties
  - Hydrogen vs Deuterium
- Stable and unstable versions of atoms

Example

- Sodium – 23
  - 11 protons, 12 neutrons
  - Very plentiful, in salt that you eat (NaCl)
- Sodium – 24
  - 11 protons, 13 neutrons
  - Not natural
  - Highly radioactive, beta decay
  - Used to find leaks in industrial pipes

Fission vs. Fusion

Fission

- Makes 20% of our electricity
- Breaking apart of Heavy Nuclei
- Nuclear Reactor tour later Today!
- Example:
  - n + U-235 → Ba-139 + Kr-94 + 3n

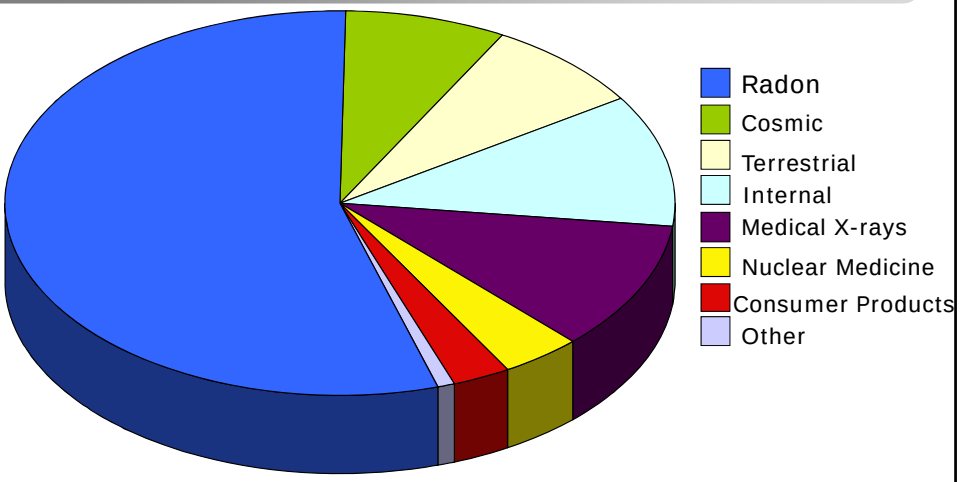
Fusion

- Powers the Sun
- Hard to get on Earth
- Combination of Light Nuclei
- Example:
  - H-3 + H-2 → n + He-4
  - Tritium + Deuterium → neutron + Helium

Where does radiation come from?

- The sun
- Soil, water and vegetation
- Internal sources
  - Potassium-40 (bananas)
  - Carbon-14 (air)
  - Lead-210 (radon)
- Man-made sources
  - Medical sources (x-rays, radiation…)
  - Nuclear Power

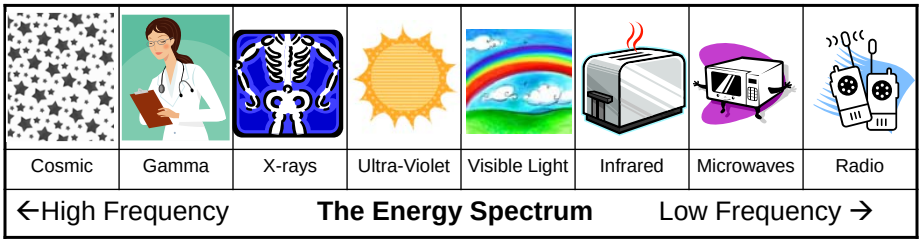
Average Annual Dose – U.S.



Types of Radiation

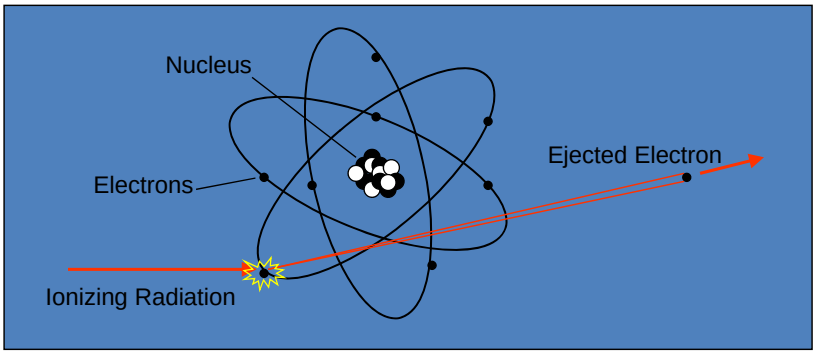
Ionizing radiation
- Produces ions in the material it strikes

- Non-ionizing radiation
  - Can cause damage by physically striking material



Why is it called *ion*izing?

