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ABSTRACT

This instructional guide, intended for student use, develops the subject of radioactivity and man through a series of sequential activities. A technical development of the subject is pursued with examples stressing practical aspects of the concepts. Included in the minicourse are: (1) the rationale, (2) terminal behavioral objectives, (3) enabling behavioral objectives, (4) activities, (5) resource packages, and (6) evaluation materials. The benefits as well as the dangers of radioactivity to man are considered. This unit is one of twelve intended for use in the second year of a two year vocationally oriented physics program. (CP)

CAREER ORIENTED PRE-TECHNICAL PHYSICS

Radioactivity and Man

MINICOURSE

ESEA Title III Project

1975

dallas independent school district

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This Minicourse is a result of hard work, dedication, and a comprehensive program of testing and improvement by members of the staff, college professors, teachers, and others.

The Minicourse contains classroom activities designed for use in the regular teaching program in the Dallas Independent School District. Through minicourse activities, students work independently with close teacher supervision and aid. This work is a fine example of the excellent efforts for which the Dallas Independent School District is known. May I commend all of those who had a part in designing, testing, and improving this Minicourse.

I commend it to your use.

Sincerely yours,

Nolan Estes

General Superintendent

NE:mag

CAREER ORIENTED PRE-TECHNICAL PHYSICS

RADIOACTIVITY AND MAN

MINICOURSE

RATIONALE (What this minicourse is about):

Radioactivity is naturally present all around us; but as nuclear technology becomes more widespread, man-made radiation will become more and more a part of our everyday environment. Therefore, everyone needs to learn something about the basics of radiation technology, its benefits, and its hazards.

In this minicourse you will develop a better understanding of the hazards of radioactive materials and radioactive radiation; and you, as a more informed citizen, can pass on to others information about radiation hazards and precautions to ~~be~~ taken to avoid unnecessary exposure. An effort will be made not to be alarmists and not to overemphasize radiation hazards, but to place the hazards of radioactivity in a realistic perspective with other hazards of everyday life. Of course, a very real and weighty environmental concern is the yet unsolved problem of handling and long-term storing of radioactive wastes and reactor fuels for the numerous power reactors planned for use in the immediate future.

The benefits for mankind derived from radiation technology are so great that our present civilization would not endure without this technology. Let's glance at a few of these benefits. The use of radioisotopes to discover the nature of a particular illness (diagnostic tool), the use of radioisotopes to cure a particular illness (therapeutic tool), the use of radioactive tracers to better understand the functions of plants and to thereby increase world food production, the use of radioactive isotopes to find ways to reduce wear in engines and machine parts, the use of radioactive radiation to sterilize food, and the use of radioactive materials to make atomic batteries are only a very few applications taken from a list of thousands of technological applications.

In this minicourse you will: (a) study the relationship of radioactivity to nuclear energy, (b) examine some of the general properties of naturally occurring and man-made radioactive elements, and (c) investigate several means of detecting radioactivity. You will also study some of the dangers which radioactive materials pose for the human body; and at the same time, a whole section will be used to show how radioactivity benefits man.

An understanding of radioactivity, its properties, its hazards, and its detection constitute a foundation for entering into a large variety of related technical fields. For example, the field of medicine includes radiation research physicians, specialists in medical radioisotopes, X-ray technicians, and the like. Also, this minicourse will be useful to students who may become technicians in a cancer clinic, assistants to a dermatologist, health physics technicians for specialized manufacturers whose processes require radioactive materials, nuclear power plant technicians, or physics or science teachers. These kinds of job prospects are good, and there has been an increase in demand for more technical help in most of these fields in recent years.

You are expected to keep a notebook during this minicourse. The notebook will contain accounts of investigations (experiments), answers to questions, and newspaper and magazine articles related to radioactivity and its application to everyday living.

In addition to RATIONALE, this minicourse contains the following sections:

1) TERMINAL BEHAVIORAL OBJECTIVES (Specific things you are expected to learn from this minicourse)

2) ENABLING BEHAVIORAL OBJECTIVES (Learning "steps" which will enable you to eventually reach the terminal behavioral objectives)

3) ACTIVITIES (Specific <u>things to do</u> to help you learn)

4) RESOURCE PACKAGES (Specific instructions for performing the learning <u>Activities</u>, such as procedures, references, laboratory materials, etc.)

5) EVALUATION (Tests to help you learn and to determine whether or not you satisfactorily reach the terminal behavioral objectives)

   a) Self-test(s) with answers to help you learn more.

   b) Final tests, to measure your overall achievement.

TERMINAL BEHAVIORAL OBJECTIVES

Upon the completion of this minicourse, you will be able to:

1) explain the general relationship of natural and artificial transmutation to radioactivity.

2) explain and illustrate the general differences between alpha particles, beta particles, and gamma rays.

3) demonstrate the use of such instruments as the electroscope, the cloud chamber, the Geiger counter, and the spinthariscope in the detection of radioactive radiation.

4) explain some of the dangers of radiation to the human body, when exposed externally or internally.

5) write down and explain at least ten (10) different benefits of radioactivity to mankind.

6) explain how radioactivity is affecting everyday life today, based on at least four (4) clippings of writeups from current newspaper or magazine artilces.

ENABLING BEHAVIORAL OBJECTIVE #1:	ACTIVITY 1-1	RESOURCE PACKAGE 1-1
Explain the general nature of radioactivity and demonstrate the detection of radioactivity by use of such instruments as the electroscope, cloud chamber, Geiger counter, and the spinthariscope.	Read Resource Package 1-1, performing all investigations. Answer questions in Resource Package 1-2; then check your answers by using Resource Package 1-3.	"Radioactivity" RESOURCE PACKAGE 1-2 "Self-test on Radioactivity" RESOURCE PACKAGE 1-3 "Answers to Self-test"
ENABLING BEHAVIORAL OBJECTIVE #2:	ACTIVITY 2-1	RESOURCE PACKAGE 2-1
Explain some of the dangers of radioactive materials and radioactive radiation to the body, as a result of either external or internal exposure, and describe the destruction of living cells by energy emitted from radioactive materials.	Read Resource Package 2-1, performing all investigations. Answer questions in Resource Package 2-2; then check your answers by using Resource Package 2-3.	"The Dangers of Radioactive Radiation to the Human Body" RESOURCE PACKAGE 2-2 "Self-test on the Dangers of Radioactive Radiation to the Human Body" RESOURCE PACKAGE 2-3 "Answers to Self-test"

ENABLING BEHAVIORAL OBJECTIVE #3:

List at least eight (8) ways that radioactivity benefits man.

ACTIVITY 3-1

Read Resource Package 3-1 and answer questions in Resource Package 3-2; then check your answers by using Resource Package 3-3.

RESOURCE PACKAGE 3-1

"Some Benefits of Radioactivity"

RESOURCE PACKAGE 3-3

"Answers to Self-test"

ENABLING BEHAVIORAL OBJECTIVE #4:

Locate in current newspapers or magazines at least four (4) articles that show how man's everyday life is affected by radioactivity.

ACTIVITY 4-1

Read Resource Package 4-1.

RESOURCE PACKAGE 4-1

"Suggested Outside Readings"

RESOURCE PACKAGE 1-1

RADIOACTIVITY *
(Basic Concepts of Radioactivity
and its Relationship to Nuclear Energy)

NATURAL TRANSMUTATION AND RADIOACTIVITY

The science and technology of radioactivity had its beginnings in the cold, wet winter of 1896, when the scientist, Henri Becquerel, in his Paris laboratory, made a startling accidental discovery (see Fig. 1). He had accidentally left a sealed, unexposed photographic film plate near a piece of uranium ore. Later, he was surprised to find the film darkened as though it had been exposed to light. He felt that something like X-rays was generated by the minerals containing uranium, and this property of uranium was given the name, radioactivity.

Soon after this, in 1898, Pierre Curie and his wife, Marie Sklodowska Curie (see Fig. 2 on next page) discovered a new chemical element, radium, whose radioactivity proved to be four million times that of uranium. However, they could not explain why.

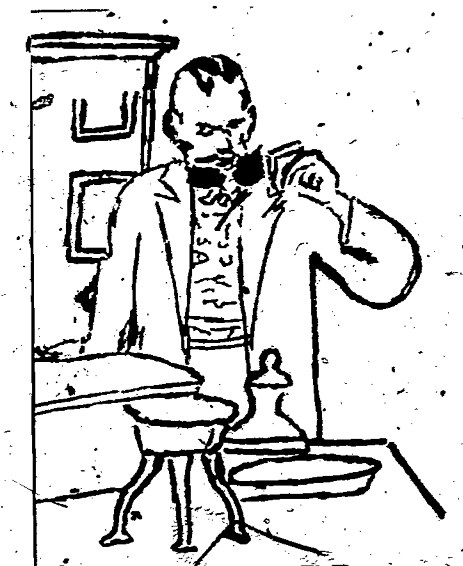

Fig. 1
BECQUEREL

Becquerel, after studying the film, concluded that it could only have been darkened by an unknown kind of energy which he called Radioactivity.

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* For another treatment of radioactivity and related concepts, examine the Nuclear Energy minicourse.

Fig. 2
THE CURIES

Soon afterward, Pierre and Marie Curie discovered that radium was also highly radioactive, but could not explain why.

Then, in 1905, Albert Einstein suggested a radical answer: "Radioactivity is matter gradually changing into energy". (see Fig. 3); and Einstein formulated his famous mathematical equation relating the energy and the mass (material property) of an element:

$$\text{Energy} = \text{Mass} \times (\text{Speed of Light})^2$$

$$\text{or,}\quad E = MC^2$$

where: E = energy; M = mass; and C = speed of light.

This natural and gradual change of the material property (mass) of an element to pure energy is called <u>radioactivity</u>, and this change is measured in what are called "half-life" periods.

Fig. 3
EINSTEIN

Then, in 1905, Albert Einstein suggested a radical answer: "Radioactivity is matter gradually changing into energy."

For any given amount of radioactive material, the time required for one half of that amount of material to transform to energy is called its half-life. Half-lives can range from fractions of a second to hundreds of thousands of years.

NATURALLY OCCURRING RADIOACTIVE ELEMENTS

There are 92 elements (kinds of matter) which occur in nature.* These elements are numbered 1 (for the lightest, hydrogen) through 92 (for the heaviest, uranium). All of the naturally occurring elements with atomic numbers greater than 83 are radioactive. Also, a small number of naturally radioactive isotopes** of elements with atomic numbers less than 83 exist.

RADIOACTIVE DISINTEGRATION

Consider radium, the radioactive element discovered by the Curies. Radium emits what are called alpha, beta, and gamma rays. The rays are bundles of energy and matter which originate from within the nucleus of the radium atom. Radium radioactivity can be investigated by placing a little radium in an apparatus such as that shown in Fig. 4, so that the radiation stream can be subjected to an electric field perpendicular to its direction; the stream of radiation is seen to be separated into three parts called historically the alpha, beta, and gamma rays.

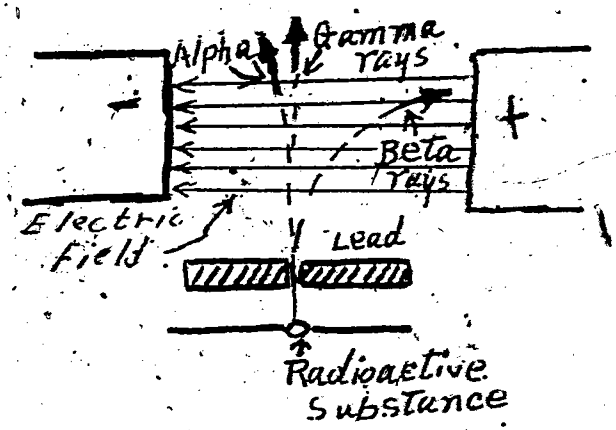

Fig. 4
ALPHA, BETA, AND GAMMA RAYS

Representing the separation of the three types of radioactive rays by magnetic field deflection.

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* There are also a few short-lived man-made elements called transuranic elements.

** Look up the definition of isotope. Make sure you understand the basic difference between an element and an isotope!

The so-called alpha ray is slightly deflected in a direction that shows it to be positively charged, while the beta ray is sharply deflected in the opposite direction (indicating that the beta ray is negatively charged). However, the gamma ray is not deflected at all, indicating that it is uncharged.

DESCRIPTIONS OF THE SO-CALLED RAYS

Alpha rays (α)

The so-called alpha rays turn out to be streams of positively charged particles from the nucleus of the radioactive elements called alpha particles. In fact, an alpha particle is exactly the same as the nucleus of the element, helium, which consists of 2 neutrons and 2 protons and has an electrical charge of +2. The nucleus of all elements is composed of neutrons and protons, collectively called nucleons. The proton and neutron have about the same properties and characteristics, except that the proton (p) has an electrical charge of one positive unit and the neutron (n) has no electrical charge.

