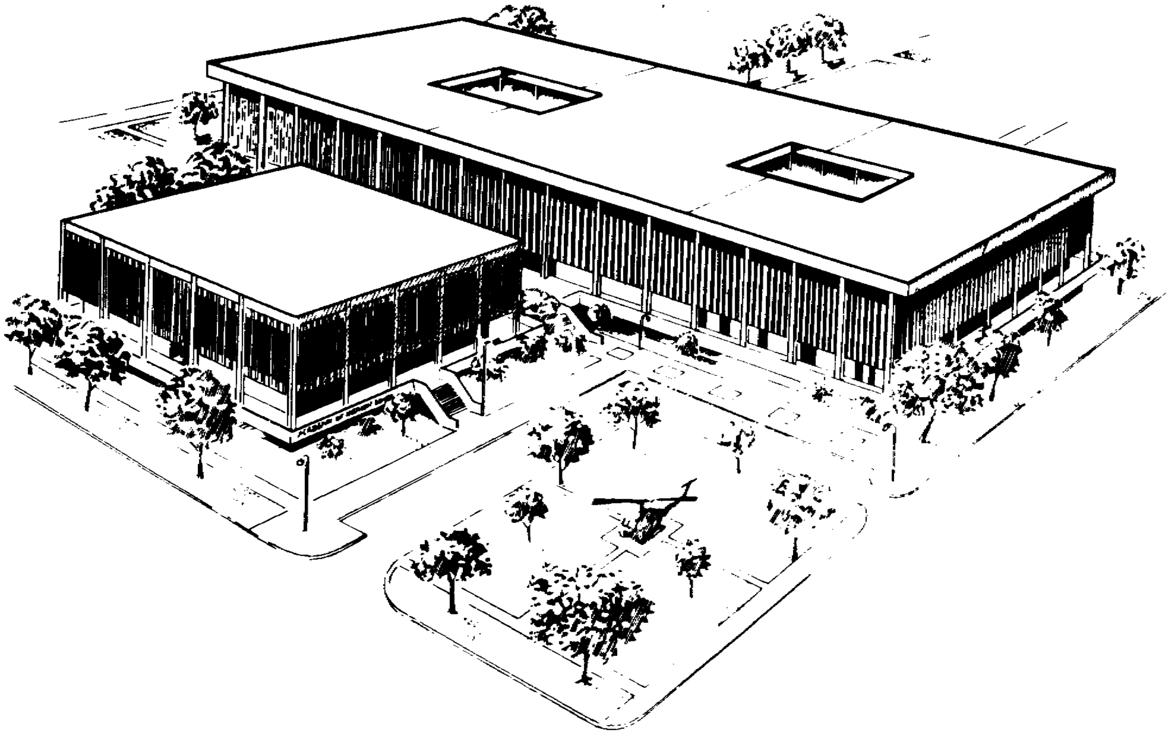
U.S. ARMY MEDICAL DEPARTMENT CENTER AND SCHOOL
FORT SAM HOUSTON, TEXAS 78234-6100



RADIOLOGICAL HEALTH

SUBCOURSE MD0180 EDITION 100

DEVELOPMENT

This subcourse is approved for resident and correspondence course instruction. It reflects the current thought of the Academy of Health Sciences and conforms to printed Department of the Army doctrine as closely as currently possible. Development and progress render such doctrine continuously subject to change.

When used in this publication, words such as "he," "him," "his," and "men" 'are intended to include both the masculine and feminine genders, unless specifically stated otherwise or when obvious in context.

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ADMINISTRATION

Students who desire credit hours for this correspondence subcourse must meet eligibility requirements and must enroll through the Nonresident Instruction Branch of the U.S. Army Medical Department Center and School (AMEDDC&S).

Application for enrollment should be made at the Internet website: http://www.atrrs.army.mil. You can access the course catalog in the upper right corner. Enter School Code 555 for medical correspondence courses. Copy down the course number and title. To apply for enrollment, return to the main ATRRS screen and scroll down the right side for ATRRS Channels. Click on SELF DEVELOPMENT to open the application and then follow the on screen instructions.

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CORRESPONDENCE COURSE OF
THE U.S. ARMY MEDICAL DEPARTMENT CENTER AND SCHOOL

SUBCOURSE MD0180

RADIOLOGICAL HEALTH

INTRODUCTION

The need for a comprehensive radiological health program has increased steadily over the last 85 years primarily as a result of two events: first, our knowledge of the biological effects of radiation exposure is becoming more definitive through experimentation and better equipment. In certain cases, we suspect that any amount of radiation exposure can be harmful. Secondly, the widespread use of sources of ionizing and nonionizing radiation, such that almost everyone has occasion to be exposed, has prompted a concentrated effort to minimize the hazards associated with the use of these sources.

The U.S. Army is no less responsible to its personnel in the use of radiation and therefore must initiate a complete radiological health program wherever the need arises.

The purpose of this subcourse is to give you a brief introduction to the history of the discovery and development of ionizing and nonionizing radiation and the types and biological effects of the various kinds of radiation. It is further designed to give you a basic working knowledge of the present legislative measures and protection criteria established in order to facilitate the implementation of a radiological safety program within your own facility.

This subcourse consists of three lessons and an examination. The lessons are:

Lesson 1. Basic Radiological Health.

Lesson 2. Ionizing Radiation.

Lesson 3. Nonionizing Radiation.

Credit Awarded:

Upon successful completion of this subcourse, you will be awarded 6 credit hours.

Materials Furnished:

Materials provided include this booklet, an examination answer sheet, and an envelope. Answer sheets are not provided for individual lessons in this subcourse because you are to grade your own lessons. Exercises and solutions for all lessons are contained in this booklet. *You must furnish a #2 pencil*.

Procedures for Subcourse Completion:

You are encouraged to complete the subcourse lesson by lesson. When you have completed all of the lessons to your satisfaction, fill out the examination answer sheet and mail it to the AMEDDC&S, along with the Student Comment Sheet, in the envelope provided. *Be sure that your social security number is on all correspondence sent to the AMEDDC&S*. You will be notified by return mail of the examination results. Your grade on the examination will be your rating for the subcourse.

Study Suggestions:

Here are some suggestions that may be helpful to you in completing this subcourse:

--Read and study each lesson carefully.

--Complete the subcourse lesson by lesson. After completing each lesson, work the exercises at the end of the lesson, marking your answers in this booklet.

--After completing each set of lesson exercises, compare your answers with those on the solution sheet, which follows the exercises. If you have answered an exercise incorrectly, check the reference cited after the answer on the solution sheet to determine why your response was not the correct one.

--As you successfully complete each lesson, go on to the next. When you have completed all of the lessons, complete the examination. Mark your answers in this booklet; then transfer your responses to the examination answer sheet using a #2 pencil and mail it to the AMEDDC&S for grading.

Student Comment Sheet:

Be sure to provide us with your suggestions and criticisms by filling out the Student Comment Sheet (found at the back of this booklet) and returning it to us with your examination answer sheet. Please review this comment sheet before studying this subcourse. In this way, you will help us to improve the quality of this subcourse.

LESSON ASSIGNMENT

LESSON 1	Basic Radiological Health.
LESSON ASSIGNMENT	Paragraphs 1-1 through 1-21; glossary.
LESSON OBJECTIVES	After completing this lesson, you should be able to: 1-1. Recognize the basic principles of radiation physics and apply them to practical situations. 1-2. Recognize basic terminology and units of measurement used in radiation physics and apply them to practical situations. 1-3. Identify the biological effects of radiation. 1-4. Identify the radiation detection instruments in common Army use.
SUGGESTIONS	After completing the assignment, complete the exercises at the end of this lesson. These exercises will help you to achieve the lesson objectives.

LESSON 1

BASIC RADIOLOGICAL HEALTH

Section I. INTRODUCTION

1-1. PURPOSE

The purpose of this subcourse is to discuss the hazards of ionizing and nonionizing radiation and the Department of Army radiation protection programs for control of these hazards so that the preventive medicine specialist will gain the knowledge necessary to aid him in implementing such programs.

1-2. SCOPE

The scope of this subcourse includes a brief history of the discovery of radiation and a discussion of basic radiation physics, to include radiation units and instrumentation, the biological effects of radiation, radiation sources and hazards, and the Department of Army radiation protection programs.

1-3. HISTORY

a. Man has always lived in a radiation environment. We are continuously bombarded each day by cosmic rays from space, terrestrial radiation from the crust of the earth, and even radiation from radioactive materials within our own bodies. It has only been during this century, however, that we have come to recognize and characterize these radiations and to artificially produce radioactive materials and manufacture radiation-producing devices for the benefit of mankind.

b. In 1895, x-rays were discovered by Wilhelm Conrad Roentgen, a German physicist, but many scientists before him paved the way for his discovery. Many major discoveries relating to electricity had been made during the three centuries that preceded the discovery of x-rays, but it was the study of electrical discharges under high voltage in vacuum tubes that led to the actual discovery of these rays. Scores of scientists had experimented with electrical discharges through different types of vacuum tubes and, no doubt, many of them had produced x-rays but had not recognized them as a new type of ray.

c. Roentgen himself was experimenting with cathode rays when he observed the presence of this new radiation. He was working with a certain vacuum tube (Crookes-Hittorf) through which a current, under high voltage, was being passed. The tube was entirely enclosed in black paper so as to exclude all the light emanating from it. During the experiment, Roentgen observed a fluorescence of some barium platino-cyanide crystals coating a piece of cardboard lying nearby. It had been known for some time that these crystals would fluoresce in the presence of a vacuum tube activated by high voltage, but it occurred to Roentgen that the fluorescence of the crystals was due to some type of ray that could pass through the black paper around the tube. When he picked up the chemically coated cardboard, his fingers came between it and the tube, and he saw the bones of his hand. He realized that he had discovered the presence of a ray that would penetrate solid matter. By replacing the chemically coated cardboard with a photographic plate, he was able to record an image of the internal structure of his wife's hand. He also noted that the rays could not be reflected or refracted by the usual means and that they were not affected by electrical and magnetic fields as were the cathode rays, which he was studying. Because he did not know the nature of these rays, he called them x-rays. Others have called them roentgen rays.

d. Following the discovery of x-rays, man was not long in learning about both the harmful and useful characteristics of this new energy source. E. H. Grubbe, a manufacturer of Crookes' tubes in Chicago, Illinois, suffered severe hand injuries by exposing his hands to x-rays. Realizing from his own experience the destructive power of x-rays, Grubbe, on January 29, 1896, treated a patient for carcinoma of the breast with his Crookes tube. Numerous applications of the x-ray for medical purposes followed Grubbe's procedure and today x-ray machines are among the most valuable therapeutic and diagnostic tools available to the clinician.

e. The year following the discovery of x-rays, Henri Becquerel observed that crystals of a uranium salt emitted rays which were similar to x-rays in that they were invisible, were highly penetrating, and could affect a photographic plate. Becquerel's discovery was followed by the identification of other "radioactive" elements and further investigation showed that there were actually three different kinds of radiation from naturally occurring radioactive substances. These three types of radiation were called alpha (α), beta (β) and gamma (ϒ) from the first three letters of the Greek alphabet.

f. It has been shown that all three radiations are not emitted simultaneously by all radioactive substances. Some elements emit α-rays, others emit β-rays, while γ-rays sometimes accompany one and sometimes the other. To date, numerous radioactive elements have been identified or artificially produced. As with x-rays, radioactive elements are used quite extensively for medical purposes for the diagnosis and treatment of a variety of diseases.

1-4. RADIOLOGICAL HEALTH AND THE PREVENTIVE MEDICINE SPECIALIST

a. Since 1895, the number of uses of radioactive materials and radiation-producing devices has continued to increase without bound. Indeed, the lot of mankind has been altered as a result of the discovery of radiation. This is demonstrated by the fact that the utilization of radiation affects just about every field of endeavor imaginable, to include research, industry, agriculture, teaching, and, of course, medicine.

b. To this extent, the preventive medicine specialist must be able to identify the sources of radiation within his facility, to evaluate the hazards associated with these sources, and finally, to implement the proper control measures to ensure safe utilization of these sources.

c. In order for him to fully appreciate the techniques involved in implementing such measures, the preventive medicine specialist must understand the principles upon which these techniques are based. Knowledge of basic radiological health will form a foundation upon which these techniques can be better understood.