Because it creates *ions* -- atoms with a charge.



Ionizing radiation

- Alpha particles

Helium Nucleus

- Beta particles

Electron

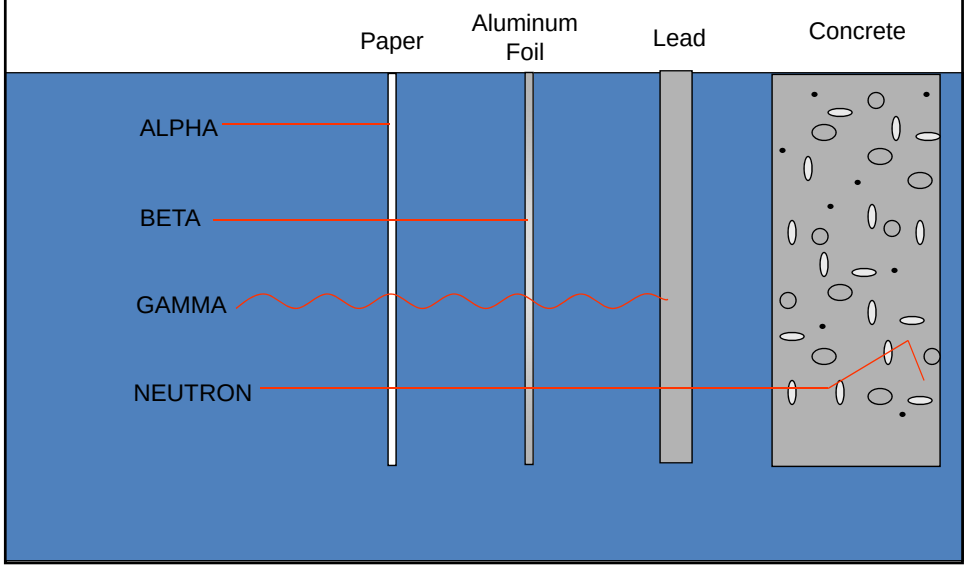
- Photons
  - Gamma rays
  - X-rays

Photon

Non-Ionizing Radiation

- Low energy photons
  - Such as light, infrared light, etc
- Neutrons
  - Neutral particle in nucleus
  - Like a proton but with no charge
  - However, neutrons are often considered IONIZING RADIATION, because their SECONDARY effects do ionize matter

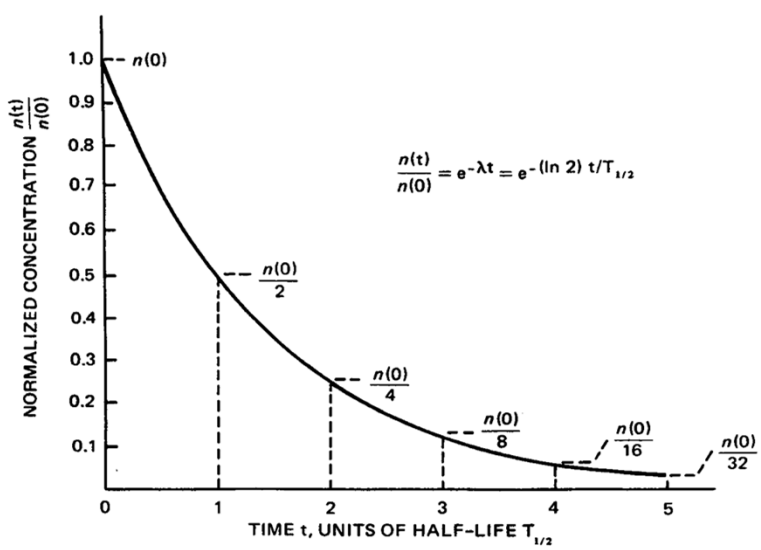
Radiation Penetration



Decay

- Radioactive material has a probability of decaying
- Overtime, this probability averages into a half life
- Half-life: Amount of time it takes for half of the radioactive substance to decay

Half-Life Demonstration



American Nuclear Society

Nuclear-Related Web Sites

www.nuclearconnect.org
Nuclear Connect, Center for Nuclear Science and Technology Information, American Nuclear Society.
Public education website about nuclear science and technology. Resources for students and teachers can be found here.