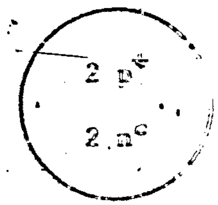


Fig. 5
ALPHA PARTICLE

In other words, protons and neutrons are the building blocks of the nuclei of the elements and are rather alike in size and shape and weight but differ in the property called electric charge (quite like having some blocks painted red while other blocks are left unpainted; the blocks would be quite alike, differing only in the property called color). Radioactive elements eject alpha particles at characteristic speeds, ranging from 10,000 to 15,000 miles per second.

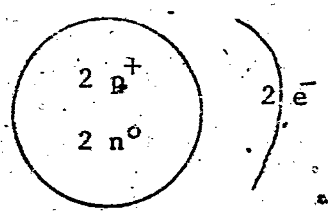


Fig. 6
HELIUM ATOM

- Alpha particles (alphas) have low-penetrating ability and can be stopped by the thinnest sheet of metal foil, or even by an ordinary sheet of paper.
- Alphas are stopped by collisions with air molecules after travelling only from 3 to 11 cm (about 1 to 4 inches).
- Alphas are chiefly responsible for the heat liberated by radioactive elements. This heating results from their collisions with air molecules.
- Alphas can <u>ionize</u> the air through which they pass. This means that because they are charged +2, they electrically pull electrons off electrically--neutral air molecules, thus leaving the molecules positively charged.
- Alphas can decompose water and convert oxygen into ozone.
- Alphas can produce severe skin burns.
- Alphas can "expose" photographic plates.

Beta rays (β)

Beta rays (betas) are streams of electrons (negatively charged particles of about $\frac{1}{2,000}$ the mass of a proton or neutron) ejected from the nucleus of radioactive elements. Radioactive elements eject beta particles at characteristic speeds, ranging from 60,000 to 180,000 miles per second (nearly the speed of light!) Betas are the same as cathode rays; both are simply streams of electrons, except that betas have much greater speeds and therefore have much greater penetrating ability.

- Betas have more than 100 times the penetrating ability of alpha particles.
- Betas readily pass through:

  1 mm of lead
  4 mm of aluminum
  10 mm (1 cm) of water

- Betas can "expose" photographic plates.

Gamma rays (γ)

Gamma rays (gammas) are a kind of photon. A photon is a bundle or quantum of electromagnetic energy; visible light and X-rays are examples of such electromagnetic quanta. Gammas are produced during violent nuclear "eruptions" in which either an alpha particle or a beta particle is forcefully ejected from a nucleus.

- Gammas have the same speed as visible light or X-rays (186,000 miles per second in a vacuum).
- Gammas are invisible and have far greater penetrating ability than even X-rays.
- Gammas have more than 100 times the penetrating ability of beta rays, and more than 10,000 times that of alpha rays. Gammas readily penetrate up to 25.4 cm (10 inches) of lead!
- Gammas can "expose" photographic plates.
- Gammas can kill bacteria and other microorganisms.
- Gammas can produce severe flesh burns.
- Gammas have a greater cauterizing ("killing") effect upon unhealthy tissue than upon healthy tissue. It is this property of gamma rays that makes radium so valuable in the treatment of cancer and certain skin infections.

GENERAL PROPERTIES OF RADIOACTIVE ELEMENTS

- All radioactive elements emit energy, some of which may be in the form of visible light. Such substances can be seen in the dark since they "glow" or phosphoresce. Also, radioactive elements can cause certain other substances to fluoresce. For example, a radium compound, added in very small quantities to zinc sulfide, can cause the zinc sulfide to glow in the dark. In fact, it is just such a mixture which is used on clock and watch hands to make them visible in the dark.

- A radioactive element tends to ionize the air near it.

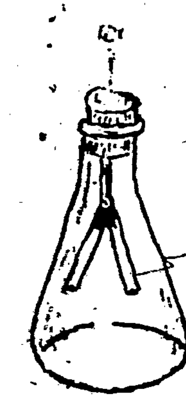
- Radioactive elements can react with light-sensitive emulsions (photographic film) even if the emulsions are well wrapped in their usual heavy black paper containers.

- Radiation from a radioactive element can kill plants, seeds, bacteria, and even animals (including man) under certain conditions.

METHODS OF DETECTING RADIOACTIVE RADIATION

Several instruments have been of importance in detecting and measuring radioactivity. Six (6) of these instruments are discussed below:

1) The first is the gold leaf electroscope. The detection and measurement of radioactive intensity is based on the fact that radioactive emissions will cause the charge on the electroscope to change (see Fig. 7). When electrically charged, the gold leaves of the electroscope separate; the greater the charge, the greater the separation. By observing the rate of change and direction of leaf separation, when subjected to a radioactive source, the source intensity and kind of radiation can be tested.

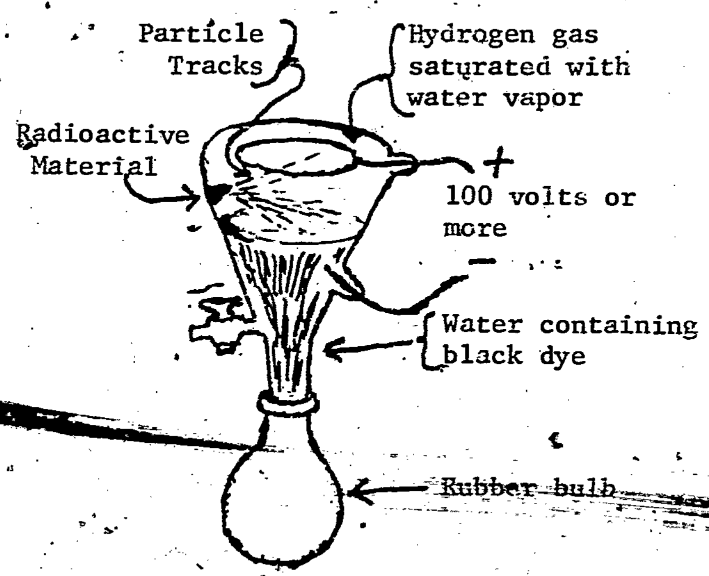


ELECTROSCOPE
Fig. 7

2) The second is the cloud chamber. By means of the condensation track in a cloud chamber (invented by the American, C. T. R. Wilson, who lived from 1869 to 1959), we are able to observe the paths of alpha particles and of many other particles produced when nuclei disintegrate (see Fig. 8 on next page). In the original apparatus, the

rubber bulb, or lower part, is filled with water dyed black. The upper compartment of the apparatus is made of glass and contains a sample of the radioactive material being studied. A 100-volt potential is maintained across the observation space in this compartment. The hydrogen gas above the black water becomes saturated with water vapor. Then, as the bulb is squeezed, the hydrogen is compressed; but when the bulb is next released, the hydrogen expands, cools, and becomes <u>supersaturated</u> with water vapor. Tracks left by alpha particles can now be seen in the observation space (a black background is provided by the dye) because the alpha particles ionize some of the hydrogen molecules, thus causing some of the supersaturated vapor to condense on the hydrogen molecules. The alpha particle tracks are like fog streams which appear to shoot out from the exposed tip of the radioactive material.

3) Another method for detecting alpha and beta rays is by means of the Geiger counter. In Fig. 9 (on next page) you will notice a metal wire, A, which is inserted through an insulator into the metal cylinder, C. The wire and the cylinder are connected to a high voltage source (about 2,000 volts, which is not quite high enough to cause a spark to jump between A and C). If an alpha or a beta particle passes through the tube, it acts as a "trigger" and causes the Geiger counter to discharge; i.e., causes a spark to jump between A and C. The amplifier is used only to increase the sound of the spark so that a



WILSON CLOUD CHAMBER
Fig. 8

crackling noise may be plainly heard in the headset (sometimes a loud speaker is used, instead of a headset), thus indicating the presence of a radioactive emission.

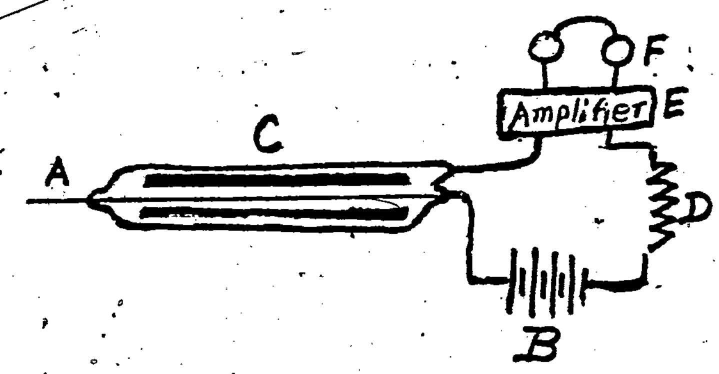


Fig. 9
GEIGER-MULLER COUNTER

4) The photographic method also may be used to detect such charged particles as alphas and betas, since they affect the emulsion of a photographic plate placed in their flight paths. When the film (emulsion) is developed, the actual tracks of these particles through the emulsion is made visible. By measuring these tracks, scientists are able to determine such particle characteristics as velocity, momentum, mass, charge, lifetime, range, and the like. And the photographic method can be used to detect the uncharged gammas, since they also will affect photographic emulsions in a manner similar to that of the common chest X-ray photographs.

5) The bubble chamber method is a more recent method of particle detection and is used mostly in research laboratories. Bubble chambers are beyond the scope of our laboratory, for they utilize volatile liquids (liquids which change readily to vapor) which are under pressure and which are heated to temperatures above their respective boiling points. Particles passing through the bubble chamber leave tracks composed of a series of bubbles. These tracks are photographed for study and analysis, just as are photographic emulsion tracks.

6) The spinthariscope method was much used in earlier days of particle research, but is little used now. This method utilizes a zinc sulfide screen, radioactive material, and a magnifying glass. Wherever charged particles strike the screen, a momentary flash of light is produced; thus the flash of light serves as a detector. By counting the flashes per unit time, one can also determine radiation intensity.

INVESTIGATION NO. 1: DETECTING AND MEASURING THE PENETRATING ABILITY OF RADIOACTIVE RADIATION

Purposes: 1) To investigate the effect of radioactive materials on an electroscope and on a Geiger counter.

2) To investigate the penetrating ability of beta radiation (in air, through cardboard, through aluminum, and through lead).

Materials Needed: Simple electroscope; cat's fur; hard rubber [illegible]; stop watch or watch with second hand; Geiger counter tube and associated apparatus; radioactive sample; wrist watch with illuminated dial; uranium compound or radioactive isotope; 20 cardboard sheets, 4 inches square and 1/32 inch thick; 15 aluminum sheets, 4 inches square and 1/32 inch thick; and 15 lead sheets, 4 inches square and 1/32 inch thick.

You have learned in this study of this minicourse that the spontaneous disintegration of the nuclei of the atoms of radioactive elements results in emission of alpha particles, beta particles, and gamma rays. This emission is called radioactivity or radioactive radiation. Such emissions can be detected by the electroscope, Geiger counter, or other method as previously described. Because alpha particles ionize the gas molecules in the air and can thereby discharge an electroscope, their penetrating ability is not great enough to affect a Geiger counter tube. On the other hand, beta particles and gamma rays can be detected by the Geiger counter tube.

In this investigation you will examine some effects of several radioactive materials, including the penetrating ability of beta particles.

Procedure:

1) Charge an electroscope by rubbing a hard rubber rod with cat's fur and then holding the charged rod near the knob of the electroscope. At the same time, touch ~~the~~ electroscope knob with a finger on the hand not holding the charged rod. Then, withdraw the charged rod. A residual charge will be left on the electroscope. This process is called charging by induction (see Fig. 10, below).