Section II. BASIC RADIATION PHYSICS

1-5. STRUCTURE OF MATTER

a. Man has long wondered about the structure of matter. As far back as 500 BC, there were many imaginative ideas concerning the true nature of matter. These ideas were in many ways little more than philosophical notions. The Greek, Empedocles, believed that all matter was composed of four basic substances or elements--earth, air, fire, and water. Other Greeks, the atomists, such as Epicurus and Democritus, thought that all matter consisted of elemental, indivisible units called atoms.

b. With the advent of scientific methods, man discovered the basic substances of which all matter is composed--the natural elements. Water was separated into hydrogen and oxygen. Air was found to be basically a mixture of oxygen and nitrogen. They and the other elements that were discovered could not be further divided into simpler substances; thus, the name element, a basic substance. There are 92 natural elements. These include, for example, iron, sulfur, aluminum, carbon, sodium, and chlorine. Several others have been produced artificially, for instance, plutonium.

c. Scientific analysis has shown that the Greek atomists were, in a sense, correct in that elements are composed of basic units or atoms. Each element has its own characteristics and its own characteristic atoms. An element is a substance, which cannot be separated into simpler substances by ordinary chemical means. An atom is the smallest unit of an element that possesses all the characteristics of the element.

d. The Greek atomists were, however, in one sense incorrect. Atoms have been found to be divisible; atoms have been divided into more fundamental particles called electrons, protons, and neutrons. The electron was first discovered as the basic unit of electricity. It is a very tiny, negatively-charged particle considerably lighter than an atom. The proton is a positively-charged particle having exactly the same magnitude of charge as the electron; however, it is much larger than the electron in mass, being approximately 1,840 times the electron mass. A gram of protons contains roughly 6×10^{23} protons. After the discovery of the electron and the proton, the neutron was predicted as the particle that would be formed if a proton and electron were closely combined. It would thus be neutral in charge. In 1932, the neutron was actually discovered as predicted.

e. There was still the problem of determining how these basic particles are arranged to make up an atom. It has been learned that atoms are composed of a positively charged central mass called the nucleus (which contains protons and neutrons) and electrons which move in orbits or shells around, but very far from, this nucleus. It is reasonable to assume the electrons experience an attractive force due to the positive nucleus. However, they move rapidly enough so that the centrifugal force (tending to throw the electrons out of orbit) balances the attractive force. Most objects in the world have no charge on them; therefore, we can reasonably suppose that the atoms of which matter is composed are electrically neutral, that is, they have no net charge. Thus, atoms normally contain exactly as many electrons moving in shells around the nucleus, as there are protons in the nucleus. There are no electrons as such in the nucleus, since neutrons are distinct particles different from either protons or electrons. Thus, because the electrons are very small in mass and since they move around the nucleus at distances relatively far from the nucleus, the atom is primarily empty space with the major portion of its mass concentrated in the nucleus. An atom is about 10^{-8} centimeters in diameter; this essentially refers to the diameter of the electron orbits, the nucleus being about 10^{-12} centimeters in diameter (Figure 1-1).

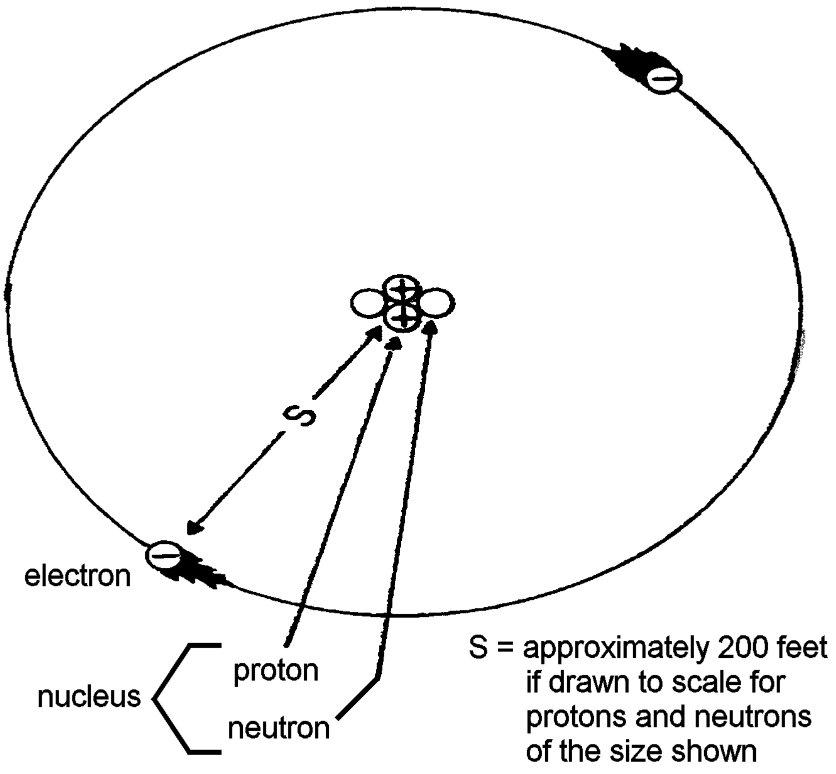


Figure 1-1. Typical simple atom.

f. Neutrons, being neutral in charge, do not affect the chemical nature of the atom and it is the number of protons in the nucleus that determines the element to which the atom belongs. For example, an atom of the lightest element, hydrogen, has one proton in the nucleus and one electron traveling around the nucleus. An atom containing two protons in the nucleus and two electrons traveling around the nucleus belongs to the element helium. Similarly, the 92d natural element, uranium, is composed of atoms containing 92 protons in the nucleus and 92 electrons traveling in shells around the nucleus. The number of neutrons in the nucleus of atoms of any particular element varies, but there are usually more neutrons than protons in the nucleus of an atom. Two atoms of the same element with different numbers of neutrons are called <u>isotopes</u>.

g. Electrons are not distributed at random about the nucleus, but they exist in arrangements that follow definite laws. The model of the atom proposed by Niels Bohr in 1913 pictures the electrons as moving in circular orbits about the nucleus. Although we now know this model is not strictly correct, its features give a good explanation of the simple phenomena, which we wish to consider. Figure 1-2 shows a picture of the hydrogen atom.

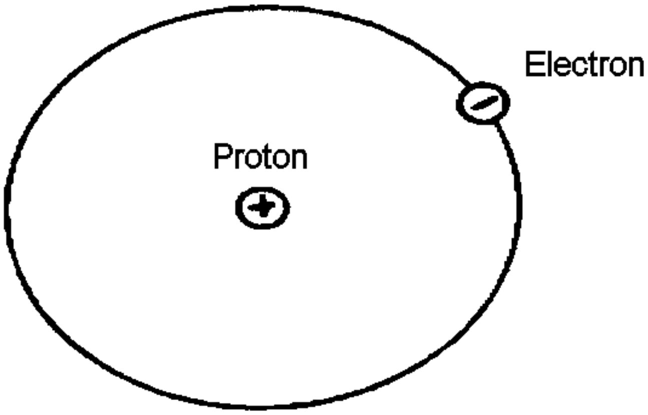


Figure 1-2. Hydrogen atom.

h. The next heaviest element after hydrogen is helium. This contains two protons in the nucleus and, consequently, two electrons revolving about the nucleus (Figure 1-3). Both these electrons may be thought of as roughly the same distance from the nucleus. It turns out that no more than two electrons will ever be found at this distance from the nucleus in helium. Of course, this is not unique with helium, but is also true of elements with more than two protons in the nucleus. Both these electrons are said to lie in a shell, which is actually an orbit around the nucleus. No more than two electrons may be present in the shell, no matter what atom is under consideration. Normal hydrogen has only one electron in the shell, so we call the shell incomplete.

i. Atoms which have more than two protons in the nucleus have an equal number of electrons; in this case, the electrons in excess of two will lie in shells past the first one. The shells are normally designated by capital letters, the first shell being denoted by “K," the second by "L," the third by "M," etc. It is possible that one of the electrons revolving about a helium nucleus might be in the K-shell and the other in the L-shell. This puts only one electron in the K-shell and the K-shell can hold two. Such a

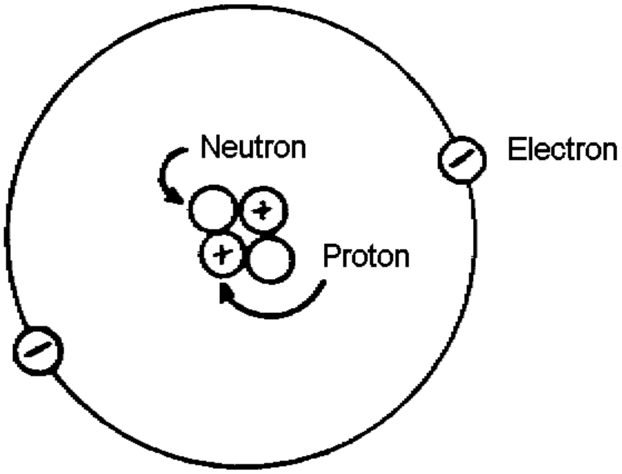


Figure 1-3. Helium atom.

condition is referred to as an “excited” atom. It is caused by subjecting the atom to an external stimulus, such as a source of radiation or collision with another atomic particle (Figure 1-4). The electron in the L-shell will jump back into the K-shell and in the process will give off a bit of electromagnetic energy. For this particular case, there will be a light of a frequency in the visible range. This bit of electromagnetic energy given off is called a photon. Therefore, the electronic structure has a great deal to do with the emission of radiation from matter. One way in which these electron jumps can be arranged to occur in large numbers is to build a neon lamp. The electric current passing through the neon gas knocks some of the electrons into higher shells and, in jumping back, light is given off. Sometimes the jump is referred to as a jump from one energy level to another.

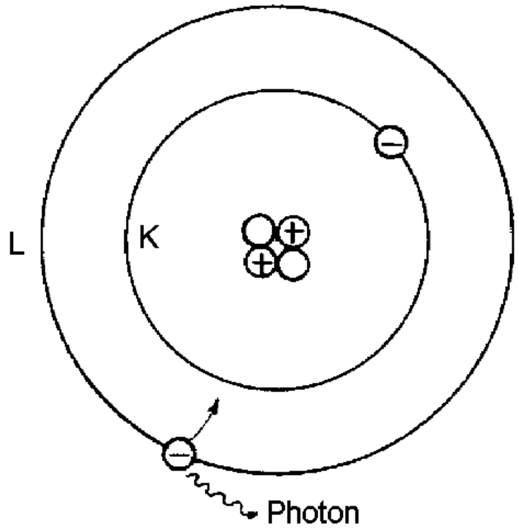


Figure 1-4. Excited atom.

1-6. CHEMICAL PROPERTIES

a. The electron structure of an atom also determines the chemical properties of an atom. So far we have talked only about filling up the K-shell. In order to fill up the L-shell, eight electrons are required. Let us look at an oxygen atom; this has eight protons, eight neutrons, and, therefore, eight electrons revolving about the nucleus. Two of the eight electrons will be found in the K-shell. This means that six are in the L-shell in a normal oxygen atom. In order to fill the L-shell and make it complete, two more electrons would be needed. Now most atoms would like to fill up their outer shell; but for oxygen, this would mean that it would have a total negative charge of -2. It is possible that the oxygen atom could borrow enough electrons from hydrogen atoms to complete the L-shell. Two hydrogen atoms would be needed. The oxygen atom would have a net charge of –2 and each hydrogen atom would then be left with a positive, +1, charge. Since positive attracts negative, this group of particles would tend to hold together. This form of chemical combination is known as ionic bonding. This hydrogen-oxygen group is called a molecule of water (see Figure 1-5).