Reactions.ans.org
ANS/Public Information/Teachers/ReActions, American Nuclear Society.
The online source for ReActions e-newsletters for teachers. View past issues.

www.ans.org
American Nuclear Society,

www.ans.org/pi/glossary
ANS/Public Information/Resources/Glossary of Terms, (2012), American Nuclear Society.
A glossary of terms related to nuclear science and technology

www.ans.org/links
ANS : Nuclear Links, American Nuclear Society.
Links to other sources about nuclear science and technology information

The following is NOT meant to be a comprehensive web listing. Rather, it should serve as a starting point for exploration. Addresses may have changed since they were last checked. No endorsement of any organization or site is intended and none should be inferred.

Basic Information about Nuclear Science and Technology

www.lbl.gov/abc
ABC's of Nuclear Science, (2012) Nuclear Science Division, Lawrence Berkeley National Laboratory.
Facts and information along with experiment ideas for chemistry and physics.

www.nndc.bnl.gov/chart
Interactive Chart of Nuclides, National Nuclear Data Center, Brookhaven National Laboratory.

http://particleadventure.org/other/othersites.html
Particle Physics Education Sites , (this page is no longer maintained)
A list of sites for information related to particle physics.

http://particleadventure.org
The Particle Adventure, (2012) Particle Data Group, Lawrence Berkeley National Laboratory.
An interactive tour of the fundamentals of particles and force.

www.nucleartourist.com
The Virtual Nuclear Tourist, (2012)
A tour of nuclear power plants around the world

www.Nuc.Berkeley.EDU
Department of Nuclear Engineering, (2013) UC Berkeley.
Resource with information about the university's program

www-d0.fnal.gov/~oneil/skinny.html
Why We Fear Nuclear Power, Not Peanut Butter, (1997) Hannah Holmes, Discovery Communications, Inc.
A light-hearted, yet informative view of risk assessment and risk perception.

Food Irradiation

http://uw-food-irradiation.engr.wisc.edu
UW Food Irradiation Education Group, University of Wisconsin Food Irradiation Education Group
Information and brochures about food irradiation.

http://ftsi.us/irradiation **/Food Technology Service, Inc.**

Call the USDA Meat and Poultry Hotline at:
1-888-MPHotline (1-888-674-6854)
Email: mphotline.fsis@usda.gov
Ask Karen Online:
http://www.fsis.usda.gov/wps/portal/informational/askkaren

National Laboratories

www.anl.gov
Argonne National Laboratory, (2013)

http://newton.dep.anl.gov
NEWTON, Ask a Scientist at Argonne National Labs! (2012) NEWTON is an electronic community for Science, Math, and Computer Science K-12 Educators

www.bnl.gov
Brookhaven National Laboratory – a passion for discovery, (2013)

www.bnl.gov/education
Office of Educational Programs, (2013)
Resources for teachers and students.

www.inel.gov
Idaho National Laboratory, (2013)

www.llnl.gov
Lawrence Livermore National Laboratory (LLNL), (2013)

www.lanl.gov
Los Alamos National Laboratory, National Security Science, (2013)

www.ornl.gov
Oak Ridge National Laboratory (ORNL), (2013)

www.sandia.gov
Sandia National Laboratory: Exceptional Service in the National Interest, (2013)

Organizations, Companies, Misc.

www.ansto.gov.au
Home – ANSTO, (2013), Australian Nuclear Science & Technology Organisation

www.cna.ca
Canadian Nuclear Association, (2013) Promoting the development and growth of nuclear technologies for Canada.

www.nuclearsafety.gc.ca
Welcome to the Canadian Nuclear Safety Commission, (2013). In English and French.

www.cns-snc.ca/
Canadian Nuclear Society, (2013), In English and French.