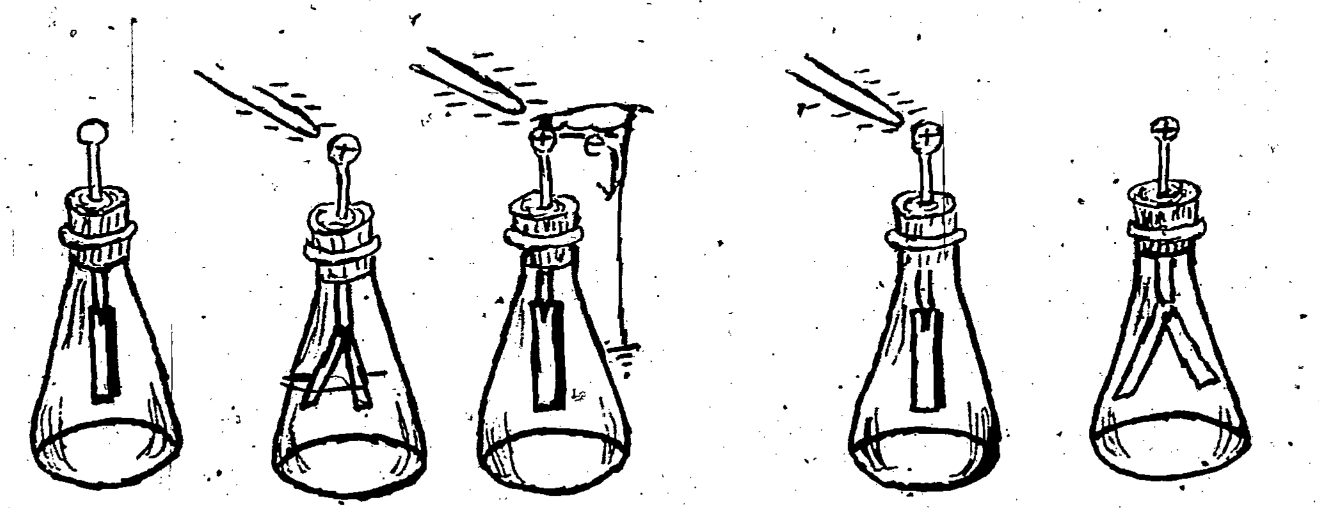


Fig. 10. THE STEPS IN CHARGING AN ELECTROSCOPE BY INDUCTION

Observe the rate of discharge of the electroscope, as evidenced by the rate at which the leaves collapse. Observe the collapse over a period of several minutes. Now recharge the electroscope in the same manner and place a radioactive sample beneath the leaves of the electroscope. Do you observe a different rate of discharge?

2) Set up the Geiger counter apparatus; count and record the background clicks.

(a) On a sheet of notebook paper (please, not in this book), enter the following:

Number of background clicks (Average/minu. Background Reading ____________

(b) Place the radioactive sample at the distance which gives a maximum reading on the Geiger counter meter scale. Record this meter value:

Maximum Meter Reading ____________

(c) Using an illuminated watch dial, place the dial at exactly the distance used for the radioactive sample, above. Record this meter value for the watch dial:

Dial Reading ____________

(d) Using a radioactive isotope, place it at the same distance used above. Record this meter value:

Isotope Reading ____________

(e) Write down any inferences or conclusions you can draw from the recorded meter values of (a), (b), (c), and (d) above.

3) Place a radioactive sample that emits beta particles 2 inches from the Geiger counter tube.

(a) Determine and record the count in a data table such as the one shown on the next page.

(b) Place the same sample 4 inches from the counter tube. Determine and record the count.

(c) Continue moving the sample away from the counter tube in 2-inch intervals until you have reached a distance of 20 inches from the counter tube. Record the count for each 2-inch interval.

SAMPLE DATA TABLE
(Please do not write on this page)

Distance (Inches)	Count	Distance	Count	Distance	Count
2		10		18	
4		12		20	
6		14		22	
8		16			

4) Plot a curve of the table data, using <u>distance</u> as the X <u>axis</u> value and <u>count</u> as the Y <u>axis</u> value. Then see if you can answer these questions (Remember that the recorded counts <u>include</u> background count):

(a) How far can a beta particle travel through air before being absorbed?

(b) What type of radioactive radiation reaches the counter tube after the betas have been absorbed?

5) Place the radioactive sample close enough to the counter tube to obtain a maximum reading on the meter. Record this count in a data table such as the one shown on the next page (Please do not write in this book!). Now place one sheet of cardboard between the sample and the counter tube. Record the count reading. Continue to place additional sheets of cardboard between the sample and the counter tube, recording the count reading after the addition of each sheet. Use a total of 20 sheets of cardboard.

Repeat the investigation, but use sheets of aluminum instead of cardboard. Take readings when 1, 2, 3, 4, 5, 6, 7, 10, 12, and 15 sheets of aluminum are placed between the counter and the radioactive sample.

Repeat the cardboard sheet investigation once more, but use sheets of lead this time.

SAMPLE DATA TABLE
(Please do not write on this page)

CARDBOARD				ALUMINUM		LEAD	
No. Sheets	Count	No. Sheets	Count	No. Sheets	Count	No. Sheets	Count
0		11		0		0	
1		12		1		1	
2		13		2		2	
3		14		3		3	
4		15		4		4	
5		16		5		5	
6		17		6		6	
7		18		7		7	
8		19		10		10	
9		20		12		12	
10				15		15	

Plot curves of these data on the same sheet of coordinate paper, placing the number of sheets of the various materials on the X axis and the respective count readings as the Y axis. Use different colored pencils to construct a graph for each of these three absorber materials.

By inferences from these graphs, answer the following questions:

1) What thickness of cardboard, aluminum, and lead produced complete absorption of beta radiation?

2) Which of the three absorbers was most effective as an absorber of beta radiation?

INVESTIGATION NO. 2: MAKING AND USING A CLOUD CHAMBER TO TRACK ALPHA PARTICLES

Purposes: 1) To construct a simple cloud chamber.

2) To use the cloud chamber to see alpha particle tracks.

Materials Needed:

1) one-pint wide-mouth vacuum bottle
2) a small blotter
3) gloves
4) paper bag
5) 2" diameter copper brass disc, any thickness
6) tweezers
7) tin snips
8) Lucite or plexiglass 4" x 4" and 1/8" to 1/4" thick
9) dull black paint
10) two pounds of dry ice
11) one 5" length of copper water pipe or tubing, outside diameter 3/4" to 1"
12) an old radium dial watch or clock
13) hammer
14) soldering iron
15) soldering flux, solder
16) 3" to 4" diameter clear plastic food dish
17) piece of silk
18) 2" x 2" slide projector or bright flashlight
19) one pint of denatured alcohol

Introduction: Preview cloud chamber detection by reading the section on the detection of radioactive materials and radioactive radiation presented earlier in this minicourse.

Procedure: (If your instructor has a cloud chamber, skip Section A and go directly to Section B.)

A. Construction of a Cloud Chamber

Study Fig. 11 (see next page). Then heat the piece of copper pipe or tubing and use it to melt a hole through the plastic cap of the vacuum bottle. If cork granules end up in the hollow cap, shake them out. Now reheat the pipe and melt a hole in the center of the plastic food dish. Solder the copper disk to the end of the piece of copper water pipe. Paint the top surface of the disk a dull black.

Next, push the pipe to which you soldered the disk through the hole in the disk and then through the hole in the cap. Cut a strip of blotting paper 1/2" wide and make a ring of it to fit just inside the top of the dish. Now your cloud chamber should resemble Fig. 11.

B. Using a Cloud Chamber to See Alpha Particle Tracks

Put on your gloves. With the hammer, break the dry ice into 1/2" lumps and place these lumps of dry ice into the vacuum bottle. Slowly pour alcohol over the lumps. At first, there will be a violent boiling; but this will subside when the temperature of the alcohol drops to that of the dry ice (about 103° F. below zero). Gradually add more alcohol until the flask is filled 1/2" from the top. Put the plastic cap on the bottle; the copper pipe should be in the cooling mixture.

Soak the blotter paper ring in alcohol and position it as shown in Fig. 11. Using tweezers, place a section of the radium watch or clock dial (or clock hand) on the black disk. Cover the disk with the square of Lucite or plexiglass. Rub the square with silk to give it a charge of static electricity and to clear the viewing region of any ions.

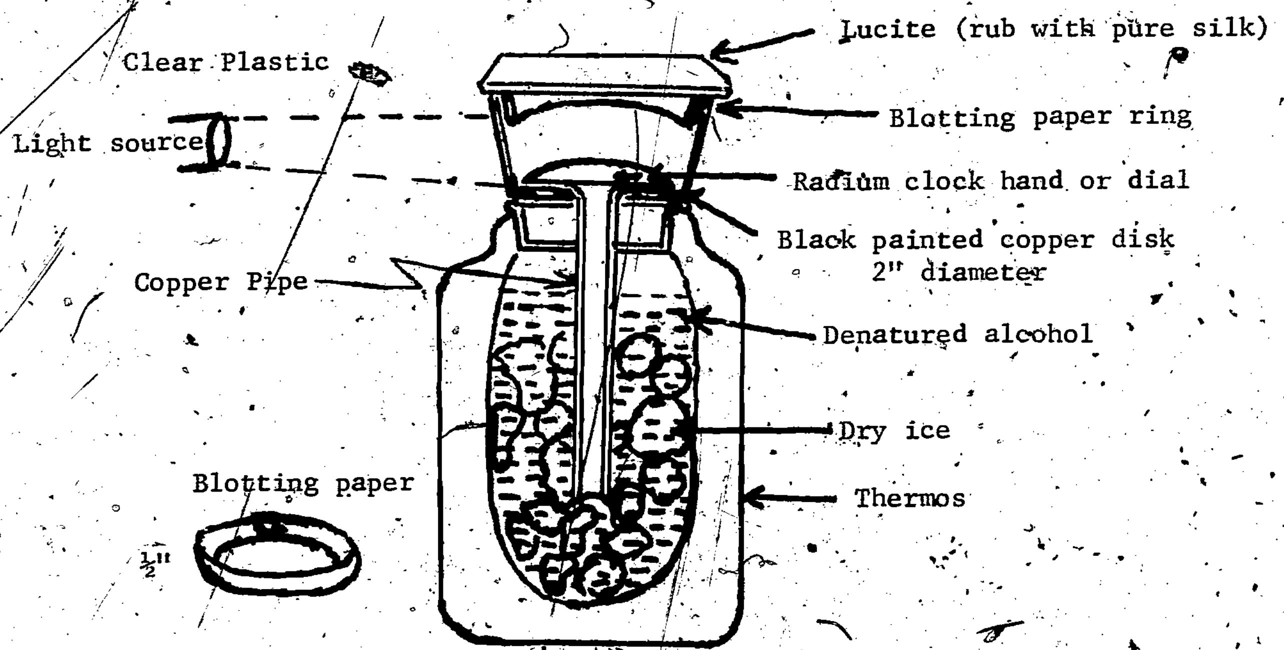


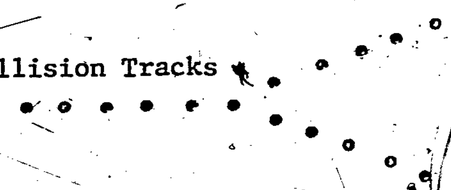
Fig. 11
CLOUD CHAMBER

Illuminate the chamber from the side with the projector or flashlight. After a few minutes, as you look down through the top, you will see the tracks of alpha particles coming out of the section of the piece of radium clock dial and crossing the disk. Your cloud chamber will continue to operate for many hours without any further attention. (Remember that on damp days you may have to recharge the cover every fifteen minutes by rubbing it.)

If you see tracks that do not originate from the radium source, they will probably be cosmic rays. If you see a forked track, this indicates that an alpha particle has collided with the nucleus of an air molecule, such as nitrogen.

Usual Track

Collision Tracks



Make drawings of your observations (identifying as much as you can) and turn them in to your instructor.

RADIOACTIVE DECOMPOSITION

The spontaneous change of the nuclei of radioactive elements into lighter nuclei (into other elements) is called radioactive decomposition. In this natural radioactive decomposition, the nucleus undergoing decay emits either alpha particles or beta particles, or both. Man can do little about the radioactive decay process--he cannot stop it; and until the turn of this century, he could not start it. However, as you shall see later, it is now possible to create radioactive nuclei artificially.

HALF LIFE

The rate at which radioactive decay occurs is fixed for each particular kind of radioactive nucleus, and nothing can be done to change this rate to any noticeable extent. For example, one half of a given sample of radium atoms will have decayed at the end of 1,620 years, and half of the remaining atoms will decay during the next 1,620 years, etc. The length of time during which half of a given number of a specific radioactive nuclei will decay is called the <u>half life</u> of that radioactive element.

The half life is mathematically related to the particular element by the following equation:

$$t^{\frac{1}{2}} \lambda = 0.693$$

where λ is the <u>decay constant</u> symbol and $t^{\frac{1}{2}}$ is the <u>half life</u> symbol.

Let us see how this equation can be used to calculate decay rate. First, consider $^{226}_{88}Ra$. Ra is the symbol for the element, radium. The 226 represents the atomic mass units (atomic weight) and is equal to the sum of the <u>protons and neutrons</u> in the radium nucleus. The 88 is the atomic number and is equal to the number of <u>protons</u> in the radium nucleus. The half life of radium is known to be 1,620 years, which we will convert to seconds.

We can write $t_{\frac{1}{2}}\lambda = 0.693$ as $\lambda = \frac{0.693}{t_{\frac{1}{2}}}$. By the simple operation of division of both sides of the equation by $t_{\frac{1}{2}}$,

$$\frac{t_{\frac{1}{2}}\lambda}{t_{\frac{1}{2}}} = \frac{0.693}{t_{\frac{1}{2}}}$$

$$\lambda = \frac{0.693}{t_{\frac{1}{2}}}$$

Then

$$\lambda = \frac{0.693}{1{,}620 \text{ yrs} \times 365 \text{ days/yr} \times 86{,}400 \text{ sec/day}}$$

$$\lambda = 1.36 \times 10^{-11}/\text{sec}$$

This means that since 1 gram of radium contains 2.665×10^{21} nuclei,

$$2.665 \times 10^{21} \text{ nuclei} \times 1.36 \times 10^{-11} \text{ nuclear disintegrations/sec} = 3.62 \times 10^{10} \text{ nuclei/sec}$$

This is over 3½ billion "counts" or disintegrations per second!