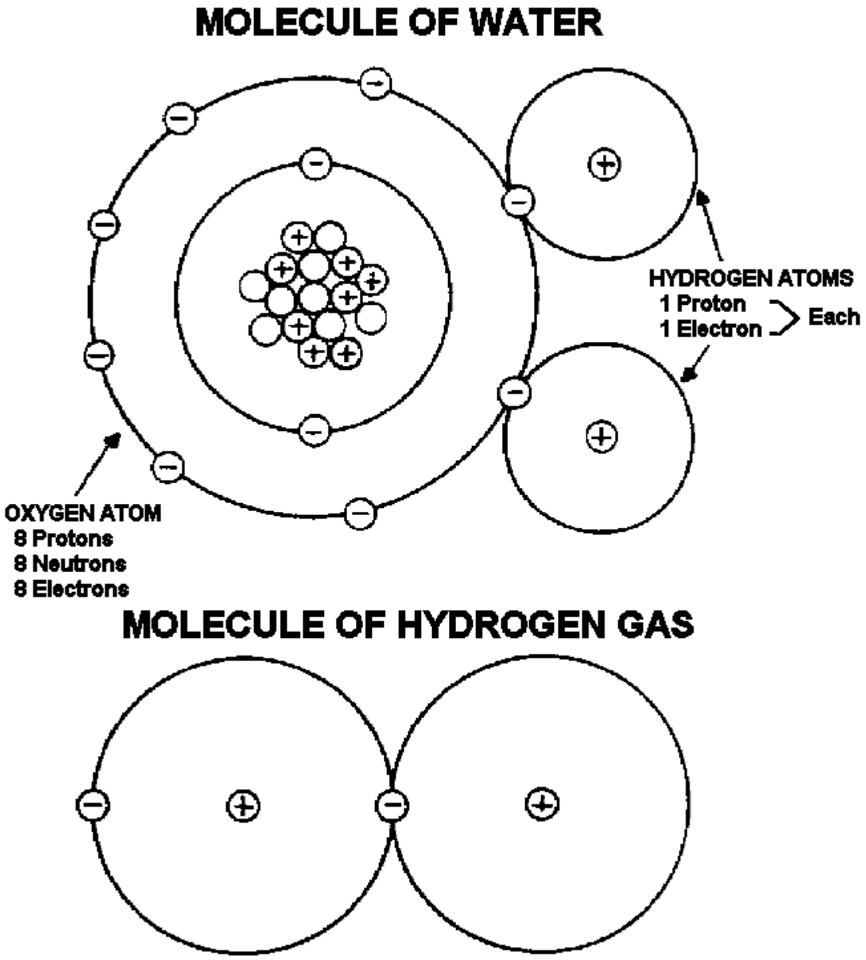


Figure 1-5. Descriptive pictures of molecules.

b. Notice that the total charge of the oxygen plus the hydrogens is zero. A molecule of water is quite stable; the hydrogen and oxygen do not separate very easily. Sometimes this molecule is called H_20 and now the reason is obvious. When the atoms of different elements combine in this way, the substance formed is called a compound. Here the compound, water, is made up of H_20 molecules. A compound is defined as the chemical combination of two or more elements.

c. Often in the process of forming compounds, large amounts of energy are given off. Hydrogen gas may explode violently and, when it does, it is simply combining with oxygen to form water.

d. Another type of molecule encountered can be formed from hydrogen. There is no reason why one hydrogen atom cannot unite with another. In this case, there would be two electrons orbiting two hydrogen nuclei. Here the K-shell would be complete at least part of the time for each hydrogen atom (see Figure 1-5). This sort of molecule is called a diatomic molecule. Hydrogen gas is composed of diatomic molecules of hydrogen. Thus, a molecule is the smallest particle of any substance, element, or compound as it normally exists in nature.

e. It is therefore apparent that the electron structures of atoms are important things. They determine the way in which compounds are made and the world we live in is composed mostly of compounds. Also, the electronic structure is intimately involved in the production of visible light and other electromagnetic radiation.

1-7. ATOMIC NOTATION

a. In order to simplify discussions concerning elements and atoms, a standard notational form is used to talk about atoms. It is based upon the primary characteristics of the atom. The first of these characteristics is the number of protons in the nucleus of the atom, which in a neutral atom is also the number of electrons in shells around the nucleus. This number, which determines the element to which the atom belongs, is called the atomic number. It is usually symbolized by the capital letter "Z." The second primary characteristic is the number of neutrons in the nucleus, a factor which, to some degree, determines the nuclear characteristics of the atom. The number of neutrons in the nucleus is described in terms of the total number of major particles in the nucleus; the total number of nucleons (sum of neutrons and protons) is called the atomic mass number. It is usually symbolized by the capital letter "A." Therefore, the number of neutrons is given by A - Z. In addition, each element has its own symbol or abbreviation, such as "H" for hydrogen or "Fe" for iron. The standard notation takes the following form:

$^{A}_{Z}X$ Where: X = Symbol of the element to which the atom belongs
Z = Atomic number
A = Atomic mass number for the particular isotope

b. Using this notation, an atom can be easily described. For example, the atomic notation at the right is for an atom with 92 protons (uranium--symbol U), 92 electrons in shells around the nucleus, and a total of 235 nucleons in the nucleus. Since 92 of the nucleons are protons, there are 143 neutrons in the nucleus of this atom.

$${}^{235}_{92}\mathrm{U}$$

1-8. RADIOACTIVITY

a. It was indicated earlier that the negative electrons are bound to the atom by the attraction of the positive protons. Within the nucleus, however, only positive charges exist and these charges repel each other. Therefore, other forces strong enough to overcome the repelling forces of the protons must exist between nucleons. Since these forces are of very short range, acting only between nucleons close to one another, they are called strong nuclear forces. It is possible in isotopes of heavier elements for the electrostatic forces between protons to overcome these strong nuclear forces. If this is the case, part of the nucleus actually may break off and escape. In other cases, rearrangements may take place, which lead to more stable configurations within the nucleus (see para e below). Nuclei in which this happens are said to be unstable or radioactive. All isotopes with atomic number Z greater than 83 are naturally radioactive and many more isotopes can be made artificially radioactive by adding neutrons, protons, or groups of these to destabilize the normally stable configuration.

b. Natural radioactivity occurs in three basic ways. Many unstable nuclei emit a particle composed of two protons and two neutrons called an alpha particle (symbol α). This configuration is also the nucleus of a helium (He) atom and is very stable. To see what results from an emission, consider the isotope of uranium with 146 neutrons and 92 protons (U-238). This is a naturally-occurring isotope, but is radioactive and an alpha emitter (Figure 1-6). Since emission removes the two protons, the uranium changes to an entirely new substance, thorium, in the form of the thorium isotope with 90 protons and 234 nucleons (protons + neutrons).

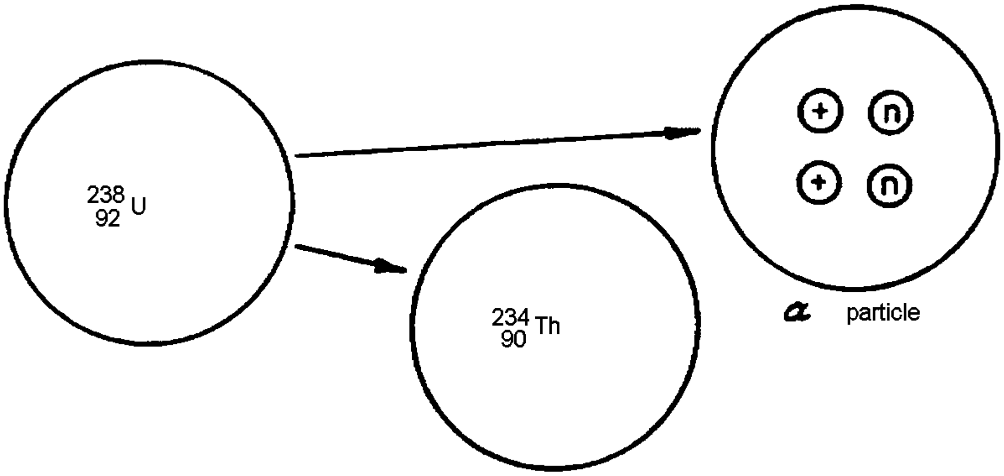


Figure 1-6. Alpha emission from U-238.

c. It often happens that unstable nuclei emit high-speed electrons called beta particles (symbol β). They are called particles, not electrons, to indicate that they are electrons that originate in the nucleus instead of electrons that originate in atomic orbits outside the nucleus. The source of electrons in this form of radioactivity is interesting since, as was previously pointed out, there are no electrons in a nucleus. This paradox is explained when it is found that a neutron can transform into a proton and an electron. When this happens, the electron (β particle) is ejected from the nucleus while the proton is left behind. Figure 1-7 pictures a hypothetical example of emission showing the decay of a neutron into a proton. The proton remains within the nucleus and an electron escapes.

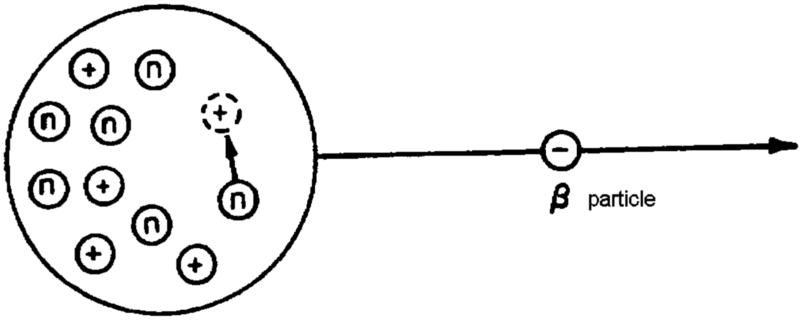


Figure 1-7. Beta emission.

d. The thorium isotope that was formed in the example on emission is also radioactive, but it is an emitter causing Th-234 to change to the element protactinium (Figure 1-8). Note that the protactinium mass number (A = 234) does not change in decay, but that the atomic number Z does increase from 90 to 91 because a proton has been gained. This gain comes about, as explained earlier, when the neutron breaks down, ejecting an electron and retaining the proton.

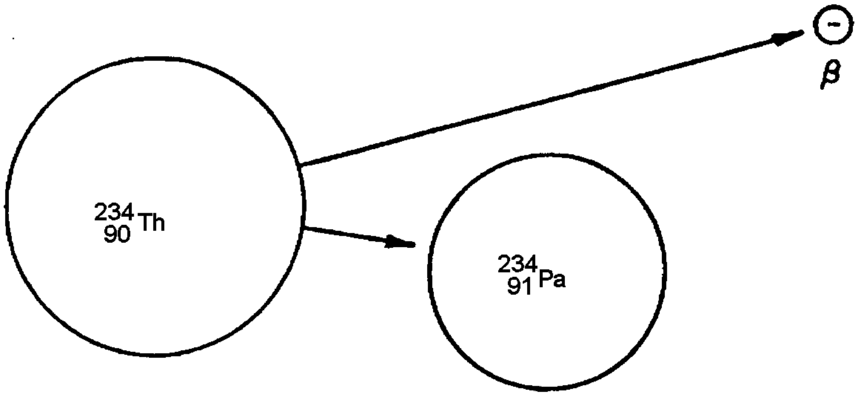
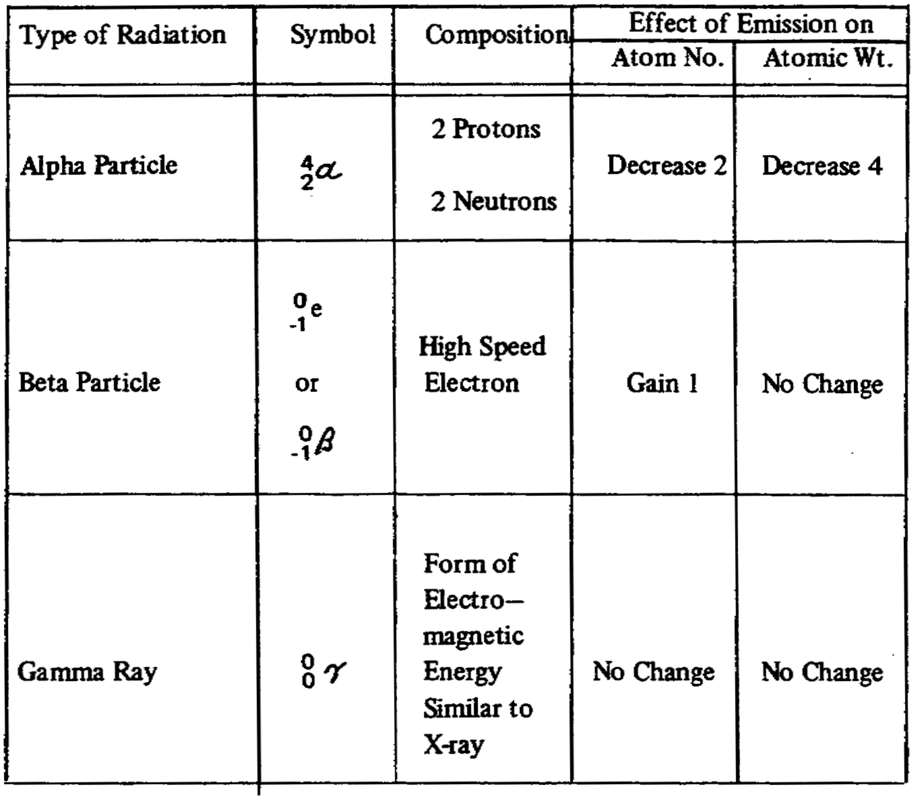


Figure 1-8. Beta emission from Th-234.

e. Previously it was said that an unstable configuration of neutrons and protons in a nucleus is sometimes made more stable by a rearrangement of the components with no particles emitted. Such changes are accompanied by radioactivity in the form of energy. With different configurations of the nucleus, the components are bound with different energies and so, upon rearrangement, energy is often released in the form of electromagnetic waves called gamma rays (symbol ϒ). These are like light waves except that their frequencies are much higher and they are not visible to the human eye. It is important to note that no change in atomic structure accompanies emission (A and Z numbers remain the same) and the only effect upon the nucleus involved is to leave it with less energy and usually with less tendency for further decay.

f. Table 1-1 presents a summary of the effect of radioactive emissions on the structure of an atom.