www.iaea.org
International Atomic Energy Agency (IAEA), 2013

www.hps.org
Health Physics Society, (2013)
Visit their facts sheets section

www.snm.org
Society of Nuclear Medicine and Molecular Imaging, (2013)
Visit their Resource Center

www.ecolo.org
Environmentalists for Nuclear Energy – International home page.
For complete and factual information on energy and the environment.

www.radwaste.org
RadWaste.org, (2011)
Your guide to radioactive waste resources on the Internet. Visit the *Teacher's Corner*

www.nuclearmuseum.org
The National Museum of Nuclear Science and History, (2013), Albuquerque, New Mexico

www.ocrwm.doe.gov/ne/office-nuclear-energy
Office of Civilian Radioactive Waste Management (OCRWM)

American Nuclear Society

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outreach@ans.org e-mail

Last updated August 2013

American Nuclear Society

ReActions

Volume 28 • October 2013

Dear Bonnifer,

Welcome to the October 2013 issue of ReActions!
Articles offer links to additional related information.

Happy reading!

In This Issue

Future ANS Teacher Workshops

Phoenix, Arizona
Sunday, March 2, 2014
Full-day Workshop
Details to be announced.

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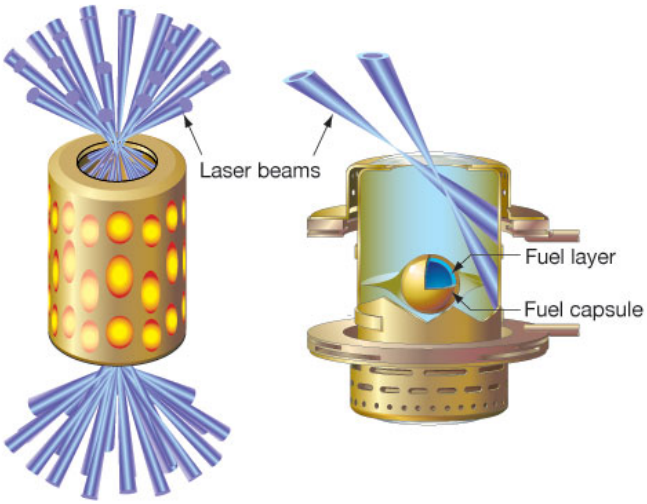
Fusion: Scientists Move Closer to Ignition

Scientists and engineers have long wanted to develop technology enabling them to utilize fusion reactions as a source of controlled power. Why? Fusion has the potential to provide very large amounts of energy. The challenge has been that attempts to harness fusion in a controlled reaction have required the input of more energy than was released during the fusion. Recent reports indicate that work at the National Ignition Facility (NIF) located at Lawrence Livermore National Laboratory (LLNL) is moving researchers forward in their quest for a self-sustaining, controlled fusion reaction.



Credit: Lawrence Livermore National Laboratory

All of the energy of NIF's 192 laser beams are directed inside a gold cylinder called the hohlraum. A tiny capsule inside the hohlraum contains deuterium and tritium -- fuel for the ignition process.

Reno, NV
Saturday, June 14, 2014
Full-day Workshop
Details to be announced.

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For Updates on these workshops, go to www.NuclearConnect.org and click EVENTS

Researchers at NIF focus 192 laser beams, all at the same time, on a target container called a hohlraum (a German word meaning "hollow room") about the size of a pencil eraser. The hohlraum holds a small super-cooled capsule of two hydrogen isotopes -- deuterium and tritium. When the lasers are fired -- in nanosecond (billionth-of-a-second) pulses - they deliver an enormous amount of energy and power. This heats and compresses the hydrogen isotopes so much that fusion takes place

Recently, the NIF completed a test which suggests that there is one significant challenge yet to overcome. That challenge? The capsule containing the deuterium and tritium breaks apart prematurely. As a result the research team is working to design an improved capsule for the hydrogen isotopes.

The researchers are encouraged by the results so far, but have a significant challenge to overcome before they achieve ignition.

***

Fusion - a nuclear reaction in which two atoms fuse and form a new kind of atom in which the two original atoms are combined.