The common measurement for radioactivity is the Curie. <u>One Curie</u> is that quantity of a radioactive material which produces 3.70×10^{10} disintegrations per second. Can you see that one gram of radium has an approximate radioactivity of <u>1 Curie</u>?

RADIOACTIVE SERIES

It was Rutherford and some of his co-workers who discovered that when one radioactive atom disintegrates (by ejecting alpha or beta particles), the remaining atom is still radioactive and may sooner or later eject another particle to become still a different atom. This radioactive decay process was found to continue through a series of elements, ending up finally with a type of atom that was lighter, stable, and not radioactive.

There are four commonly known radioactive series. One of these starts with $^{238}_{92}U$ and is called the 4n + 2 series. The only change in mass number possible in this series is either zero or -4; all of the elements in this series will have mass numbers which differ from 238 by some multiple of 4 (see Fig. 12, on next page).

There are three other natural series. One of these starts with $^{235}_{92}Ra$ and is called the uranium-actinium series, or 4n + 3 series. Another with $^{232}_{90}Th$ as the starting member is called the Thorium, or 4N series. The last series, the Neptunium series, starting with plutonium, $^{241}_{94}Pu$, is the 4n + 1 series. The only member of this last series found in nature in appreciable quantities is the stable and final product, bismuth, $^{209}_{83}Bi$.

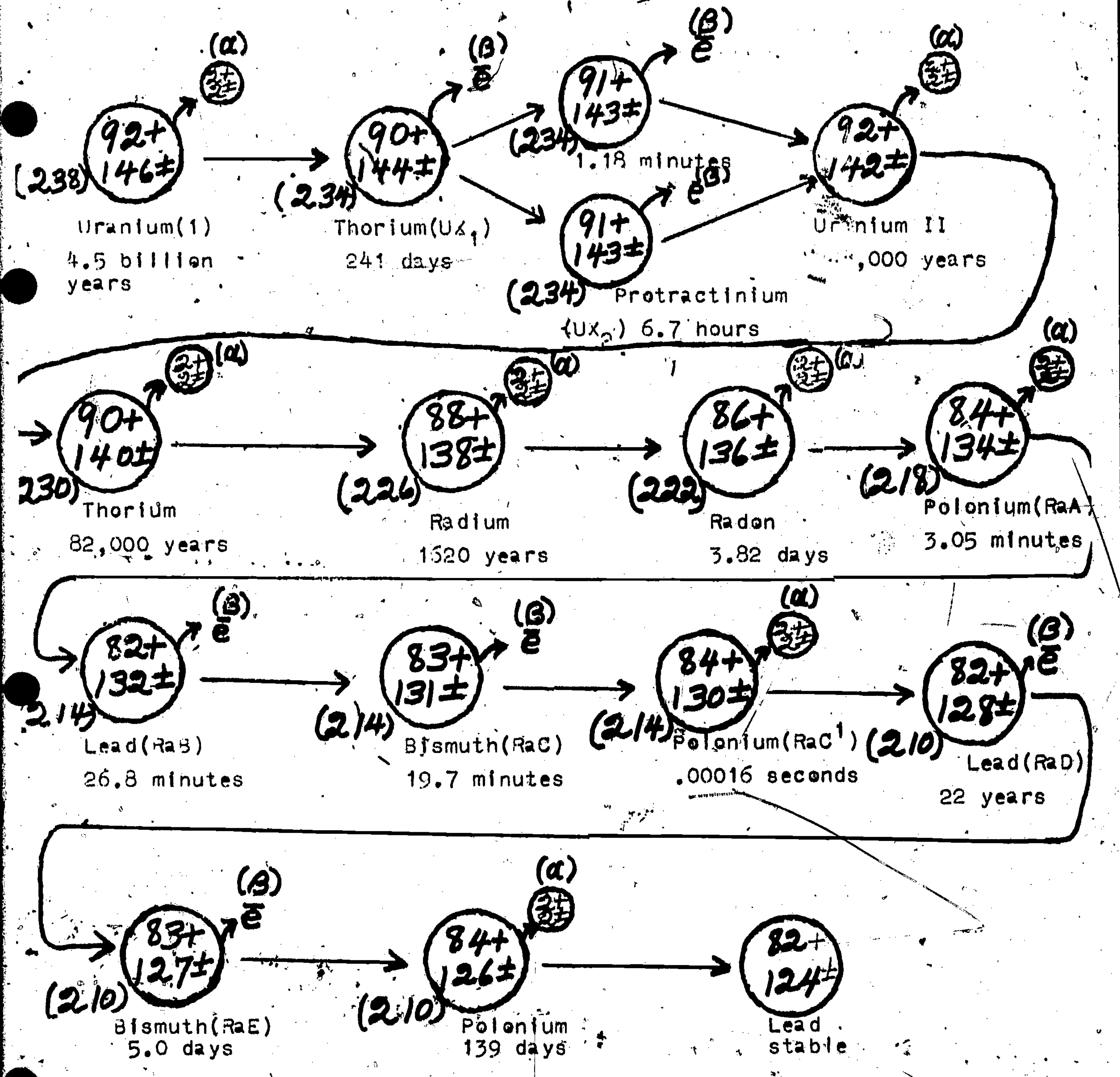


Fig. 12
CHIEF MEMBERS OF THE URANIUM-RADIUM FAMILY
(4n +2 Series)

Showing (1) half-life periods, (2) atomic mass numbers, and (3) atomic numbers. Protons are represented by a + and neutrons by a ±, so that you can see where particles come from and so that conservation of charge is not violated. The diagram also shows alpha particles (α) as helium nuclei (being given off) and beta particles (β) as electrons (e) coming from the nucleus (due to the disintegration of neutrons). Gamma rays are also given off during most of the transformations, but are not shown in the diagram.

FOR THOSE WHO WANT TO KNOW MORE:

RADIOACTIVE DISINTEGRATION BY ALPHA PARTICLE EMISSION

The nucleons inside the nucleus of an isotope* have large amounts of stored electrical and nuclear energy. Think of two protons and two neutrons forming the single nuclear unit called the alpha particle, and consider this unit as a sub-unit of a large nucleus. Then picture this sub-unit as acquiring enough energy to be able to escape from the larger nucleus. Generally, for any nucleus, escape is a rare event; and it is impossible to predict exactly when such an event will occur. But with really large numbers of nuclei, we can determine a constant rate of disintegration. We have expressed this rate in terms of half life. The time required for any given isotope to disintegrate to half its original value is called its half life, just as we learned in a previous section.

Energy released by radioactive disintegration derives from the change of masses of the particles. For example,

$$^{226}_{88}Ra \rightarrow {}^{222}_{86}Rn + {}^{4}_{2}He + Q$$

where $^{4}_{2}He$ represents the alpha particle; Q represents the energy liberated in the disintegration process; Ra represents the radium nucleus; and Rn represents the lighter, radioactive nucleus produced by the

----

* An isotope is an element having a given number of protons but having different neutron numbers; thus its weight (mass) varies, but in no way is its chemical behavior changed.

disintegration (the element is radon). To calculate Q, one must calculate the change in nuclear mass. From a table of atomic mass units, the mass of Ra = 226.10309 AMU and the mass of Rn = 222.09397 AMU. Also, the mass of He is given as 4.00388 AMU. So the nuclear reaction starts on the left side of the equation with Ra and yields Rn + He + Q on the right side, as shown below:

Notice that Rn + He = 222.09397 AMU + 4.00388 = 226.09785 AMU. Therefore, the mass difference between the mass values of the parent nucleus, Ra, and the two daughter nuclei, Rn + He, =

226.10309 AMU - 226.09785 AMU.

This mass difference between parent and daughter nuclei = Q = 0.00525 AMU, which can be converted to energy units by the equation,

1 AMU = 931 Mev.

Therefore,

Q (in Mev) = 0.00524 AMU x 931 Mev/AMU

Q = 4.878 Mev (nearly 5 million electron volts)

DISINTEGRATION OF BETA PARTICLE EMISSION

When a radioactive isotope disintegrates by emission of a beta particle (by electron ejection), the atomic number of the resultant nucleus increases by one, while the mass number remains unchanged. The neutron number must decrease, since a neutron minus an electron results in a proton! For example, the isotope bismuth 210 emits a beta particle according to the nuclear reaction:

$$^{210}_{83}Bi \longrightarrow {}^{210}_{84}Po + e^- + Q$$

To support this idea of beta decay, you might imagine a neutron in the nucleus being split into a proton and electron, with the proton remaining in the nucleus and the electron being ejected from it.

There is just one problem with this simple notion, the released energy Q is observed to be not always the same. To account for a continuous distribution of energy Q (due to continuous distribution of velocities among the beta particles until a maximum velocity known as the end point velocity is reached), it was suggested in 1931 by Wolfgang Pauli that this difficulty could be resolved by assuming that two particles are emitted in beta decay. One particle was an electron, and the other was a then unknown type of particle which later was called the neutrino. The total energy Q could thus be shared by the electron and the neutrino, and various combinations of shared energy would yield various velocities up to the maximum end point velocity. The equation for this is as follows:

$$\underset{\text{(neutron)}}{\text{N (in nucleus)}} \longrightarrow \underset{\text{(proton)}}{\text{P}} + \text{(in nucleus)} + \underset{\text{beta particle}}{e^-} + \underset{\text{neutrino}}{\bar{\nu}}$$

The neutrino was finally discovered in 1956. The neutrino has no charge and very little mass. It possesses much energy, so it moves very near the speed of light. Therefore, it has tremendous penetrating ability. It has been calculated that to stop an average neutrino, a block of lead would have to be so long that it would take the fastest neutrino about 50,000 years to go from one end to the other!

ARTIFICIAL RADIOACTIVITY

Many naturally stable nuclei, when bombarded by high-speed particles, can be transformed into different nuclei. These kinds of man-made nuclear transformations are accompanied by nuclear disintegration, and sometimes such bombardment results in the formation of unstable nuclei. The bombarding particles are often alphas, protons, deuterons, or neutrons. Man-induced nuclear transformations include:

1. Fission - the splitting of a heavy nucleus into two lighter nuclei; some of these fission products are radioactive.
2. Fusion - combining light nuclei to form a heavier nucleus; some of these fusion products are radioactive.

Man-made transmutation of one element into another was first accomplished by Lord Rutherford in 1919 by bombarding nitrogen ($^{14}_{7}N$) with alpha particles ($^{4}_{2}He$). This nuclear reaction is shown on the next page.

$$^{14}_{7}N + ^{4}_{2}He \longrightarrow ^{17}_{8}O + ^{1}_{1}H$$

Notice that the transmutation changes nitrogen-14 to oxygen-18, a stable form of oxygen. By processes similar to Rutherford's, it is possible to produce many <u>isotopic</u> forms of an element, most of which are unstable. These man-created unstable elements are called <u>artificial radioactive elements</u>, to distinguish them from the naturally occurring radioactive ones. As an example, when ordinary phosphorous ($^{31}_{15}P$) is hit by a fast-moving deuteron* ($^{2}_{1}H$), the following reaction occurs:

$$^{31}_{15}P + ^{2}_{1}H \longrightarrow ^{32}_{15}P + ^{1}_{1}H$$

The $^{32}_{15}P$ nucleus is unstable and decomposes, emitting a beta particle and forming stable sulfur, 16:

$$^{32}_{15}P \longrightarrow ^{0}_{-1}e + ^{32}_{16}S$$

Artificially radioactive isotopes, such as $^{32}_{15}P$, are commercially available and are used widely in medical and research laboratories.

----

* <u>Deuterium</u> ($^{2}_{1}H$) is "heavy hydrogen," an isotope of ordinary hydrogen ($^{1}_{1}H$), and its nucleus is called a <u>deuteron</u>.

Another radioactive isotope, ${}^{14}_{6}C$, is being commercially produced in large quantities by means of neutron (${}^{1}_{0}n$) bombardment, as shown below:

$$ {}^{14}_{7}N + {}^{1}_{0}n \longrightarrow {}^{14}_{6}C + {}^{1}_{1}H $$

Carbon 14 has a half life of 5,360 years and decomposes with the emission of a beta particle. Carbon 14 is used in the dating of artifacts. You might wish to read more about how archeologists, geologists, anthropologists, and other scientists use the carbon-14 dating technique to determine the approximate age of some artifact. Ask your teacher or librarian for some references.