Type of Radiation	Symbol	Composition	Effect of Emission on	
			Atom No.	Atomic Wt.
Alpha Particle	${}^{4}_{2}\alpha$	2 Protons 2 Neutrons	Decrease 2	Decrease 4
Beta Particle	${}^{0}_{-1}e$ or ${}^{0}_{-1}\beta$	High Speed Electron	Gain 1	No Change
Gamma Ray	${}^{0}_{0}\gamma$	Form of Electro—magnetic Energy Similar to X-ray	No Change	No Change

Table 1-1. Radioactive Summary.

g. Alpha, beta, and gamma radiations are the primary emissions resulting from natural radioactive decay. There are many other types of emissions that occur from artificially-produced radioactive material. These artificial nuclei may emit neutrons, positive electrons, and other emissions not important to this discussion. The neutrons are especially important in applications of nuclear energy for they can cause nuclear fission, a reaction fundamental to nuclear explosions and the generation of nuclear power.

1-9. RADIOACTIVE DECAY

a. The step-by-step process by which radioactive elements emit α, β and γ radiations, change into other elements, and finally reach stability is called a decay series. The steps from U-238 to Th-234 to Pa-234 described above represent two steps in what is called the natural radioactive uranium series, U-238 being the original element in the series. There are several other steps described here in this uranium series before stability is reached and there is no longer any radioactive change. The last step in this process occurs when the element polonium (Po-210) emits an alpha particle and becomes the element lead (Pb-206), which is stable. This is the end of the uranium series, but there are other radioactive series involving other heavy elements.

b. The question arises--how long does it take U-238 to decay into the next series step of Th-234 or for the last decay step, polonium, to decay into stable lead? The question of the time involved in radioactive decay is explained by the use of a term called <u>half-life</u>. Half-life is defined as the length of time it takes for one-half of a given number of atoms of one element to decay into another element. For example, if you have 5,000 atoms of U-238 today, in a period of time designated as one-half life, you would have only 2,500 atoms of U-238 remaining. This would take 4-1/2 billion years. Half-lives may vary from fractions of microseconds to billions of years. Some half-lives of typical elements are given in table 1-2.

$^{238}_{92}U$	-	4.5 billion years
$^{235}_{92}U$	-	700 million years
$^{239}_{94}Pu$	-	24,000 years
$^{226}_{88}Ra$	-	1,620 years
$^{210}_{84}Po$	-	138 days

Table 1-2. Half-lives of typical elements.

Section III. RADIATION UNITS

1-10. BACKGROUND

a. Although radioactivity was discovered in the late 19th century, it was originally considered a scientific curiosity with little practical value. During this time researchers discussed findings in terms of the effects of radiation or in terms of the type of equipment used in a particular experiment. For example, an experimenter might describe the type of x-ray tube and voltage used or he might describe the effects on the skin of a man exposed to radiation. A widely used unit was the so-called erythema dose--the amount of radiation which could cause an abnormal redness of the skin due to capillary congestion.

b. As experiments became more precise, and the experimenters became aware of the effects of radiation upon living tissue, the need arose for an accurate unit to enable comparison among the various types of x-ray machines that had proliferated during World War I. Experience gained in the war also showed the need for a careful study of the effects of radiation on personnel; such a study would require a standard unit for evaluating radiation doses.

c. For these reasons, the International Commission for Radiological Protection (ICRP) was formed. Meeting in Geneva, Switzerland, in 1925 and again in 1928, the ICRP recognized this need. The search for a suitable unit culminated in 1932 in the adoption of the term "roentgen."

1-11. UNIT OF EXPOSURE

a. Named after the discoverer of x-rays, the roentgen (R) is applicable only to x-rays and gamma radiation. The roentgen is defined in terms of the ionizations produced by x and gamma radiation in air.

b. As radiation passes through air, it will interact with the gas atoms and produce ionizations. In each ionization, an ion pair is formed, consisting of an electron and a positive ion. The charge on the electron is equal in magnitude to that on the positive ion but opposite in sign; if the two are allowed to recombine, the charges will be neutralized and a neutral atom will result. If, however, an electric field is present, the two ions will not recombine but will move in opposite directions, eventually to be collected by the electrodes that created the electric field. When the ions are collected, they will neutralize a small portion of the charge originally placed on the electrodes. The amount of charge that is thus neutralized may be measured; this fact is the basis for the definition of the roentgen.

c. One roentgen is that quantity of x or gamma radiation which will produce one electrostatic unit of charge of either sign in 0.001293 grams of air at standard temperature and pressure or 2.584×10^{-4} coulomb/kg of air.

d. The electrostatic unit (esu) of charge equals, approximately, the electrical charge of two billion electrons. The mass of air specified in the definition is the mass of approximately one cubic centimeter (cc) of air under conditions of standard temperature and pressure. By referring to the definition, then, we can see that one roentgen produces approximately two billion ionizations in each cubic centimeter of air. Of course, the measuring chamber need not have a volume of exactly one cubic centimeter. Increasing the chamber volume to 10 cubic centimeters, for example, would simply mean that one roentgen would cause approximately 20 billion ionizations in this volume, capable of neutralizing 10 esu of charge.

e. Conversion factors of this kind have been utilized to arrive at alternate forms of the definition of the roentgen:

(1) 773.4 esu per gram of air.

(2) 1.611×10^{12} ion pairs per gram of air.

(3) 87.8 ergs per gram of air.

f. The alternate form, paragraph (3) above, is derived from paragraph (2) above and the laboratory measurements of the amount of energy required to cause one ionization in air. As the measurements are extremely difficult to make, the value given represents an estimate.

g. The roentgen is still used in the measurement of x and gamma radiation. As these types of radiation travel in straight lines and will easily penetrate body tissue, it is meaningful to talk of exposure--the quantity of radiation, which passes through a given volume in space. Exposure is based upon the <u>ability</u> of the radiation to produce ionizations in air; however, as is the case of light rays measured by an exposure meter, the radiation need not actually interact with the body tissue or with anything else.

h. For this and other reasons, it was soon recognized that the concept of exposure was severely limited in its application. It was not defined for radiation other than x and gamma and it was not directly related to damage produced in living tissue. The "absorbed dose" concept was therefore developed; it is based on the quantity of ionizing radiation, which actually interacted with matter, producing ionizations and releasing energy. As the unit of energy in the metric system is the erg, the natural unit for absorbed dose was ergs released per gram of material.

1-12. ABSORBED DOSE

a. The rad is a unit of absorbed dose and it describes energy absorbed per gram of absorbing material.

1 rad = 100 ergs absorbed per gram of any substance

or

0.01 joules per kilogram

b. When water or soft tissue absorbs x or gamma radiation (100 KeV to 3 MeV), the absorbed dose per roentgen is between 0.93 and 0.98 rad. Therefore, rads and roentgens are approximately the same for x or gamma rays in those energies.

c. The rad is used for x and gamma rays and the particulate radiations, alpha and beta particles, and neutrons.

d. Recently, the 15th General Conference of Weights and Measures adopted some new names and units. The Gray (symbol Gy) has been adopted as the special unit of absorbed dose.

1 rad = 0.01 joule/kilogram

or

1 Gy = 100 rads

1-13. DOSE EQUIVALENT

a. The absorbed dose does not provide us with an indication of biological damage since it is concerned with energy absorption only. It was desirable to establish an index of damage produced by different kinds of radiation. The relative biological effectiveness (RBE) factor was introduced.

b. Using damage produced by x-rays (200 KeV) as the standard, other forms of radiation were compared and RBE values assigned.

c. For example, if our 200 KeV x-rays produce reddening of the skin with a dose of 200 rads, but another type of radiation produces the same effect with 100 rads, we can compare dose and calculate the RBE.

$$\text{RBE} = \frac{\text{rads of Standard (Skin Reddening)}}{\text{rads of Other Radiation (Same Effect)}} = \frac{200}{100} = 2$$

So we would assign the other radiation an RBE value of two. This value is used primarily in the study of radiobiology.

d. The RBE demonstrated the need for a unit of dose that would take into account biological damage. Thus, a unit of dose equivalent was established and called the roentgen equivalent man (rem).

$$\text{rem} = \text{rad} \times \text{RBE (Radiobiology)}$$

or

$$\text{rem} = \text{rad} \times Q \times N$$

where Q is the quality factor and N is any other modifying factor. This is used in radiation protection.

e. Recently, a new name and unit of dose equivalent has been introduced. The Sievert (symbol Sv) is the new unit of dose equivalent.

$$1 \text{ rem} = 0.01 \text{ joule/kilogram} = 0.01 \text{ Sv}$$

Therefore, 1 Sv = 100 rem.

1-14. DOSE RATE

a. Up to now, we have discussed dose as a total quantity. A dose of radiation is an expression of how much. A particular dose might be the result of a year’s exposure or a day’s exposure to radiation.

b. This brings us to another term to consider--dose rate. The dose rate tells us how fast or slow radiation is being delivered. Dose rate is to dose as miles per hour is to total miles driven.

c. The dose rate is expressed as dose per unit of time, i.e., rads/hour, roentgens/sec, etc.

d. Total dose is obtained by multiplying the dose rate by the time of exposure where the dose rate remains constant.

$$\text{Dose} = \text{Dose Rate} \times \text{Time}$$

UNIT	***ABBREVIATION***	***DEFINITION***
Roentgen	R	The quantity of x or gamma radiation that will produce, in 0.001293 grams (1 cc) of standard air, ions carrying one electrostatic unit (esu) of charge of either sign.
Radiation Absorbed Dose	rad	The quantity of ionizing radiation of any type that results in the absorption of 100 ergs per gram in any material.
Roentgen Equivalent Man	rem	The quantity of ionizing radiation of any type which, when absorbed by man, produces a physiological effect equivalent to that produced by the absorption of one roentgen of x or gamma radiation.

Table 1-3. Summary of radiation units.

Section IV. BIOLOGICAL EFFECTS OF RADIATION

1-15. BACKGROUND

Ever since the discovery of x-rays by Wilhelm Conrad Roentgen in 1895 and the discovery of natural radiation by Henri Becquerel in 1896, man has been attempting to utilize the beneficial properties of radiation without suffering any adverse biological consequences. As early as 1898, scientists realized that it was essential to learn more about radiation effects on living cells. X-rays and radioactive isotopes already were being used widely in medicine and research and many individuals were receiving damaging exposures. In order to intelligently utilize nuclear energy, it became necessary to understand how and when radiation could be a hazard to human health.

1-16. DAMAGE MECHANISMS

a. It is often difficult to envision how radiation, which cannot be seen, heard, smelled, or felt, can cause injury or death to a healthy man. The answer is not fully understood, but a partial insight into the damage mechanism is gained when we realize that man is composed of millions of microscopic cells and that radiation damage occurs on the cellular and subcellular level.

b. When radiation is absorbed by a living cell, the primary damage is caused by ionization and excitation of the atoms and molecules of that cell. These interactions occur with any type of matter, whether living or nonliving; but in a living cell, the ionized or excited atoms and molecules may be highly reactive chemically. Under these circumstances, secondary reactions will occur, resulting in changes in cellular structure, damage to essential constituents, and observable biological injury.

c. In addition to the direct action of radiation, molecules damaged by radiation can also produce cellular injury. In fact, the formation of free radicals from water is the primary means of cell injury by ionizing radiation. The most frequently formed water radical, the hydroxyl radical attacks neighboring molecules that are important for homeostasis. The resulting damage to the genetic material of the cell is considered to be the major cause of cell death.

d. It is the combination of these primary and secondary reactions that results in acute and chronic radiation injury. The interrelationship of causes and effects is extremely complex and is dependent not only on the energy of the radiation, but also on the total dose, dose rate, presence of oxygen, sex, nutritional status, and other physiological factors which affect the body.

e. These factors in combination lead to the observation that the cells of the body which seem most radiosensitive are those which reproduce most rapidly and are in a state of high-metabolic activity. Regions of the body such as blood-forming organs, gonads, and hair follicles show injury at much lower dosages than slow or nonreproducing tissues such as nerve tissue.