Ignition - a point at which the fusion reaction produces more energy than is needed to initiate it

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Explore these resources for more information about the National Ignition Facility.

What is NIF?
https://lasers.llnl.gov/about/nif/about.php
https://lasers.llnl.gov/about/nif/
http://en.wikipedia.org/wiki/National_Ignition_Facility

Recent news releases from NIF
http://lasers.llnl.gov/newsroom/press_releases

Access a gallery with interesting videos from NIF
https://lasers.llnl.gov/multimedia/video_gallery/

The seven wonders of NIF
https://lasers.llnl.gov/about/nif/seven_wonders.php

Inertial Confinement Fusion: How to Make a Star
https://lasers.llnl.gov/programs/nic/icf

More related images
http://www.aps.org/about/physics-images/archive/nif-target.cfm

Other places to read about the NIF milestone
http://www.bbc.co.uk/news/science-environment-24429621
http://www.foxnews.com/science/2013/10/08/massive-laser-brings-us-one-step-closer-to-mastering-fusion/

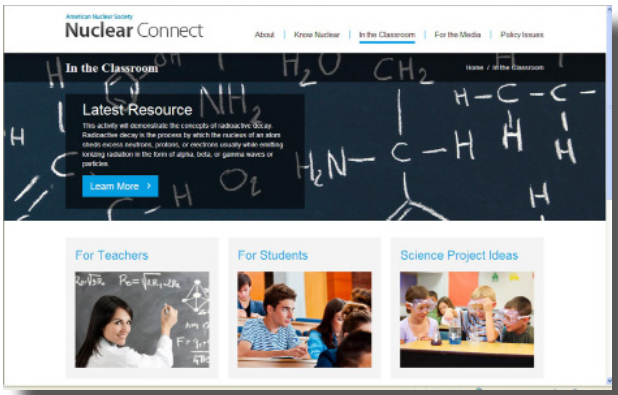
Video of Countdown to a Laser Shot
http://www.youtube.com/watch?v=CgdSVt6vHV0

Video: NIF as Featured on BBC
http://www.youtube.com/watch?v=DyB7Ho_W9RE

The Center for Nuclear Science and Technology Information is an outreach initiative of the American Nuclear Society (ANS). The Center was created to foster interest in and increase understanding about nuclear science and technology.

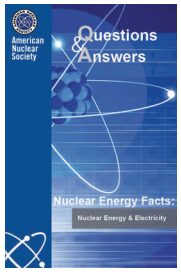
Connect with Us!

We conduct various educational events like workshops for teachers, classroom presentations, seminars for congressional staff, and webinars for journalists.



www.NuclearConnect.org

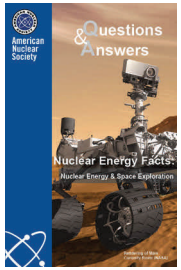
Booklets



Nuclear Energy Facts - Q&A:
Nuclear Energy and Electricity

Item ID: 750020
$2.00 each

This booklet contains the answers to 40 of the most commonly asked questions about nuclear energy's use in generating electricity. Public concerns about need, costs, safety, and waste disposal are addressed with references and additional resources.
Full color 64-page booklet. 5.5″ x 8.5”.

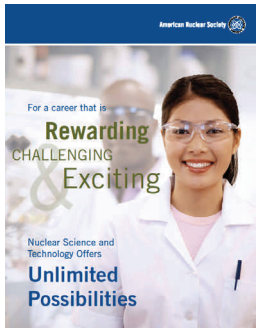


Nuclear Energy Facts - Q&A:
Nuclear Energy and Space Exploration

Item ID: 750020
$1.00 each

This booklet contains the answers to over a dozen commonly asked questions about the role of radiation and nuclear energy in space exploration. Covers radiation in space, power and propulsion, RTGs, and questions about potential accidents involving nuclear energy in space exploration. Full color 28-page booklet. 5.5" x 8.5".