In some beta reactions, the nucleus expels a <u>positron</u> (e^+)* rather than an electron. In such a nucleus, a proton (${}^{1}_{1}p$) changes into a neutron (${}^{1}_{0}n$) plus a positron (e^+) and a neutrino (ν). In the reaction, the transmuting nucleus changes to the nucleus of the next <u>lowest</u> element on the periodic table, because it loses a proton and gains a neutron. The general reaction is written as follows, where X is the original nucleus and Y is the next lower-ordered nucleus formed by the reaction:

$$ {}^{\text{(At. Mass)}}_{\text{(At. No.)}}X \longrightarrow {}^{\text{(At. Mass)}}_{\text{(At. No. -1)}}Y + e^{+} + \underset{\text{Neutrino}}{\nu} $$

----

* The positron is quite like an electron (<u>negatron</u>), except that it has a positive electric charge.

A typical reaction is the decay of carbon-11 (atomic number 6) to boron-11 (atomic number 5), as shown:

$$^{11}_{6}C \longrightarrow {}^{11}_{5}B + (e^{+}) + (\nu)$$

It may be of interest to you that almost two-thirds of all of the isotopic forms of the elements are man-made.

RESOURCE PACKAGE 1-2

SELF TEST ON RADIOACTIVITY

Completion:

1. Radioactivity was discovered by ____________________.

2. In 1905 Albert Einstein suggested that radioactivity was ____________________.

3. Radium disintegrates, giving off ______________, ______________, and __________.

4. In radioactivity we have an example of ____________________.

Answer the following:

5. Give at least three methods for detecting radioactive radiation.

6. What is transmutation?

7. How does an alpha particle differ from a beta particle?

8. How does a gamma ray differ from alpha and beta particles?

9. What is meant by half life?

10. What is a Curie?

11. What is a neutrino?

12. What would it take to stop a neutrino?

13. What is an isotope?

14. What is radioactivity?

15. Name and discuss briefly two basic, but different, processes for obtaining energy from nuclei.

RESOURCE PACKAGE 1-3

ANSWERS TO SELF TEST ON RADIOACTIVITY

1. Henri Becquerel.

2. matter gradually changing to energy.

3. alpha particles, beta particles, and gamma rays.

4. transmutation.

5. (1) gold leaf electroscope, (2) cloud chamber, (3) Geiger counter, (4) photographic emulsion, (5) spinthariscope, (6) bubble chamber, and (7) spark chamber.

6. Transmutation is the change of one element into another, and it results from a change in the number of protons in the nucleus.

7. Alpha particles are positively charged particles (helium nuclei); beta particles are electrons (negatively charged particles).

8. Gamma rays are non-charged electromagnetic energies (photons), similar in nature to X-rays (like super-energetic X-rays) and are basically wave-like in nature; alpha and beta radiations are charged and are particle-like in nature.

9. Half life is the length of time during which half of a given amount of a specific radioactive material will decay.

10. A Curie is the quantity of radioactive material which produces 3.70×10^{10} disintegrations per second.

11. A neutrino is a particle having very little mass, no charge, and possesses so much energy that it moves very nearly at the speed of light; it is a product of beta particle decay.

12. To stop an average neutrino, you would need a block of lead so long that it would take light (photons) 50,000 years to go from one end of the block to the other.

13. An isotope is one of two or more forms of atoms (elements) with the same atomic number, but with different atomic masses.

14. Radioactivity is the process by which matter gradually changes into a lighter form of matter; in this process matter is gradually transformed into energy.

15. Nuclear energy is released when matter changes to energy. This is accomplished by an atom-splitting process called fission or by an atom-fusing process called fusion.

RESOURCE PACKAGE 2-1

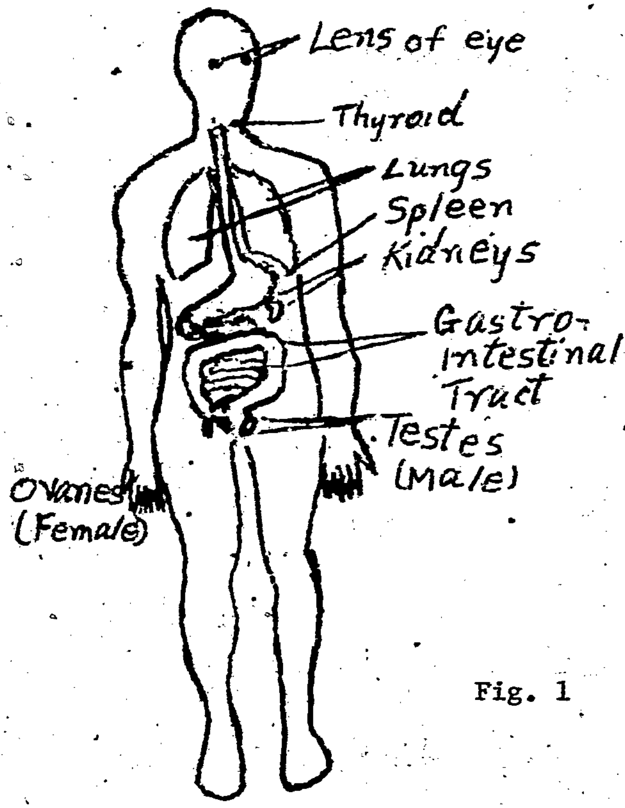
THE DANGERS OF RADIOACTIVE RADIATION TO THE HUMAN BODY

In this section, you will be introduced to some of the biology of the human body, which will be significant in the study of radiation damage.

In terms of human body weight, about 60% is due to water and about 40% is due to the lighter elements. The body is built up of cells and cellular products; it contains blood fluids, minerals, bones, etc. (see Fig. 1). The cells are organized successively into tissues, organs, and body systems. Some cells are stable and remain unreplaced throughout life; whereas other cells are constantly being replaced. Cells which require replacement include blood cells, reproductive cells, skin cells, cells lining the alimentary tract, etc.

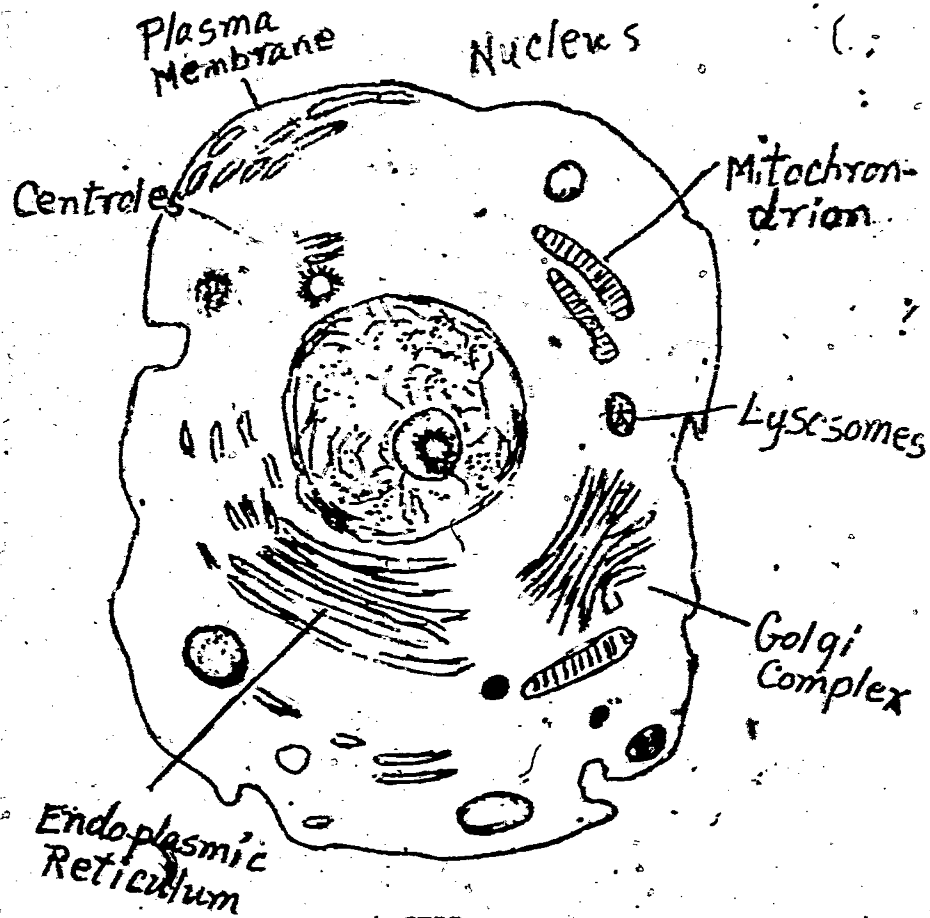
As stated above, the body is organized into organs and tissues, each of which carries out only a portion of the total function of the whole body. There is, therefore, an interdependence of organs and related tissues; damage to one of the body components can (and usually does) have a deleterious (harmful) effect on the others.

Human reproduction results from the union of cells, one from the male (spermatozoon) and one from the female (ovum). After this union (fertilization), a period of growth results in a mass of undifferentiated cells, then in differentiation of cell masses into organs and tissues, and finally into the young organism (fetus) itself.



SOME BODY ORGANS

Fig. 1



A CELL
(Magnified several hundred thousand times)

The body system has an immunological character, which enables it to counter the presence of substances foreign to itself, whether these are invading organisms or some foreign material which has been deliberately or accidentally introduced.

It is an established fact that materials will undergo some damage or alteration if they are irradiated, with the degree of damage depending upon the material and the amount of radiation. In contrast to the nuclear reactions resulting from bombarded elements, as discussed previously, living organisms consist mostly of chemical compounds. Such compounds can suffer chemical alteration if irradiated. Tanning is a common example of chemical alteration of body tissue (skin) due to irradiation (ultraviolet rays from the sun).

RADIATION DAMAGE TO THE HUMAN BODY AND BODY SYSTEMS

Radiation can affect all parts of the body, but the effects with which we will mostly concern ourselves are those on cells and body fluids. For our introductory purposes, we will ignore radiation damage to such "inanimate" structures as tendons, bones, and the like.

The mechanism of radiation damage falls into two main categories: (1) direct action and (2) indirect action.

Direct Action

Direct action is the disruption of some part of the structure of the cell by the action of the bombarding radiation. Damage may be general damage, upsetting to a greater or lesser extent the overall activity of the cell. On the other hand, damage may occur only to a part of a cell which has a specific function; for example, a gene. When a specific body structure, such as a cell part, is directly damaged by direct-action radiation, the part is called a <u>target</u> and the theory which treats radiation damage as being caused by hitting the relevant target is called "<u>Target Theory</u>." It was initially thought that the Target Theory might account for all radiation-induced damage in the body, but it was soon learned that <u>indirect action</u> can also be a source of damage.

<u>Indirect Action</u>

In indirect action, no part of the cell structure is damaged directly; but extremely chemically active groups of atoms (called <u>free radicals</u>) are formed by the radiation process. It is these free radicals which eventually disrupt the body functions. In the ionization* of water, the following equation can be used to show how free radicals can be formed:

$$H_2O \longrightarrow H^+ + OH^-$$

where the OH^- and H^+ are ions.

By a more complex process than the simple dissociation, ionizing radiation can produce in water the reaction,

$$H_2O \longrightarrow H + OH$$

---

* An ion is an atom or molecule which has become electrically charged.

The two products on the right, above, are not the relatively inactive ions of the first equation, but are <u>uncharged</u>, highly chemically-active free radicals. Such chemically-active free radicals enter vigorously into combination with nearby molecules; and if a molecule is part of a cell, the result is disruption of some cell function.

Where oxygen is present, the effect of ionizing radiation is increased, due to the formation of hydrogen peroxide and the free radical, HOO^-.

RADIATION DAMAGE TO REMOTE SITES

The cells in the human body are interdependent. A principal connecting link between all cells is the blood, which supplies cells with food, oxygen, and other chemicals while carrying away carbon dioxide, nitrogenous waste, etc.

In some cases, the overall effect on the body due to a slight variation in the amount of certain secretions can be very large. For example, if an endocrine gland is even slightly altered, the body can be greatly upset. Another example; if blood-forming tissues temporarily cease to function, the oxygen supply to all body parts can be cut off; and this, of course, can cause other malfunctions of different organs. So you can see that radiation damage at a local site, either direct or indirect, may affect body parts remote from the irradiated area. This process is sometimes called "<u>action at a distance</u>."

MORE ON RADIATION DAMAGE TO CELLS

Radiation damage to cells is often classified as somatic damage and as genetic damage.

Somatic Damage

Somatic damage is damage which affects cell functions, such as cell division (the ability of a cell to divide normally, but not the ability to reproduce). In somatic damage, the cell may cease division for a while, but later on may resume normal activities.

Genetic Damage

Genetic damage is damage to the genes within cells which causes impairment in the cell's ability to reproduce offspring which are characteristic of the parent cell. In organisms, genetic damage results in inability to reproduce offspring which are characteristic of the parents.

MORE ON RADIATION DAMAGE TO THE HUMAN BODY

Radiation damage to the human body includes direct and indirect radiation damage to individual cells and takes into account the phenomenon of action at a distance. This radiation damage may be somatic and/or genetic; only in this case the definitions already given must refer to the whole body instead of just to a cell.