1-17. ACUTE EFFECTS

a. The effects of a radiation exposure may be grouped into two categories--those appearing within days or weeks and those developing over a period of months to years. Effects appearing early result from massive cell-killing and as a group are associated into the acute radiation syndrome. In man, this rapid depletion of radiosensitive cells produces some effects within hours of the exposure and is usually resolved during the first month after the exposure. A convenient method of describing these effects is through the time course of their development.

b. Prodrome. Occurring in the first 24 to 48 hours after an exposure to ionizing radiation, nausea, vomiting, fatigue, and malaise are symptoms frequently expressed by the victim. As a group, these symptoms are rarely observed in individuals exposed to less than 50 rems but are almost always seen in those exposed to a dose greater than 200 rems. During this period of prodrome, the blood count will change in response to the radiation dose, the severity of the change depends on the actual dose. Fifty rems are considered a minimum dose for the appearance of changes in the blood count.

c. Acute radiation syndrome. After the prodromal period and a period of latency whose duration will depend upon the dose, occurs the period of manifest illness. Beginning toward the end of the first week following the exposure, a person receiving a modest dose of ionizing radiation will experience some continued nausea, diarrhea, inflammation of the throat, and loss of appetite. At a more severe dose (viz., usually greater than 200 rems), the individual will experience bloody diarrhea, fever, bruising (of the gums in particular), and hair loss. The loss of hair is a good indicator of this level of exposure. At doses beyond which survival is not usually possible (e.g., greater than 1,000 rems), the degree of development of the above symptoms will be more severe and will show no signs of dissipation. Death usually occurs during the second or third week following the exposure.

d. Although the signs and symptoms listed above will apply for the average human with a uniform exposure, there are several factors that will affect the individual's response to the radiation. The dose, type of radiation, area exposed, sex, age, and general health status are each important modifiers of the response. For example, factors relevant to the bone marrow injury are the dose, quality of the radiation, and the uniformity of the irradiation. This is a result of the location of the bloodforming organ within the body. Long bones, the sternum, costals, and cranium are all active sites of marrow production. Any single area not exposed will normally provide sufficient marrow reserve. Also, because active sites of marrow production change during development and aging, age becomes another important determinant. The intestinal lining, a second site critical for the development of radiation injury, can be affected by a highly localized dose. For this reason, radiation quality and depth of penetration are important to this type of injury. X-rays and gamma radiation have great penetrating ability and can affect vital organs.

e. The dose at which 50 percent lethality occurs is measured and quoted as the LD 50/30. For most mammals this dose is approximately 500 rems; for humans it is 350 to 450 rems. The outcome for a particular exposure cannot be accurately predicted. However, the LD 50 (50% of deaths) for man is believed to be somewhere between 200 and 500 rads. This is usually quoted as 450 rads.

1-18. DELAYED SOMATIC EFFECTS OF RADIATION

a. A chronic exposure (as opposed to an acute exposure) is one received over a long period of time. Frequent occupational exposures or constant irradiation due to internally deposited isotopes fall within this category. The effects of a chronic exposure are long range and often difficult to determine; it is difficult to prove that such damage as cancer, leukemia, life-shortening, and genetic mutations are induced by radiation in any particular case. Statistical evidence, however, does link damage of this type to radiation exposures. Long-term <u>effects</u> of this type are not limited to being caused by chronic <u>exposures</u>; acute radiation exposures may also result in long-term effects.

b. Cancer or carcinogenesis is one long-term effect of radiation. There is a higher incidence of cancer among those who have received significant doses due to either chronic or acute exposure to radiation than in persons who have not. By 1922, a large percentage of the pioneer radiologists suffered from cancer. It is generally accepted that the probability an individual will suffer from cancer increases proportionally to his total absorbed dose.

c. Another long-term effect is leukemia, or cancer of the white blood cells. The evidence, as with cancer, is statistical, but there is a higher incidence of leukemia among those who have been exposed to excessive amounts of radiation than in the unexposed population.

d. By a similar statistical reasoning process, some studies have shown that radiation exposure decreases the life span of the irradiated population. By exposing large numbers of experimental animals to low levels of radiation over their entire life span, it has been shown that life span-shortening does occur and is probably due to accelerated aging.

e. Finally, one of the most significant long-term effects is the possibility of genetic damage or mutation. A mutation is a hereditary change that can be passed from generation to generation. Most mutations are harmful rather than beneficial; it is therefore not desirable to increase the mutation rate.

(1) In 1928, it was shown that radiation exposure increased the genetic mutation rate in fruit flies. Since that time, this mutation effect has been observed in many animals, but data in humans are lacking due to the complexity of human genetics.

(2) The important point to remember in considering the relationship between radiation and genetic effects is that radiation does not create new mutations, but rather increases the rate of mutations already present in the population. Most mutations are recessive; that is, both parents must possess mutant germ (reproductive) cells before the offspring will exhibit the mutant characteristic. For this reason, several generations may pass before the mutation will actually be seen in the population.

f. It is not known whether the effect at low exposures may be determined by assuming that there is a linear relationship between dose and effect, where even very small doses will produce some effect, or whether a threshold dose exists below which no effect will occur. Evidence indicates that cancer would fit the nonthreshold model, while other effects, such as cataracts, are threshold in nature. For radiation protection purposes, the linear, nonthreshold approach is used and all occupational exposures are maintained as low as reasonably achievable (ALARA).

Section V. RADIATION DETECTION INSTRUMENTS

1-19. DETECTOR FUNDAMENTALS

a. Nuclear radiation cannot be detected by any of the human senses; therefore, detection instruments must be used to measure radiation intensity. If such instruments were not available, it would be possible for personnel to be exposed to sizable, even lethal, doses of radiation without warning at the time of exposure. Only with the knowledge provided by radiation detection instruments can personnel be adequately warned against exposure.

b. Instruments for detecting and measuring radiation are called radiac instruments. The word "radiac" was coined from the first letters of words describing what the instruments are intended for--radioactivity detection identification, and computation.

c. Radiac instruments measure radiation by the detection and evaluation of an event produced by radioactive decay. There are several different methods, based upon the various phenomena associated with nuclear radiation, which can be used to detect and measure radiation. The major methods are:

(1) Electrical collection of ions. When gases are ionized by radiation, the ions formed move about in a haphazard manner and eventually the negative and positive ions will be neutralized. However, if an electrical field is established in a confined volume of gas by two oppositely charged surfaces (electrodes), the negative ions will move toward the positive electrode while the positive ions will move toward the negative electrode. Upon hitting the electrodes, the ions will be neutralized and will reduce the charge on the electrode. The amount of reduction can be measured and will give an indication of the amount of radiation present.

(2) Scintillation. Certain crystalline materials, such as zinc sulfide, and sodium iodide, have the property of emitting flashes of light (scintillation) when struck by ionizing radiation. The intensity of the light emitted by the scintillating crystal is proportional to the energy of the ionizing radiation.

(3) Semiconductors. When ionizing particles strike certain semiconductors, hole-electron pairs (ions) are either created or destroyed, resulting in a pulse of current proportional to the intensity of the radiation field.

(4) Photographic. Ionizing radiation causes chemical changes to photographic film similar to the effects of ordinary light. Varying quantities of ionizing radiation result in a corresponding change in the optical density of the developed film, providing a reliable means of detecting and measuring radiation.

1-20. SELECTION CRITERIA

a. Numerous radiation detection instruments exist which utilize one or more of the operating principles discussed above. The selection of instruments to use in radiation environments is based on the kind of information sought and type of radiation involved.

b. In most cases involving radiation protection surveys, the instrument operator is seeking information concerning the amount of radiation per unit time (dose rate) or the accumulated amount (total dose). Therefore, we categorize radiation detection instruments as rate meters or dosimeters, depending on the information they provide.

1-21. INSTRUMENTS

a. The U.S. Army has recently replaced several instruments used for measuring the gamma radiation dose rate and total gamma radiation dose to include:

(1) The radiac set, AN/PDR-27 (Geiger counter), a dose rate instrument used for measuring low intensity (zero to 500 milliroentgens per hour) gamma radiation and detecting beta radiation, and

(2) The radiacmeter, IM-174/A, a dose rate instrument used for detecting and measuring high level (up to 500 roentgens per hour) gamma radiation only.

b. Both the AN/PDR-27 and the IM-l74/A were replaced by the AN/VDR-2 (see Figure 1-9). The AN/VDR-2 detects, measures and displays gamma dose rate from background to 100 Gy/hr; detects and displays beta particle radiation from background to 5 cGy/hr; and measures, stores, and displays accumulated dose from 0.01 uGy to 9.99 Gy. This device is autoranging (that is, the readout is digital and requires no input from the operator to read from the lowest to highest dose/dose rate).

Figure 1-9. Radiac Set, AN/VDR-2

c. The radiacmeter, IM-93/UD (Tactical Dosimeter—0 to 600 roentgens) or pocket dosimeter (see Figure 1-10) measures total gamma radiation dose and utilizes a variation of the electrical collection of ions principle of operation with immediate information capability. The U.S. Army currently has three standard pocket dosimeters with different operating ranges:

(1) Radiacmeter, IM-9/PD (Clinical Dosimeter)—zero to 200 milliroentgens.

(2) Radiacmeter, IM-147/PD (NBC Defense Team Dosimeter)—zero to 50 roentgens.

(3) Radiacmeter, IM-93/UD (Clinical Dosimeter)—zero to 600 roentgens.

The choice of dosimeter depends on the radiation environment and is based on the dose range to be encountered. As mentioned before, this instrument is used as a personal device to indicate the total exposure to the individual wearing it.

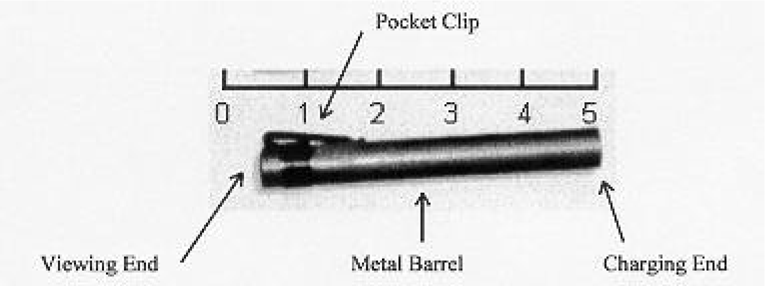


Figure 1-10. Radiacmeter, IM-93/UD (Clinical Dosimeter)

d. The pocket dosimeters mentioned above are being replaced by the AN/UDR-13 Pocket Radiac (see Figure 1-11). The new Pocket Radiac is a radiation dosimeter that measures initial and residual gamma radiation and prompt neutron radiation. It can measure dose from 1 to 999 cGy (neutrons/gamma-prompt initial and fallout) and dose rate from 0.1 to 999 cGy/hr (gamma fallout).

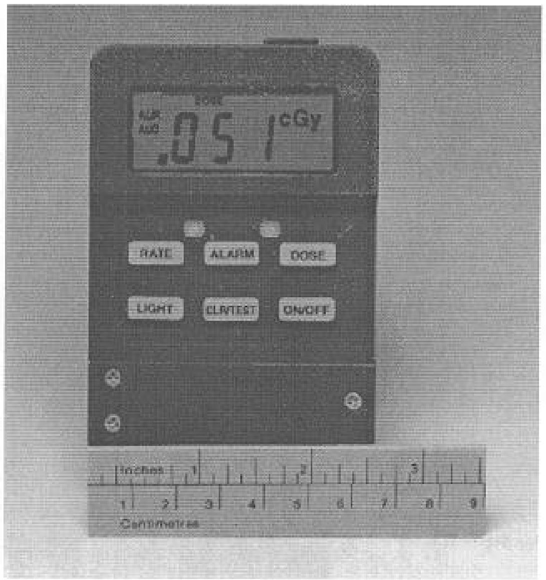


Figure 1-11. Pocket Radiac – AN/UDR-13

e. The Thermoluminescent Dosimeter (TLD) (see Figures 1-12 and 1-13) is a total dose device, which measures beta, x-ray, gamma, and neutron radiation. It utilizes the thermoluminescent principle of operation. Energy or radiation is absorbed by the detector molecules and raises them to an excited or metastable state. They remain in this excited state until they are heated to a temperature high enough to cause the molecules to return to a normal or ground state. When these molecules return to their normal state, they give off the excess energy they contain, in the form of light. The amount of light is proportional to the energy or radiation absorbed. The emitted light is measured with a photomultiplier tube that serves to convert the light photons into an electrical signal that can be quantified. The TLD is worn by an individual as a personnel-monitoring instrument. The TLD, however, is not self-reading. It requires a sensitive reader to quantify the dose. For peace-time use, the TLDs are shipped to the Test, Measurement, and Diagnostic Equipment facility at Redstone Arsenal, Alabama for analysis. During battlefield operations, the AN/PDR-75 Reader (see Figure 1-14) is used for analysis of the DT-236 Dosimeter. Variations of the TLD are used quite extensively in both military and civilian practices involving the use of radiation.