Careers in Nuclear

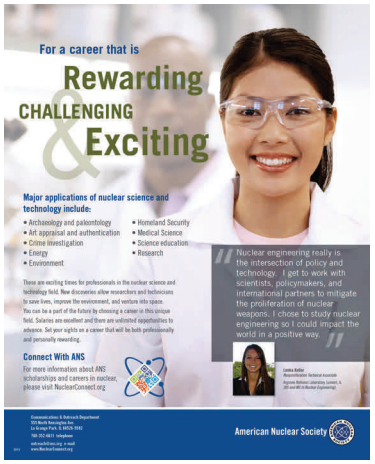


Career Brochure

Item ID: 750059
$.75 each

Career Poster

Item ID: 750063
$10.00 each



These materials highlight the careers that have been created by the atom: medical science, energy, and the environment. Brochure—Full color 4 page booklet. 8.5" x 11". Poster—Full color 16” x 20”

American Nuclear Society

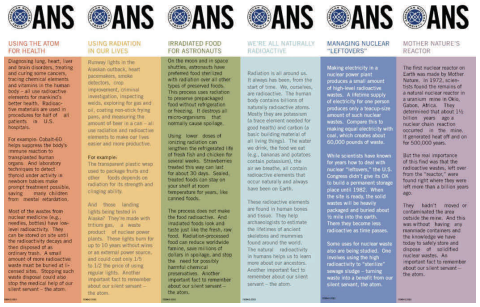
Public Information Materials

FOR TEACHERS

Recognizing the importance of a well-informed public, the American Nuclear Society uses its members' special scientific knowledge to create materials concerning the beneficial uses of nuclear science and technology. These publications and other public information materials explain the important place of nuclear science and technology in modern life.

For the ReActions e-newsletter and teaching resources go to
www.NuclearConnect.org

Most Popular

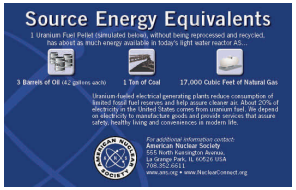


Our Silent Servant - The Atom Bookmarks

Item ID: 750043
$20.00 per package of 300

These 2 x 8 inch bookmarks with nuclear energy messages make a perfect handout for teachers, students, libraries, exhibits, etc.! Six titles in six different colors are available: We're All Naturally Radioactive, Using Radiation in Our Lives, Irradiated Food for Astronauts, Mother Nature's Reactor, Managing Nuclear "Leftovers," and Using the Atom for Health. (Aimed at 5th through 12th grade levels).

May be purchased in packs of 300 as one title or assorted titles.
Assorted title package contains 50 of each title.



Source Energy Equivalents Pellet Card

Item No. 750027
$2.00 each

A simulated uranium fuel pellet is attached to this card. The quantity of energy that can be released from this amount of nuclear fuel is compared to three major energy sources: oil, coal, and natural gas. With a graphic illustration of source equivalents, this card is a useful resource for public information exhibits, discussion groups, students, scout groups, etc. (Aimed at 7th - 12th grade students and adults).

Atoms Family Activity Book

Item No. 750055
$5.00 each

A booklet for students from kindergarten through grade 5 provides learning activities from simple counting and writing exercises to coloring projects and word puzzles. Children will learn what an atom is, how a nuclear plant makes electricity and how radioisotopes are used. (Aimed at grades K-5).

Brochures

Personal Radiation Dose Chart

Item ID: 750022
$.25 each

Our daily exposure to radiation comes from numerous sources within our environment. The annual dose to which we are subjected depends upon where and how we live, and what we eat, drink, and breathe. This easy-to-use chart shows how to estimate that dose and compare it to (Aimed at 5th grade through 12th grade levels.)
Full Color. 8.5" x 11" Tri-fold.

Sustainable Development

Item ID: 750060
$.25 each

This brochure addresses how nuclear science and technology are crucial to Sustainable Development. It also discusses the contributions of nuclear science and technology to improved health, improved quality of life, and increased capacity for economic development (as an outgrowth of scientific research using nuclear technology).
Full Color. 8.5" x 11" Tri-fold.

A Day With the Atom

Item ID: 750060
$.75 each

So what would our world be like today if radiation had not been harnessed to serve our human needs? One way to gain a small appreciation for this modern servant is to go through a typical day with our antennas particularly sensitized for radiation awareness. Learn more about how we use nuclear science and technology every day from the time we get up to when we go to bed.
Full color 4-page brochure. 8 1/2" x 11".

American Nuclear Society

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www.NuclearConnect.org

January 2014