Excessive radiation exposure affects the body in several ways:

1) Radiation sickness is produced by a massive overdose of penetrating external radiation; and it results in nausea, vomiting, diarrhea, low resistance to infection, and hemorrhages and possibly death.

2) Radiation injury consists of localized radiation effects, such as burns, loss of hair, and skin lesions. Genetic damage is also a form of radiation injury.

3) Radiation poisoning results from the entrance of radioactive materials into the body, and it can result in anemia and cancer.

Obviously, an individual can be harmed by radiation by two different means: (1) external radiation and (2) internal radiation.

External Radiation

External radiation can be categorized into: (1) long-range, high penetrating, external radiation and (2) short-range, less penetrating, external radiation.

In case of the long-range type, the rays originate from some radioactive materials outside of the body. The rays are highly energetic and penetrate the body to some depth before doing damage to tissues.

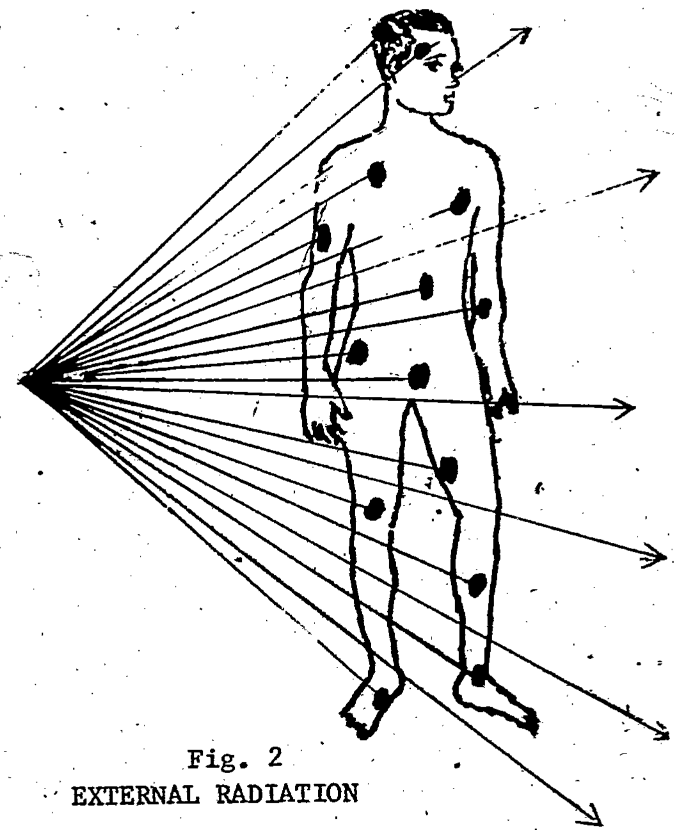


Fig. 2
EXTERNAL RADIATION

Notice in Fig. 2 that the rays come to the man from the radioactive source. Rays penetrate to different depths in the body before spending their energies. Also, notice that a large portion of the radiation passes through the man's body without stopping.

<u>Internal Radiation</u>

In handling radioactive material, it is possible that the material may become airborne where it can be breathed. Special precautions should be taken against this ever happening. If radioactive material should get into your mouth and be swallowed, this could be fatal. Therefore, all radioactive material must be handled so as not to get it on your hands or into your nose or mouth (see Fig. 3 on next page).

IMMUNOLOGICAL EFFECTS OF RADIATION

If foreign protein is injected into the body, at first nothing happens. If a few days later a small quantity is injected again, a severe reaction will occur; this reaction is known as <u>protein shock</u>. The reason for this shock is that in response to substances called <u>antigens</u> in the first injected protein, the body has made protective substances called <u>antibodies</u>. These protective antibodies react violently with the protein antigens of the second injection, and protein shock results.

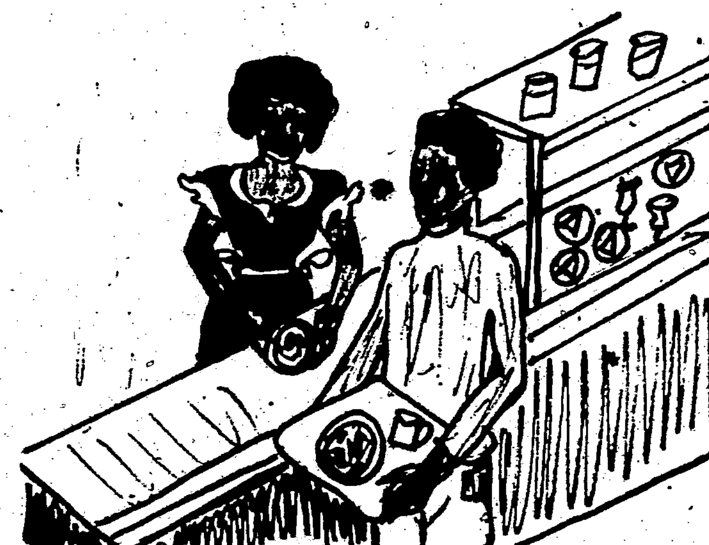
Radiological research has shown that protein shock does not occur if the individual has been irradiated before the first injection; in other words, irradiation inhibits immunological responses.

BY SWALLOWING or BY BREATHING

Two ways of getting radioactive material into the body

Protection against breathing dust

Wash up after handling radioactive material.



Don't eat around radioactive material. Eat in the lunchroom.

Fig. 3
SOME SAFETY HINTS

The inhibition of immunological response can be of medical benefit or it can be a medical hazard. Such immunization is a good technique to use in transplanting organs or tissue. For example, the life of a patient needing new blood-forming tissue may be saved by first irradiating the patient and then injecting bone marrow taken from another person. The foreign bone marrow will not be rejected because of the effects of the prior radiation.

However, the absence of immunological response has its disadvantages too. For example, the body is left without adequate defense against even ordinary disease, and the patient may even die from an infection like the common cold.

OTHER RADIATION DAMAGE

There is evidence, from work on experimental animals, that radiation produces abnormally rapid aging. Other deleterious effects include cancer, cataracts, and improper cell differentiation during the first few weeks of pregnancy (resulting in malformation of the embryo's organs and tissues).

MEASUREMENT OF RADIATION DAMAGE

The Roentgen

The unit of measurement for external radiation exposure is the roentgen (r). The roentgen is defined as an exposure or dose of X-rays which will form 1.6 x 10^{12} ion pairs when absorbed in one gram of air (the milliroentgen is 1/1,000 roentgen). It is a unit of exposure to radiation but not of energy absorbed by the body due to radiation.

No human could survive 1,000 roentgens of <u>total body</u> radiation delivered in a short time. Biologically, however, this is not the same as 1,000 roentgens delivered to only a small portion of the body; a person might well survive this. In terms of harmful effects, body area, intensity of radiation, and exposure time are all important factors.

Because of individual differences, the term that is usually used medically is the so-called <u>lethal dose</u>. The lethal dose (LD) is the amount of radiation required to kill all of a certain fraction of a population exposed for a specified time. The LD/50 for penetrating external radiation is about 500 roentgens delivered to the total body in 24 hours or less, which means that at this intensity and time duration, half of the people exposed would eventually die.

At 200 to 250 roentgens of total body radiation delivered in 24 hours or less, some people would die right away; others would survive. From 100 to 200 roentgens of total body radiation, for the same time exposure, would result in persons suffering nausea, fatigue, vomiting, and general sickness; but there would not be any deaths. At about 50 roentgens of total body radiation, for the same time exposure, persons exposed would have slight temporary blood changes (which their bodies would correct in time). At 25 roentgens of total body radiation, for this same short time, there would be no noticeable medical effects.

The term, <u>medium lethal dose</u> (MLD) is sometimes used for the dose which kills 50% of the individuals within a specified time, instead of the LD/50 expression.

In actual applications, the biologic effectiveness of any radiation depends upon several factors; possible factors would include: type and degree of biologic damage, absorbed dose rate, material pH*, material temperature, etc.

<u>Rem</u>

The <u>rem</u> (<u>roentgen equivalent man</u>) is a unit of radiation dosage which is the <u>biological equivalent</u> to the rad; in other words, it takes the <u>RBE</u> into account. The rem is defined by the relation:

Dose in rem = Dose in rad x RBE

Because the rem provides an indication of the extent of biologic damage that results from absorption of nuclear radiation, it is a unit of biologic dose. A table of rem values on the next page presents some of the associated biological effects of radiation (see Fig. 4).

PROTECTION AGAINST RADIATION HAZARDS

The dose to any individual must be kept below certain levels. The dose to the general population must be kept so low that genetic damage cannot occur. There are certain <u>critical organs</u> that must be taken into consideration in figuring the maximum permissible level (MPL) for individuals. Cells whose functions require the process of cell division, especially those of the skin gut wall, the blood-forming tissue, and the gonads, are most sensitive to radiation and are called critical organs. Organs such

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* pH refers to the relative acidity or alkalinity of a material.

Fig. 4 - Table

THE BIOLOGICAL EFFECTS OF RADIATION

SUMMARY OF EFFECTS LIKELY TO RESULT FROM WHOLE BODY EXPOSURE TO RADIATION

0-25 Rem	50 Rem	100 Rem	200 Rem	400 Rem	600 Rem
No detectable clinical effects. Probably no delayed effects.	Slight transient blood changes. No other clinically detectable effects. Delayed effects possible, but serious effect on the average individual very improbable.	Nausea and fatigue with possible vomiting above 125 r. Marked changes in blood condition with delayed recovery. Shortening of life expectancy.	Nausea and vomiting within 24 hours following latent period of about one week. Epilation, loss of appetite, general weakness and other symptoms, such as sore throat and diarrhoea. Probably death in 2 to 6 weeks in a small fraction of the individuals exposed. Recovery likely unless complicated by poor previous health, superimposed injuries, or infections.	Nausea and vomiting in 1 to 2 hours after a latent period of about one week. Beginning of epilation, loss of appetite, and general weakness accompanied by fever. Severe inflammation of mouth and throat in the third week. Symptoms such as pallor, diarrhoea, nosebleeds, and rapid emaciation in about the fourth week. Some deaths in 2 to 6 weeks. Eventually death to probably 50% of the exposed individuals.	Nausea and vomiting in 1 to 2 hours. Short latent period following initial nausea. Diarrhoea, vomiting, inflammation of mouth and throat toward end of first week. Fever, rapid emaciation, and death as early as the second week with eventual death of probably all exposed individuals.

as the thyroid, which may be greatly damaged by a concentrated internal dose, or the eye, which is sensitive to radiation and usually responds by the formation of cataracts, are also critical organs. In practice, it is consideration of the dose to one or more of these critical organs that sets the permissible limits of dosage for the rest of the body.

The simplest general approach to assuring radioactive radiation protection is to set the maximum level of radioactive radiation below the level that is known to produce a detectable effect on the body; i.e., keep the level below 25 rems. This can be done by (1) reducing the <u>quantity</u> of a radioactive material, (2) keeping the radioactive source at a safe distance, and (3) shielding the radioactive source from otherwise exposed persons.

INVESTIGATION NO. 1

EFFECT OF RADIATION ON MICROORGANISMS

Purposes: (1) to show some effects of radiation on a population of yeast cells.

(2) to determine the LD/50 for a population of yeast cells.

<u>Materials Needed</u>:

dry yeast	germicidal ultraviolet lamp
potato dextrose or grape juice agar	stop watch or clock with second hand
sterile petri dishes	Erlenmeyer flask (1 liter capacity) with cotton plug

Materials Needed (cont.)

- graduated cylinder or volumetric flask (1 liter capacity)
- sterile distilled water
- metric rule
- sterile pipettes

Introduction:

Exposure to radiation can be fatal to an organism. Of course, the more radiation to which an organism is exposed, the more likely it is to be killed. The individual organisms in a species vary considerably in the amount of radiation they are able to tolerate. Some individuals may be killed by very little radiation, while others may withstand much more. One convenient way to describe the effect of radiation on a particular species is to speak of some average fatal dose. Such a dose has been defined as the amount of radiation that will kill just 50 percent of the individuals in a species (LD/50). The other 50 percent of the population will be killed only if the radiation dose is greater than the average fatal dose (the term, LD/50, meaning "lethal dose for 50% of the population").

Procedure:

If the petri dishes of agar have not already been prepared for you, melt the agar and pour it into sterile petri dishes, using careful aseptic techniques.

Weigh out 0.75 g of dry yeast and suspend it in one liter of sterile distilled water. Plug the liter flask with cotton and swirl it to mix the contents thoroughly. Using a pipette, transfer 5 ml of the yeast suspension into a sterile petri dish. Place the ultraviolet lamp 10 cm above the table top and turn the lamp on. CAUTION: DO NOT LOOK DIRECTLY INTO THE LAMP. IT IS HARMFUL TO THE EYES. Place the petri dish containing the 5 ml of yeast suspension under the lamp for exactly 5 seconds.