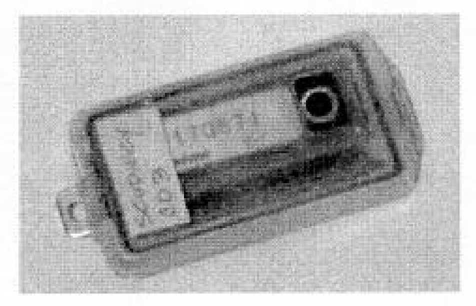


Figure 1-12. Thermoluminescent Dosimeter.

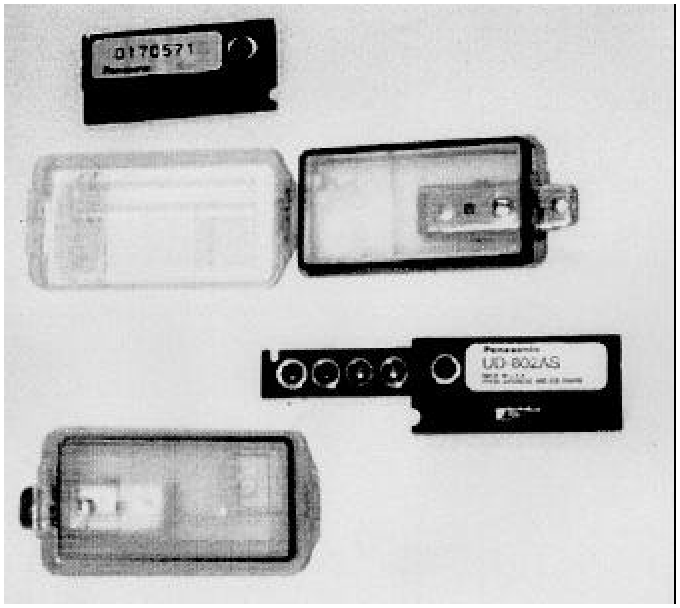


Figure 1-13. Thermoluminescent Dosimeter components.

Figure 1-14. The AN/PDR-75 Reader with DT-236 (Wrist Watch/Tactical) Dosimeters.

f. The instruments discussed in the preceding paragraphs are by no means all that exist in the U.S. Army inventory. Additional instrumentation is often necessary for special cases, such as low level alpha radiation monitoring or determining neutron emission from certain types of nuclear reactions. There are a number of instruments, which are designed specifically for these purposes, and will be found wherever the need for such devices exists.

g. Occasionally, the preventive medicine specialist may assist in the use of such instruments or devices and will at that time have the opportunity to evaluate the particular radiation environment and monitoring program in detail.

Continue with Exercises

EXERCISES, LESSON 1

REQUIREMENT. The following exercises are to be answered by marking the lettered response that best answers the question, or by completing the incomplete statement, or by writing the answer in the space provided at the end of the question. After you have completed all the exercises, turn to "SOLUTIONS TO EXERCISES" at the end of the lesson and check your answers.

1. A (an) _______________ is a substance which cannot be separated into simpler substances by ordinary chemical means.

   a. Compound.

   b. Atom.

   c. Molecule.

   d. Element.

2. It is the number of ____________________ in the nucleus of an atom that determines the element to which the atom belongs.

   a. Protons.

   b. Electrons.

   c. Neutrons.

   d. Mesons.

3. Two atoms of the same element with different numbers of neutrons are called __________________________.

   a. Isotones.

   b. Isobars.

   c. Isotopes.

   d. Isomers.

4. In the atomic notation $\overset{a}{z^{X}}$, the letter A represents:

   a. The number of electrons in the atom.

   b. The number of neutrons in the atom.

   c. The number of protons in the atom.

   d. The number of protons plus neutrons in the atom.

5. Naturally-occurring radioactive materials produce ____________________________ __________________and _____________________________ radiations.

   a. Alpha, beta, neutron.

   b. Alpha, beta, gamma.

   c. Proton, alpha, gamma.

   d. Beta, gamma, neutron.

6. The radiation with the greatest penetrating ability is:

   a. Beta.

   b. Alpha.

   c. Neutrons.

   d. Gamma rays.

7. In beta decay, the atomic mass number:

   a. Increases by one.

   b. Stays the same.

   c. Decreases by one.

   d. Decreases by four.

8. A radioactive material which decays through five half-lives will result in __________ of the original amount.

   a. 1/8.

   b. 1/16.

   c. 1/32.

   d. 1/61.

9. The roentgen is a unit of x or gamma radiation:

   a. Exposure.

   b. Absorbed dose.

   c. Accumulative dose.

   d. Energy absorption.

10. The rad represents an absorption of:

    a. 93 ergs/gram.

    b. 93 calories/gram.

    c. 100 ergs/gram.

    d. 100 calories/gram.

11. When radiation is absorbed by a living cell, the primary damage is by:

    a. Formation of cell poisons.

    b. Genetic rearrangement within the cell nucleus.

    c. Loss of cell protoplasm and nuclear material.

    d. Ionization and excitation of the atoms and molecules of that cell.

12. The LD-50 for radiation exposure in man is:

    a. 100 to 200 rads.

    b. 200 to 500 rads.

    c. 500 to 800 rads.

    d. 800 to 3,000 rads.

13. The length of time it takes for one-half of a given number of atoms of one element to decay into another element is the atom's:

    a. Half-life.

    b. Atomic number.

    c. Radioactive change.

    d. Radioactive stability.

14. Of the following, the most important factor in selecting a radiation detector is:

    a. Weight and portability of the instrument.

    b. Type of radiation.

    c. Cost of the instrument.

    d. Chemical form of the radiation.

15. What types of radiation does the AN/VDR-2 detect?

    a. Gamma only.

    b. Gamma and alpha.

    c. Gamma and beta.

    d. Gamma, alpha, and beta.

16. Chronic exposure to radiation may result in which of the following?

a. Cancer.

b. Decreased lifespan.

c. Genetic mutations.

d. All of the above.

17. When considering the relationship between radiation and genetic effects, it is true that radiation:

a. Creates new recessive mutations

b. Creates new dominant mutations.

c. Increases the rate of mutations already present in the population.

d. Decreases the rate of mutations already present in the population.

Check Your Answers on Next Page

SOLUTIONS TO EXERCISES, LESSON 1

1. d. Element. (para 1-5c)

2. a. Protons. (para 1-5f)

3. c. Isotopes. (para 1-5f)

4. d. The number of protons plus neutrons In the atom. (para 1-7a)

5. b. Alpha, beta, gamma. (para 1-8)

6. d. Gamma rays. (para 1-11g)

7. b. Stays the same. (para 1-8e; table 1-1)

8. c. 1/32. (para 1-9b)

9. a. Exposure. (para 1-11)

10. c. 100 ergs/gram. (para 1-12a; table 1-3)

11. d. Ionization and excitation of the atoms and molecules of that cell. (para 1-16b)

12. b. 200 to 500 rads. (para 1-17e)

13. a. Half-life. (para 1-9b)

14. b. Type of radiation. (para 1-20)

15. c. Gamma and beta. (para 1-21b)

16. d. All of the above. (para 1-18a)

17. c. Increases the rate of mutations already present in the population. (para 1-18e(2))

End of Lesson 1

LESSON ASSIGNMENT

LESSON 2	Ionizing Radiation.
LESSON ASSIGNMENT	Paragraphs 2-1 through 2-17.
LESSON OBJECTIVES	After completing this lesson, you should be able to: 2-1 Identify the major sources of ionizing radiation and the basic principles involved in the generation of such radiation. 2-2. Identify the major organizations and programs for radiation protection.
SUGGESTIONS	After completing the assignment, complete the exercises at the end of this lesson. These exercises will help you to achieve the lesson objectives.

LESSON 2

IONIZING RADIATION

Section I. SOURCES OF IONIZING RADIATION

2-1. GENERAL

a. There are a number of radiation sources that can be found on a military installation.

b. The medical facilities in the Army are among the largest users of radiation. In order to get a good picture of this radiation use, we will consider the kinds of sources to be found.

2-2. NATURAL BACKGROUND RADIATION

a. It is useful to begin any discussion of radiation sources with an understanding of the exposure from natural sources of radiation. You must realize that you are exposed to natural radiation all the time. That is the radiation that comes from space, the radiation that comes from the crust of the earth, and some radioisotopes that we all have inside our bodies. Actually, there is little we can do to reduce this exposure; it is part of living.

b. On the average, we receive approximately 100 mrems/year from natural background radiation. This dose varies depending on where you live. The point here is that we are all exposed to this radiation naturally.

2-3. MAN-MADE RADIATION

a. Used extensively as a diagnostic tool, medical radiation is the single greatest source of man-made radiation exposure to the general population.

(1) <u>Diagnostic x-rays</u>. This source accounts for greater than 90 percent of man's exposure to man-made radiation.

(2) <u>Therapeutic radiation</u>. Therapy facilities are usually found at medical centers only. Therapeutic radiation is produced by using radioisotopes such as Cobalt-60 or by using medical accelerators.

(3) <u>Nuclear medicine</u>. Radioactive materials are used here to view organs of the body for diagnostic information.

b. Industrial Radiation.

(1) Nondestructive testing is a widely used technique in industry. An example of this is the x-ray cabinet used in airports to examine the contents of hand luggage.

(2) Commodities manufacture. Many items, like the lensatic compass, contain radioactive material. Frequently, items that glow in the dark do so because they contain radioactive material.

c. Fallout from atmospheric testing of nuclear weapons also contributes to the radiation we receive.

d. Nuclear power effluents contain some radioactive materials. They are controlled by the Nuclear Regulatory Commission and monitored by the Environmental Protection Agency.

e. Consumer Products. Some consumer products we use daily contain radioisotopes or produce radiation.

(1) Color television sets have an amplifier that produces low energy x-rays. These amplifiers are shielded to protect the consumer.

(2) Some smoke detectors use radioactive material in their operation. This source is well sealed and of very low activity.

2-4. MACHINE-PRODUCED RADIATION SOURCES

a. Although there are a number of different machines designed to produce ionizing radiation, the one most commonly found, particularly in a medical facility, is the x-ray machine. X-ray machines play an important role in medical diagnosis and for this reason they are abundant. A medical center may have as many as 25 to 100 separate x-ray or fluoroscopy units.

b. X-rays, visible light, and gamma rays are all electromagnetic waves because they consist of oscillating electric and magnetic fields. These electromagnetic radiations (EMR) can be arranged on a scale of wavelength, frequency, or energy content. Electromagnetic radiations create wavelike disturbances in space similar to the disturbances created if a stone is dropped into the center of a pool of water. A series of crests and troughs are formed and these constitute an electromagnetic wave. The distance between any two successive crests or troughs is known as the wavelength (λ). In a vacuum, all EMR travel at the speed of light (3×10^{10} centimeters /second). The number of waves (crests) passing a certain point per unit time is referred to as the frequency (ν). The frequency will decrease as the distance between crests (wavelengths) increases.

The following equation shows this relationship.

$$C = \lambda\nu$$

C represents the speed of light and is a constant value. Thus, if frequency is increased, wavelength must decrease. If wavelength is increased, frequency must decrease.

c. When discussing EMR, we refer to the energy (E) of radiation quite often and there is also a relationship between energy and frequency. This relationship can be expressed using Planck's constant (h) as follows:

$$E = h\nu$$

Therefore, if we increase the frequency, the energy increases. Similarly, if we consider wavelength--as the wavelength decreases, the energy increases. Thus, short-wave radiations have higher energies than long-wave radiations.

d. Electromagnetic radiation does not possess any electrical charge; that is to say, it is electrically neutral. X-rays have the same properties as gamma rays; they differ only in origin. Gamma rays are emitted from the nucleus of an unstable atom. X-rays, on the other hand, originate from transitions between electronic energy levels (orbital electron shells).