Remove the yeast suspension from under the lamp. Using another sterile pipette, transfer 0.1 ml of the irradiated yeast suspension to the agar in one of the petri dishes. Spread the suspension evenly over the surface of the agar by rotating the dish with a gentle circular motion. Mark the cover of the petri dish to indicate the length of exposure (5 seconds).

In the same manner irradiate other samples, one at a time, for periods of 15, 30, and 60 seconds and for 2, 5, 10, and 20 minutes. Place 0.1 ml of each of the irradiated samples in a separate petri dish of agar. Mark each with its respective length of exposure to the ultraviolet irradiation.

Inoculate each of two agar plates with 0.1 ml of yeast suspension which has not been exposed to ultraviolet radiation. Then incubate the inoculated agar plates in the dark at about 25° C. for 48 hours. During this incubation period, any cells that survived the radiation exposure will multiply and their daughter cells will form visible yeast colonies.

Count the number of colonies formed in each of the non-irradiated cultures of cells. Let the average number of colonies present in these <u>control cultures</u> represent 100% survival. Then compare the number of colonies in each irradiated culture (<u>experimental culture</u>) to the average number of colonies in the two untreated cultures; from this comparison, find the percent of survivors. (One hundred percent minus the percent of survivors is the percent of cells killed by the radiation treatment.)

Prepare a graph, with the length of time of exposure to irradiation on the horizontal axis and the percent of the original population killed on the vertical axis. Be especially careful in plotting the time on the horizontal axis. Remember that each square on the graph paper is supposed to represent a certain number of seconds or minutes. The points representing 10 minutes and 20 minutes, therefore, will be much farther apart than the points representing 15 seconds and 30 seconds. Draw a smooth curve through the points.

QUESTIONS

1. Approximately what length of exposure kills one half the cells? (Draw a straight horizontal line from the point on the vertical axis representing 50% fatalities. Where this line intersects the curve, drop a vertical line to the time scale and read the approximate time exposure.)

2. Can you explain the shape of the curve?

3. If you were planning a similar experiment using the same techniques and lengths of exposure but a different species of microorganisms, would you be able to use information from the present experiment to predict the LD/50 for the new species? Explain.

4. Would you expect the shape of the curve obtained for this new species to be about the same? Explain.

RESOURCE PACKAGE 2-2

SELF-TEST ON DANGERS OF RADIOACTIVE RADIATION TO THE HUMAN BODY

1. What is meant by direct action in radiation damage to the human body?

2. What is meant by Target Theory?

3. What is meant by indirect action in radiation damage to the human body?

4. Explain the meaning of action at a distance.

5. What is the difference between somatic damage and genetic damage?

6. Define the following:

   (a) radiation sickness
   (b) radiation injury
   (c) radiation poisoning

7. What are two general ways your body can be exposed to radiation?

8. Define the following:

   (a) Roentgen
   (b) Rad
   (c) RBE
   (d) Rem
   (e) MLD
   (f) LD
   (g) LD/50
   (h) MPL

9. Radioactive radiation protection can be assured by: (1) ______________________ and (2) ______________________.

RESOURCE PACKAGE 2-3

ANSWERS TO SELF-TEST ON DANGERS OF RADIOACTIVE RADIATION TO THE HUMAN BODY

1. Direct action is the disruption of some part of the structure of a cell by the action of bombarding particles from radioactive materials.

2. The theory that treats radiation damage as being caused by hitting a relevant target (specific structure) is called the <u>Target Theory</u>.

3. Indirect action is where no part of the cell structure is damaged directly, but extremely active groups of atoms called free radicals are formed. These very active free radicals enter into combination with cell molecules, resulting in disruption of cell functions.

4. Action at a distance occurs because the cells of the body are interdependent and the principal connecting link is the blood. The effect on the body of a slight variation of some secretions poured into the blood stream can be very large, and these effects are known as action at a distance (since the parts affected can be a distance away from the irradiated part which initially produced the slight variation of secretion).

5. Somatic damage is any damage which affects the cell functions (but not including the ability of the cell to reproduce); genetic damage includes damage to the genes, which causes impairment in the ability to reproduce offspring having the characteristics of the parent.

6. (a) Sickness produced by a massive overdose of penetrating external radiation.
   (b) Localized injurious effects.
   (c) Illness resulting when radioactive materials enter the body and cause such diseases as anemia and cancer.

7. Two general ways the body can be exposed to radiation are (a) external exposure and (b) internal exposure (ingestion) of radioactive material by mouth or nose.

8. (a) The roentgen is the quantity of gamma radiation or X-rays which will form 1.6×10^{12} ion pairs when absorbed in one gram of air.

   (b) The rad is equal to the energy absorption of 100 ergs per gram of irradiated material.

(c) The RBE of a given radiation is the ratio of the absorbed dose (rads) of gamma radiation (of specified energy) to the absorbed dose of the given radiation required to produce the same biologic effect.

(d) The rem is a unit of dose biologically equivalent to the rad, when the RBE is taken into account.

(e) MLD is the dose which kills 50% of the exposed individuals within a specified time.

(f) LD is the amount of radiation required to kill all exposed individuals within a specified time.

(g) LD/50 is the dose of radiation which would kill half of the exposed individuals within a specified time.

(h) MPL is the maximum permissible level of radiation which assures no harmful effects.

9. Radioactive radiation protection can be assured by: (1) setting the maximum level of radioactive radiation below the level that is known to produce a detectable effect on the body, (2) reducing the quantity of radioactive material involved, (3) putting the source at a safe distance, and (4) shielding the source and/or the persons exposed.

RESOURCE PACKAGE 3-1

SOME BENEFITS OF RADIOACTIVITY

There are many beneficial applications of radioactivity. This minicourse discusses only a few.

RADIOACTIVE TRACERS

Radioactive isotopes are widely used as tracers to trace or to monitor biological processes in man, animals, and plants (see Fig. 1 below). Such tracers send out signals which can be detected by electrical or chemical means, and this makes it possible to map their paths through an organism or its component organs, tissues, etc.

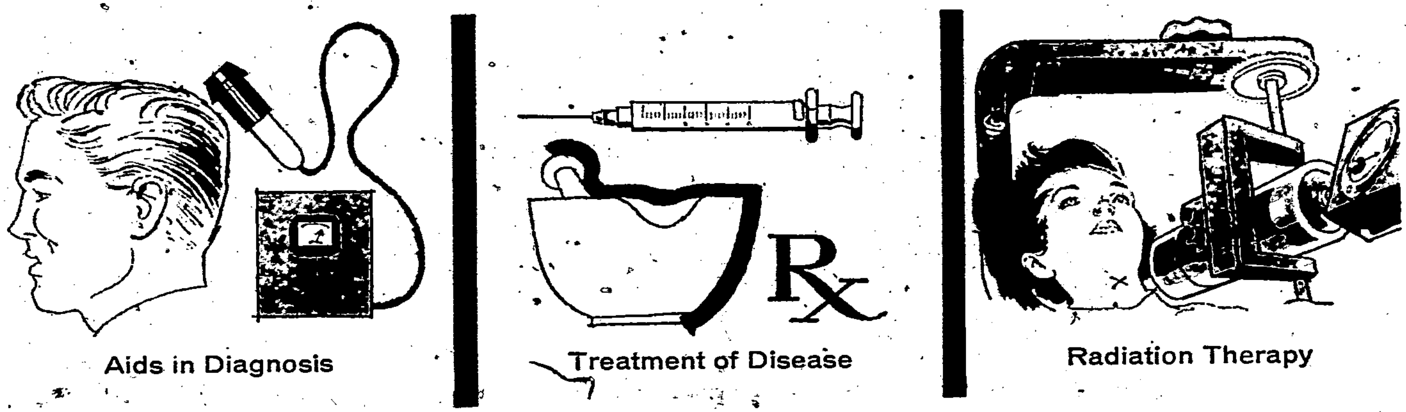


Fig. 1
RADIOACTIVE TRACERS

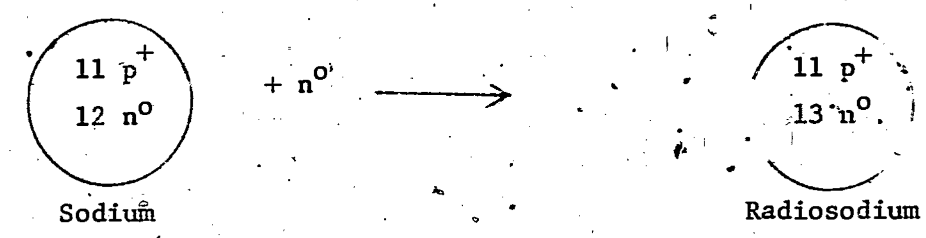
Tracers Used in Diagnosis

The thyroid gland is one of the important glands in the body. Medical research has shown that the thyroid gland will absorb practically all of the element iodine which enters the body. If a radioactive isotope of iodine is introduced into the body (the isotope behaves chemically exactly like ordinary iodine), it will be absorbed by the thyroid gland. By the use of a Geiger counter, a surgeon can determine the extent and the time involved in iodine absorption by the thyroid; these measures are keys to how well the thyroid is functioning.

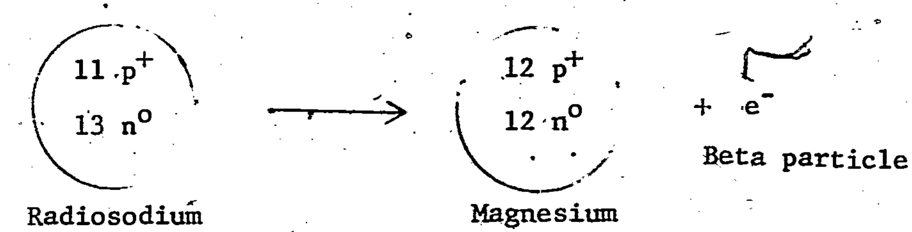
Some Other Tracer Applications

The application of radioactive elements as tracers is based on the fact that with the help of the Geiger counter, exceedingly small quantities of an isotope can be traced. For example, bismuth is a stable element of considerable medical interest. One isotope of bismuth, called RaE, has a half life of 5 days. Stable bismuth is prepared with a small addition of RaE (which has exactly the same chemical properties); then the path of the bismuth in an animal or human is traced by testing various parts of the body for radioactivity. Since cancerous tissue retains larger amounts of bismuth than healthy tissue, the location of cancers can be pinpointed.

Radioactive sodium is also used in medicine. It is sodium-24, an isotope of sodium-23.



Radiosodium has a nucleus of 13 neutrons. This nucleus is unstable. Radiosodium acquires stability by emitting a beta particle, and the transmuted element becomes magnesium.



One of the uses of radiosodium is to investigate poor circulation of the blood due to a circulatory obstruction. A small quantity of a solution of radiosodium chloride is injected into a vein in the forearm. At the same time a Geiger counter is placed near one foot. If circulation is normal, the radiosodium is carried in the blood stream and is detected by the Geiger counter in a few seconds. But if circulation is poor, there is a delay in the time the blood reaches the foot. During the delay, the Geiger counter can be moved from place to place until the region of obstruction of normal blood circulation is found.

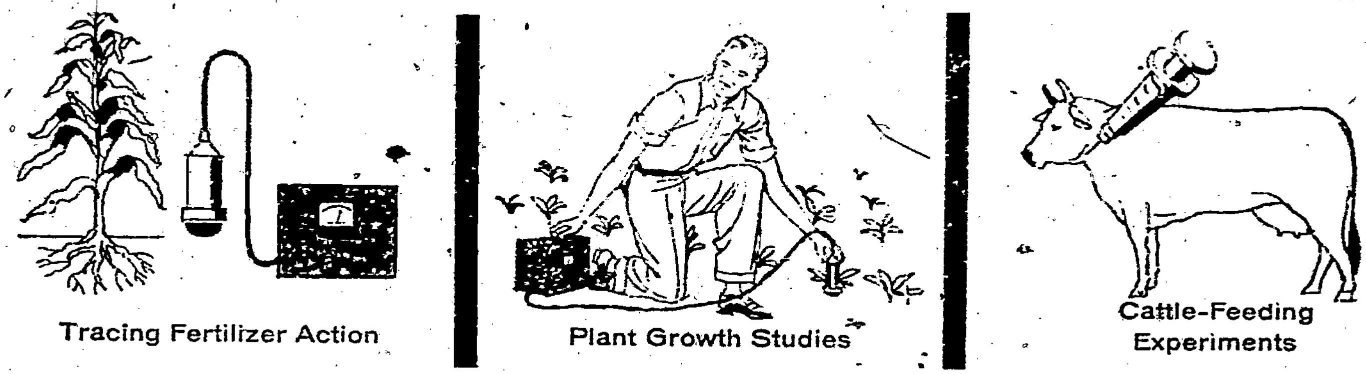


Fig. 2
TRACERS IN AGRICULTURE

In agriculture, radioactive isotopes are helping biologists solve some of the mysteries of how plants live and grow (see Fig. 2). They are using radioactive carbon and hydrogen to trace the intricate process called photosynthesis, the process by which plant tissues are formed. Some scientists hope to duplicate this process and thus produce food artificially (see Fig. 3 on next page).

Radioactivity can also be used to change the inherited characteristics of plants and animals. For example, such use has produced a new kind of oat resistant to blight.

There are many other uses for radioactive tracer elements. For example, radioactive iron is used to check engine wear in test engines. The engines' pistons are made of radioactive iron. As a piston wears, radioactive iron is detected in the lubricating oil system.

Fig. 3
AGRICULTURAL TRACERS

In greenhouse laboratories, agricultural research workers often "tag" or label certain fertilizers or minerals with radioactive elements such as phosphorus or iodine. When leaves of plants grown in these greenhouses under research conditions are exposed to photographic film, the research worker can tell how the nutrient or mineral has been distributed throughout the plant. This often allows for better use of fertilizer methods in the field.

Radioactivity may be used to determine the thickness of sheets of metal, to trace leakage in pipes, to find flaws in pipes, etc. These uses represent only a small portion of the many technical uses of radioisotopes (see Fig. 4 below).

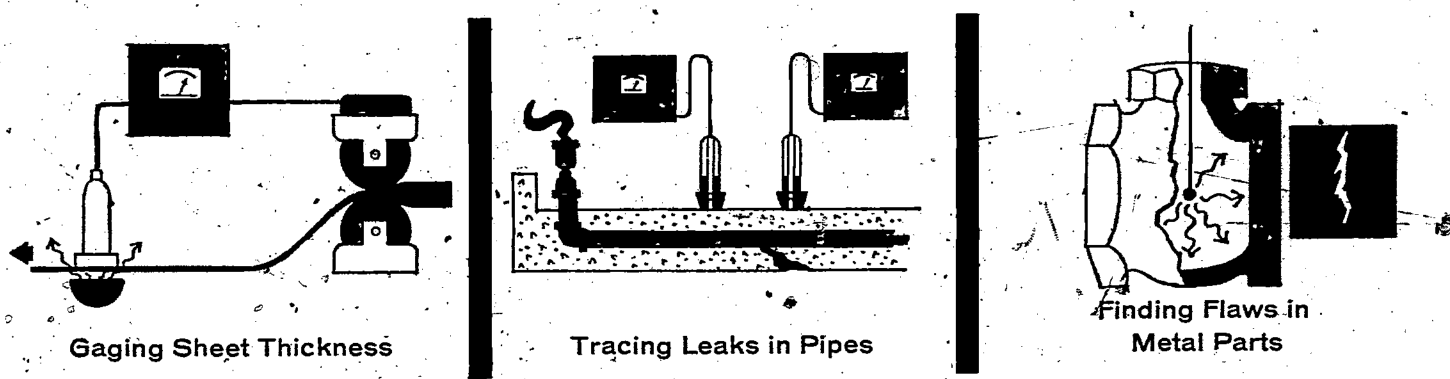


Fig. 4
SOME TECHNICAL USES OF RADIOACTIVE TRACERS

RADIOACTIVE ISOTOPES IN THERAPEUTIC MEDICINE AND DESTRUCTION OF LIVING CELLS

An important use of radioactive materials is based upon the fact that they emit energy which can bring about the destruction of living cells; for example, in the treatment of cancer. A cancer is a group of cells growing much too rapidly. Radioactive radiation is used to kill the cells of these rapidly growing tissues and thereby to bring about an arrest of the cancerous condition (see Fig. 5 on next page).

The therapeutic effect of radioactivity is illustrated by the use of certain radium preparations. Radium preparations have a slow, destructive effect on the skin, producing sores similar to burns. This effect proves beneficial in the treatment of skin tumors, for tumors are more susceptible to radiation destruction than healthy tissue. In treating skin tumors, beta and gamma rays are more effective than alpha rays, since alphas have little tissue penetrating ability. Therefore, radium proper (being an alpha emitter) is not used. Radon (although itself an alpha emitter), however, has daughter elements, which after short half lives, emit two beta particles and gamma rays. Thus radon is very useful for radiotherapy.

In hospitals, radium (the costly parent substance), in the form of a chloride, is kept in a closed glass container from which radon, the radioactive by-product, is taken at regular intervals. The radon is collected in tiny "needles" (glass tubes as thin as needles) about ¼ inch long. While the needles are

Fig. 5
KILLING CANCEROUS CELLS

Radioactive "lamps" direct rays from radioactive cobalt onto cancerous tissue. The "lamp" revolves around the patient so that healthy tissue will not receive an overdose of radioactivity.

used on the patient, they lose their activity with a life of 3.82 days. These needles are of no further medical value after one or two weeks, since most of the radon has disintegrated into RaD, which, in turn, has a half life of 22 years (these old radon needles could be valuable for a physics laboratory, where polonium, which is a good source of pure alpha rays, can be separated out).

Another use for the property of radioactive material to destroy living tissue is in the sterilization of foods and drugs. The foods or drugs are sealed in moisture-proof wrappers to prevent contact with outside air. Then they are exposed to massive doses of radiation, so that all living organisms in the package are killed. If the organisms are killed, the food is sterilized. Further, if a lesser dose of radiation is used, the food can be <u>pasteurized</u> (that is, not all of the organisms are killed, but enough are killed that the food can be stored for a reasonable time without being destroyed by bacteria).

Where radiation sterilization is used in the manufacture of drugs, it is often because sterilization by the use of heat would damage the drugs. Radiation can kill bacteria without raising the temperature of the drugs.

RADIOACTIVE ISOTOPES TO MAKE AIR CONDUCTIVF

The accumulation of static electricity is a serious hazard in industrial areas where explosive vapor-air concentrations may exist. Radioactive isotopes (<u>radioactive static eliminators</u>) can be used to eliminate static accumulations of electrical charge because the rays from the radioactive material ionize the air and form a conducting path along which electric charge can flow to the ground. This process is identical to that of a lightning discharge, only not as violent and without the "sparking" (bolt). Obviously, it is not necessary that there be any electrical contact with the material itself.

RADIATION USED TO EXCITE THE ATOMS OF CERTAIN MATERIALS

It is generally believed that it is radium on a watch or clock dial which glows in the dark. This is not so, but the radioactive radium does emit energetic particles which cause a chemical phosphor, such as zinc sulfide, to glow in the dark when bombarded (excited) by these emissions (see Fig. 6 on next page).

Another important use of this phenomenon of radioactive excitation is in the field of chemical processing. By the use of radiation energy, certain chemical changes can be brought about, which can change the properties of a product. For example, when polyethylene was first developed, it could not be subjected to the temperature of boiling water. Now, at a certain point in the production process, polyethylene is subjected to the emissions from certain radioactive materials. This radiation frees a couple of hydrogen atoms (which are released as hydrogen gas) and thus changes the manner in which the atoms of polyethylene are linked together, producing so called cross-linked polyethylene. Such a polyethylene can be safely subjected to boiling water temperatures and can, therefore, be used in many applications as a substitute for glassware (even when the container must be sterilized, such as a baby bottle, etc.)

Fig. 6
RADIUM WATCH DIAL

VOLTAGE PRODUCTION

This is the direct production of electrical potential from the energy released from radioactive atoms. The quantity of energy per emission is relatively minute, but a so called "atomic battery" can be made and used wherever a dependable source of long-time electrical energy in small quantities is required.

RADIOACTIVITY AS A MEANS OF DATING ARTIFACTS

One common radioactive element used for dating plants, animals, and organic artifacts is carbon-14 ($^{14}_{6}C$). Carbon dioxide (CO_2) is constantly being removed from the air by plants. It is then used photosynthetically in the plant's manufacturing process. A result of this photosynthesis is the storage of carbon-14 (originally in the atmospheric CO_2) in the plant's tissues. Also, carbon-14 is produced in nature by cosmic rays which interact with stable nitrogen ($^{14}_{7}N$) in the atmosphere to produce radioactive $^{14}_{6}C$.

Assume that the percentage of $^{14}_{6}CO_2$ in the air has been approximately the same for millions of years. Remember that all plants ought then to have a constant concentration of $^{14}_{6}C$ in their tissue composition, because they use this fixed percentage of radioactive $^{14}_{6}C$ in photosynthesis. When the plant is alive, $^{14}_{6}C$ is continually disintegrating; but it is also continually being <u>replaced</u> by the photosynthesis process. Therefore, the amount of C-14 in living plants is the same as the amount of C-14 in the atmosphere. When the plant dies, no more $^{14}_{6}CO_2$ is replaced by photosynthesis; now only disintegration can take place and the $^{14}_{6}C$ concentration in the plant must begin to decrease. By measuring the $^{14}_{6}C$ level in a plant, it is possible to tell how long the plant has been dead. If an archeologist unearths logs in the excavation of an ancient city, radioactive dating of the timber will indicate approximately when the trees were cut down.

RESOURCE PACKAGE 3-2

SELF TEST QUESTIONS ON HOW RADIOACTIVITY BENEFITS MAN

1. How do radioactive materials make it possible to trace biological processes in man, animals, and plants?

2. Name two uses for radioactive materials in medicine.

3. Give a medical-clinical use for radioactive sodium.

4. Give at least two important uses for radioactive isotopes, based on their property of destroying living cells.

5. How does the use of certain radioactive materials reduce accumulation of static electricity?

6. In the case of a radium dial watch, is it the radium that glows in the dark? Briefly discuss this.

7. Give an example of how radiation energy can be used to excite atoms and to thereby change somewhat the chemical and physical nature of the irradiated substance.

8. What are some of the ways radioisotopes are used in agricultural technology?

9. Give a few industrial uses of radioactive materials.

10. Explain how radioactive carbon $^{14}_{6}C$ is used to date logs, bones, timber, and other organic artifacts found around ancient cities after excavation by archeologists.

RESOURCE PACKAGE 3-3

ANSWERS TO SELF-TEST QUESTIONS ON HOW RADIOACTIVITY BENEFITS MAN

1. By sending out signals that can be detected by electrical and chemical means.

2. As radioactive tracers in diagnosis and treatment of certain diseases. The use of radioactive materials in the treatment of certain diseases is often called radiation therapy.

3. Radioactive sodium is used to investigate poor circulation of blood in man.

4. In the treatment of cancer and in the sterilization of food and drugs

5. The rays from the radioactive material ionize the air and form an invisible conducting path of ionized air molecules, along which electric charge can flow to the ground.

6. No. The radioactive radium emits particles which cause a phosphor material (such as zinc sulfide) to glow.

7. Polyethylene cannot be subjected to boiling water; but if treated with radiation energy, a couple of hydrogen atoms are removed and escape (as a gas). The resultant product is cross-linked polyethylene, which can be put in boiling water and which can be used as a substitute for glass in making such things as baby bottles, etc.

8. In agriculture, radioactive isotopes are helping biologists solve the mysteries of how plants live and grow.

9. In industry, radioactivity is used to determine the thickness of sheets of metal, to trace leakages in pipes, to find flaws in pipes, etc.

10. While organisms (plants or animals) are alive, the ${}^{14}_{6}C$ in them is maintained at a constant level; but when the organism dies, the amount of ${}^{14}_{6}C$ begins to decrease because it is decaying radioactively while no life processes are occurring--which would normally absorb additional ${}^{14}_{6}C$ from the environment. By measuring the level of ${}^{14}_{6}C$ left in the deceased organism, it is possible to tell how long the organism has been dead. This is called <u>carbon dating</u>.

RESOURCE PACKAGE 4-1

SUGGESTED OUTSIDE READINGS

If you look through current newspapers, scientific magazines, and other such sources, you will find many articles on radioactivity and its many applications to science, technology, and industry. See how many such articles you can find in a reasonable time period. In addition, use the materials published by the Atomic Energy Commission (your teacher should have these publications); AEC publications are authoritative reviews of the current state of nuclear science. The following are some suggested readings from a few of the booklets published by the Atomic Energy Commission; these may be used as a starting point for your outside readings:

I

"Radioisotopes in Medicine"
By E. W. Phelan
U. S. Atomic Energy Commission/Division of Technical Information

II

"Whole Body Counters"
By Frederick W. Lengemann and John H. Woodburn

III

"Food Preservation by Irradiation"
By Grace M. Urrows
U. S. Atomic Energy Commission/Division of Technical Information

IV

"Radioisotopes in Industry"
By Philip Baker, et al
U. S. Atomic Energy Commission/Division
of Technical Information

V

"Radioisotopes and Life Processes"
By Walter E. Kisieleski and Renato Basserga
U. S. Atomic Energy Commission/Division of
Technical Information

VI

"Application of Nuclear Science to Agriculture. Atoms in Agriculture"
By Thomas S. Osborne
U. S. Atomic Energy Commission/Division of Technical Information