2-5. X-RAY TUBE

a. All modern x-ray tubes are known as Coolidge tubes (Figure 2-1). In this tube, electrons are supplied by an electrically heated filament. The electrons are accelerated by a high electric field to the anode or target. When an electron strikes the target, part of its energy is degraded to heat (~99%) and the remainder goes toward producing x-rays. As the voltage (potential) is increased, the minimum wavelength radiated decreases, thus producing higher energy x-rays. Very few electrons give up their total energy in a single encounter; therefore, many photons of energy lower than that expected will be produced.

b. The current, which heats the filament, is sometimes referred to as the tube current. As the current is increased, the number of electrons produced is increased. Increasing the number of electrons increases the number of x-rays produced. Therefore, we can say that an increase in the tube current increases the <u>quantity</u> of x-rays. Tube current is expressed in terms of milliamperes (mA).

c. In expressing x-ray energies, it is customary to state the peak kilo-voltage (kVp) used. Increasing the potential, or kVp, increases the acceleration and the energy of the electrons. This results in the production of higher energy x-rays. If electrons are accelerated across a potential of 100 kVp, we can produce x-rays having a maximum energy of 100 kilo electron volts (keV). So we can say that increasing the kVp will increase the quality or hardness of the x-ray. Quality or hardness refers to the penetrating ability of x-rays.

d. The target used in these tubes is usually tungsten or tungsten-molybdenum. This material is used because of certain properties that are desirable for use in the x-ray tube. For instance, with all the heat produced when the electrons strike the target, it is desirable to have a material with a high melting point. Tungsten's melting point is 3,370° C. One other desirable property of tungsten is the fact that it produces a usable characteristic x-ray, which will be discussed later.

e. X-rays are emitted in a broad energy spectrum, ranging from an amount of energy equivalent to the maximum energy of the accelerated electron down to the minimum energy x-ray, which can penetrate the window of the x-ray tube. This spectrum is composed of two components--continuous and characteristic x-rays.

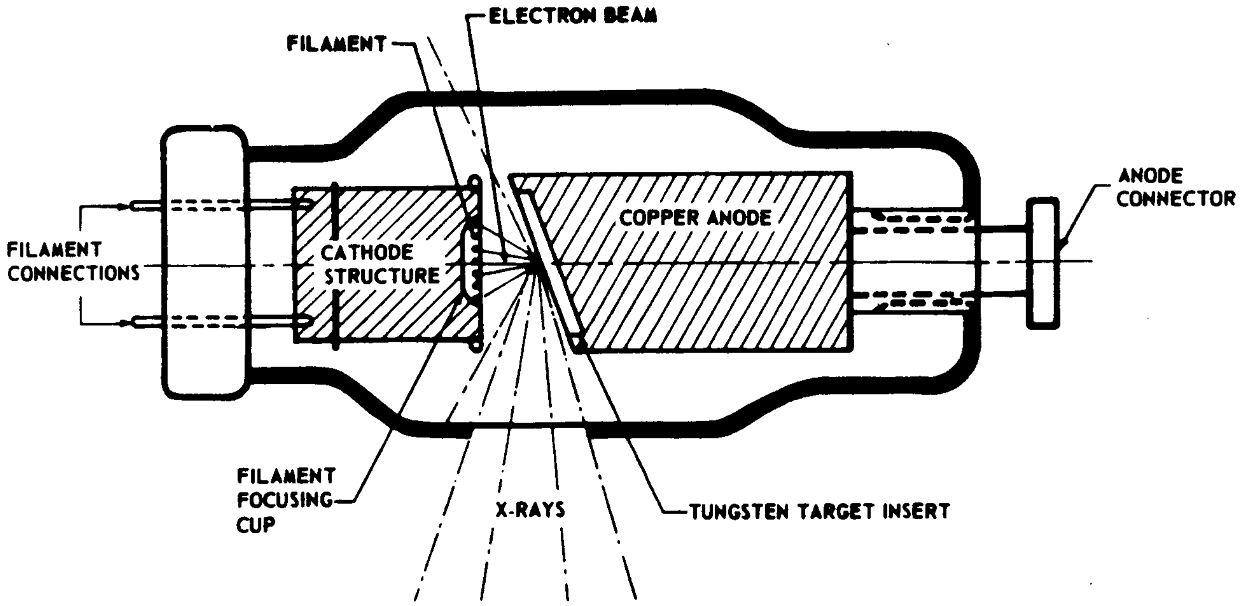


Figure 2-1. X-ray tube.

f. Continuous x-rays exhibit a range of energies because not all of the electrons striking the target lose all their energy. This continuous emission is known as bremsstrahlung, or braking radiation, from the German language. Electromagnetic theory holds that a moving electric charge will radiate energy whenever it is accelerated. The same is true in cases where a charged particle is decelerated.

g. Characteristic x-rays appear as sharp peaks if superimposed over the continuous spectrum (Figure 2-2). The wavelengths of these x-ray emissions are unique characteristics of the element used as the target material. In the x-ray tube, the accelerated electron occasionally ejects one of the orbital electrons from a shell of one of the atoms in the target. This loss of a negative charge gives the atom a net positive charge and thus attracts an electron from an outer shell or a free electron to fill the vacated space. The abrupt change in velocity when the attracted electron reaches its final position results in the emission of an x-ray possessing an energy characteristic of the target material.

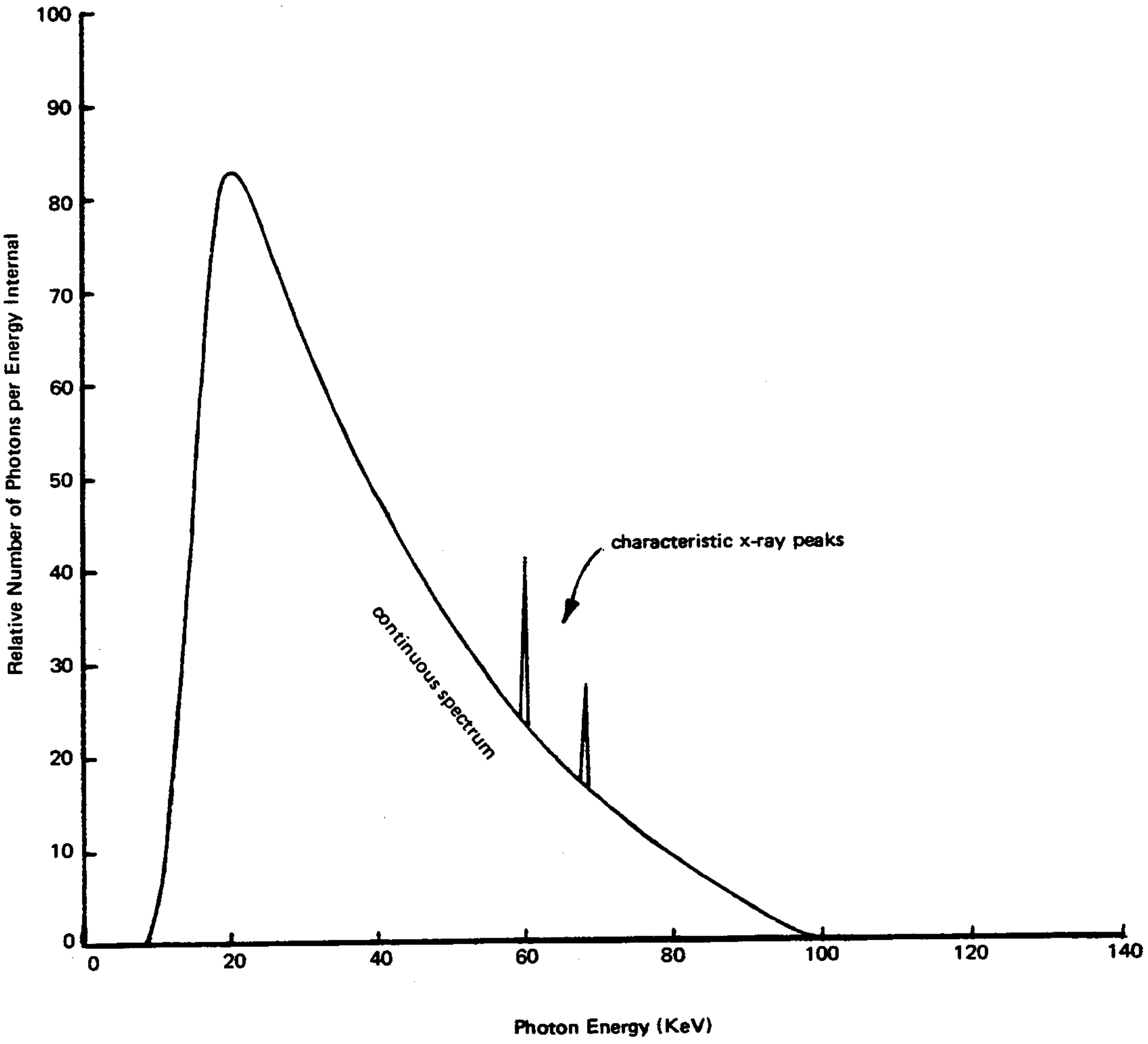


Figure 2-2. X-ray spectrum.

h. The use of x-rays for radiography calls for hard x-rays--that is, x-rays with energy high enough to penetrate the subject and expose the film. The x-ray beam also contains a range of low energy or soft x-rays. These x-rays do not contribute anything to radiography, but they can add to the patient's dose; therefore, we must remove these soft x-rays from the beam. We do this by using a technique known as filtration. By inserting a dense material into the beam, we can remove soft x-rays, thus leaving a beam containing only hard x-rays. X-ray units come with the inherent filtration of their components; however, we can provide additional filtration as may be required. Materials such as aluminum or copper are used for additional filtration.

i. Due to the possibility of scatter radiation in x-ray facilities, it is important to limit the size and shape of the x-ray beam. This is the concept of collimation. Of equal importance here is that only the area of interest in the patient should be exposed to the beam. Collimation is an aid in limiting the patient's dose from x-rays.

j. In considering filtration, we use the concept of half value layers. A half-value layer (HVL) is that thickness of a specified material which, when placed in the path of a given beam of radiation, reduces the exposure rate by one-half. Materials used are lead or aluminum and copper equivalents of lead. This concept is also used when considering the shielding required for x-ray facilities.

Section II. RADIATION PROTECTION PROGRAMS

2-6. EARLY RADIATION PROTECTION MEASURES

a. X-rays and radioactivity were discovered less than 100 years ago. In less than a year, some of their adverse biological effects had been observed and precautions taken to avoid them. The essence of those protective measures are essentially the same today.

(1) Shielding. The idea is to surround the radiation source with a material that will reduce radiation exposure. Sometimes we can put shielding on the individual.

(2) Distance. We can also reduce exposure by increasing the distance from the radiation source.

(3) Time. Limiting time of exposure will limit the actual exposure.

b. The first radiation protection standards, as they were then called, were simply specified thicknesses of lead necessary to reduce a radiation beam to some unspecified level thought to be acceptable. The reason for this rather vague specification was that until 1928, there was no acceptable or agreed upon means for measuring radiation quantitatively.

c. The individuals at risk during this period were the medical doctors and radiologists. They were essentially the only users of x-rays and radioactive material. They could recognize the damage caused to themselves by tremendous overdoses and, until the late 1930s, members of the medical professions were the pioneers who strove hard and actively toward the development of protective procedures.

d. Their concern was accented by one of the great landmarks in radiation history--namely, the development of the Coolidge hot cathode x-ray tube, which could be run for long periods at very large outputs. By 1920, there were substantial numbers of badly injured physicians and, more or less simultaneously, the United States, United

Kingdom, Germany, and other countries began taking active and organized steps to better understand the simple biomedical effects of radiation. They also began to give much greater attention to the physical aspects of radiation protection.

e. It was not unnatural, therefore, that the first protection standard was based on an amount of radiation necessary to cause a clearly recognizable effect--a skin erythema; it was called skin erythema dose. In retrospect, it is believed that in terms of current radiation quantities, the skin erythema dose would have amounted to at least 500 roentgens.

2-7. INTERNATIONAL ACTIONS

a. In 1928, in Stockholm, the first international agreement on radiation quantity was reached. The unit known as the roentgen, by means of which dose could be measured (whether on the patient or in the space which the patient would occupy), was adopted. From this point on, it was possible to evaluate radiation quantitatively.

b. It was in this same year (in fact, at the same meeting) that the International Council of Radiological Protection (ICRP) was established. The original group consisted of six persons. The number six was dictated by the unwieldiness of its sister commission, the International Commission on Radiological Units and Measurements (ICRUM), which had over 30 members at the time. In 1928, the only reasonably well formulated radiation protection recommendations were those put together by a British Protection Committee and these were adopted essentially in their original form. From then until 1950, the form of the international recommendations changed very little, adding mainly more details to fill in the basic skeleton.

c. In the meantime in the United States, there were several protection committees, each attached to one of the medical or radiological societies. Because of this splinterring, they had not dealt effectively with the overall problem. To overcome this, a consolidation of several activities was made in the summer of 1929, resulting in what was then called the Advisory Committee on X-ray and Radium Protection. It is this group, which has been in continuous operation since 1929, that gradually developed, through several organizational and name steps, into what is now known as the National Council on Radiation Protection and Measurements (NCRPM).

d. From the outset, this group aggressively tackled the broad problems of radiation protection and, by 1941, it issued five major reports on the subject, which provided the basic pattern for protection for at least the next decade.

2-8. TOLERANCE DOSE

a. 1934 marked another important dateline. At that time, international agreement was reached on a value for a tolerance dose for radiation workers. The value was given as 0.2 roentgens per day, measured at the surface of the body or an equivalent phantom. This amounted to roughly 60 roentgens per year. In the United

States, there was an established practice of measuring the dose in air and we selected the figure of 0.1 roentgen per day or about 30 roentgens per year. There was no important difference between this and the international value other than the mode of measurement.

b. It might be noted that during the buildup of the Manhattan project and the development of atomic energy, the guiding standard for radiation protection was that set up by the committee and published in its third protection report in early 1936.

c. As in the case of the radiologists clearly injured by x-ray exposure, the 1930s produced another unfortunate series of injuries--this time clearly related to exposure to radioactive products. These were the well-known cases of the radium dial painters, many of whom died as a result of their injuries. Some others still living are showing signs of their injuries. A study of this situation by the advisory committee led to the recommendation for what might be termed a permissible body burden of radium. This was specified as 0.1 microgram (or microcurie) of radium. This value also formed an important baseline for the Manhattan project and atomic energy operations.

d. Following this selection of a permissible body burden for radium, a continuous and painstaking series of studies of the subject has been carried out ever since the 1930s and has involved every person known to have been exposed to radium or its products in any form. All of these studies have shown the almost unbelievable fact that the value selected in 1941 is just as valid today as it was believed to be then. In the whole history of radium exposures, no one has been found with neoplastic injury related to a body burden of less than 0.1 microcurie of radium. Even more astonishing is that beginning at about 0.2 of a microgram and on up, there is increasing evidence of dose-related injury.

2-9. ADVENT OF ATOMIC ENERGY

a. The mid 1940s marked the beginning of a whole new era, namely the development of atomic energy and the production of large quantities of artificial radioactivity. Quite aside from weapons, the normal research in atomic energy produced various kinds and quantities of radiation, presenting problems that in the 1930s were almost unimaginable.

b. There is another factor of importance here. Because of the existence of controlled atomic energy, radioactivity was brought to public attention through its military use during the war. The unprecedented speed in the development of nuclear energy and its probable impact on the future of warfare had a tremendous effect on a completely unprepared public. In fact, one could almost say that until this event, the ordinary citizen had been passively unaware of ionizing radiation except as it may have been encountered by an occasional patient.

2-10. MAXIMUM PERMISSIBLE DOSE

a. In 1946, the remnants of the pre-war advisory committee were called together for the purpose of examining the nature and magnitude of the new radiation protection problems that we were obviously facing. This resulted in an immediate enlargement of the group and the establishment of seven specialized committees to deal with what were then the more clearly recognized problems facing us.

b. Immediately prior to this and as a part of the work carried on during the Manhattan project, a great many radiobiological and biomedical experiments had been carried out--probably more in two or three years than in the preceding two or three decades. This was done primarily to ensure protection of radiation workers and, in the process, the studies essentially upheld the 1936 permissible dose for x and gamma rays and the 1941 permissible body burden for radium.

c. The first major change in our permissible dose standards was introduced in 1949, at which time the basic value for radiation workers was lowered from 0.1 roentgen per day to 0.3 roentgens per week, or the equivalent of about 15 roentgens per year. This was essentially a reduction by a factor of two over the value established in 1936.

d. The introduction of this new value has been the source of a great deal of misinterpretation and misunderstanding. The reason for lowering the level at this time was not based on any new biomedical information that showed that the radiation was more harmful than we had thought before. It was lowered purely and simply in recognition of the fact that there would probably be much larger numbers of people exposed; many different kinds and quantities of radiation involved; and that lowering the permissible levels by a factor of two was technically feasible and would not involve unreasonable costs or restrictions. The decision was made in spite of the fact that there was no new evidence for injury at the previously accepted levels.

e. The NCRPM report putting forth the new permissible dose levels was completed in 1949, but not published until 1954. This was primarily because it was recognized as a very large and important step in radiation protection philosophy and it was felt that the report should be tried out on the scientific and technical public for an extended period before publication. During the five-year period, the 1949 report was issued as important input and basis for much of the discussion in the tri-partite conferences between England, Canada, and the United States in 1949, 1950, and 1953. It also provided the first input to the ICRP beginning in 1950 and at least through its 1956 meetings.

f. Many of the features of the 1949 report are still reflected in our present day philosophy and, in only a few areas, has our increase in knowledge been sufficient to necessitate any appreciable change in our philosophy.

g. The 1949 report was written primarily for the protection of radiation workers both in industry and medicine; but also being more general, it introduced the concept of a lower level for nonoccupational exposure that was set at 1/10 of that for radiation workers. This was in part because of the recognized greater sensitivity of young persons and, even more so, of the fetus. At the same time, it recommended the same level of exposure for the population as a whole. It was further recommended that for the population, the total exposures be averaged over a period of one year. This was in tacit recognition of the fact that, for such low levels of exposure, it probably did not make any difference whether they were received all at once or spread uniformly over a long period of time. Conservatively speaking, this concept is correct.

h. Thus, fetal sensitivity was recognized and special warnings given about exposure of the fetus or of women during childbearing stages. So also were the genetic effects of radiation recognized, but at that time, in a fairly qualitative way. (Herman Muller, who had long been concerned about the possible genetic effects of radiation, was a member of the committee.)

i. The possibility of lifespan-shortening due to radiation exposure was recognized. This was believed to be nonspecific and demonstrable only by statistical means.

j. The report included discussions of the long-term effects of radiation and the mechanisms of recovery and nonrecovery from exposure and it dealt very clearly with the lack of information on the effects of very low doses of radiation. It was the philosophy in this report that has led to the conservative assumptions regarding the linear nonthreshold relationships between dose and effect, which, if interpreted literally and carried to the extreme, could unduly restrict radiation use. It was this situation which led the committee to adopt the general concept that any radiation exposure might involve some risk, however small. It further recognized that the setting of protection standards would have to involve value judgments in comparing the risks and the benefits that would somehow offset them.

k. This risk-benefit or, better, risk-cost concept is one of critical importance to the evaluation of the whole radiation protection problem.

2-11. RADIATION PROTECTION GUIDANCE

Several international and national organizations provide guidance in matters of radiation protection. These organizations are not official agencies of the Government; however, their recommendations are often adopted by Federal, state, and local regulatory bodies.

a. International Commission on Radiological Protection (ICRP). The ICRP (established in 1928) formulates basic radiation protection philosophy. Originally concerned chiefly with medical x-ray protection, the ICRP has expanded its scope to include all forms of ionizing radiation. The ICRP leaves the establishment of detailed technical recommendations to national organizations.

b. International Commission on Radiological Units and Measurements (ICRUM). The ICRUM (formed in 1925) works closely with the ICRP. The ICRUM develops internationally acceptable units of radiation and radioactivity and recommends procedures for their application. Physical data required for the application of radiation units are developed and reported by the ICRUM.

c. International Atomic Energy Agency (IAEA). The IAEA (organized in 1956) is a specialized agency of the United Nations. The objective of the IAEA is to promote peaceful uses of atomic energy. Recipients of IAEA assistance are required to observe health and safety measures prescribed by the Agency.

d. National Council on Radiation Protection and Measurements (NCRPM). Founded in 1929, the NCRPM is a group of scientists and other technical experts concerned with radiation protection. As a national organization, the NCRPM adopts the basic radiation protection philosophy of the ICRP to the needs of the United States. The NCRPM publishes its recommendations in a series of reports. The reports have found wide application in the formulation of Federal radiation protection regulations.

2-12. GENETIC EFFECTS OF RADIATION

a. A gene is a specific sequence of DNA, which specifies the information required for the cell to construct a specific protein. Traits such as hair color, eye color, stature, and handedness are familiar displays of specific genes--some known, some unknown. The alteration of a single base of the DNA sequence can be enough change to affect an observable trait. Familiar examples of diseases involving single gene traits are Tay-Sachs disease, cystic fibrosis, thalassemia, and, as a special example, sickle-cell anemia, involving only a single base change.

b. For single gene defects to be expressed in the first generation, the trait must be dominantly expressed. To date, some 500 to 900 characteristics are thought to be dominantly expressed in the human. Extra digits, dwarfism, and some forms of anemia are examples. Most genes, however, are present in two copies, the proper functioning of either being sufficient for normal needs. In this case, the trait is said to be recessive and several generations are required in order to see the change. Tay-Sachs disease is a well-known example of this category of traits. A third category of gene effects, six-linked recessive mutations, are a special case of the category of recessive traits in that the defect is found on the X chromosome. Females, having two copies of the X chromosome, do not express the single recessive gene; however, males may inherit and express these conditions. Familiar examples are hemophilia and color blindness.

c. An exposure to ionizing radiation creates mutations or gene changes in all of the categories listed above. New mutations or traits are not seen, but rather increases are observed in the known mutable traits. All together, approximately one percent of all humans are born with some identifiable mutation. This one percent is distributed over a thousand or more traits, making the measurement of a small increase in the mutation of any one trait an impossible task.

d. The estimate of the genetic risk of radiation is made extremely difficult by the above situation. Therefore, the Committee on the Biological Effects of Ionizing Radiation (BEIR) estimated the dose required to double the natural incidence of mutations, considering that background radiation was responsible for all known mutations. Radiation, of course, is not responsible for all natural mutations, but this position represents an error in the direction of safety. This "doubling dose" forms the basis for present day risk estimation. The current estimates of the "doubling dose" for the categories of mutations listed above are based upon animal data. These estimates lie between 50 and 250 rems.

2-13. JOINT COMMITTEE ON ATOMIC ENERGY

a. In the meantime, concern over weapons testing continued to increase. The public pressure for "action" was so great that, in 1957, the Joint Committee on Atomic Energy undertook the first of its renowned series of hearings on radiation protection matters. It started initially with problems of fallout, but soon moved into other areas which, except for weaponology, really had more important significance to the population as a whole. These hearings, which began in 1957 and continued at least until 1970, have compiled one of the finest records of the development of radiation protection practice that exists.

b. In part because its earlier philosophy was not completely stated and in part because of misunderstanding of the linear dose-effect nonthreshold concept, as brought out in the joint committee hearings, the NCRPM appointed a special committee in 1959 to examine just this one point. This committee, including radiobiologists, physicists, and physicians, studied the problem intensively for a year. It concluded that while it was not possible to demonstrate or prove any relationship between dose and somatic effects in the low-dose region, it would be prudent and in the conservative direction to assume that there is a single linear dose-effect relationship and that there was no threshold below which no effect would occur. This only confirmed the earlier position of the NCRPM, the ICRUM, the National Academy of Sciences, and others.

c. However, the report and its discussion made it very clear that these were statements of assumption and not statements of established fact. It is the lack of distinction between the two that has caused no end of misinterpretation and trouble during the past decade.

d. The NCRPM and other experienced groups have restudied the question intensively over the last decade and still no basis for changing the position has been found. On the other hand, it is becoming more and more evident that there are important deviations from the assumed linear relationships between dose and effect, depending upon the rate at which the dose is delivered. There is even the possibility that there may be some thresholds of a practical, if not absolute, nature. All of these things are in the direction of indicating that in the low-dose region, the radiation hazard is less than we thought it to be at the time that we made our last major revision of protection standards in 1957.

2-14. FEDERAL RADIATION COUNCIL

a. Let us turn to the question of radiation protection standards of the Government. Largely because of the hearings by the Joint Committee, the Federal Government in 1959 suddenly came to the realization that for the past two or three decades, any radiation protection standards that it had used had been derived from an organization that was nongovernmental and over which it had no authority--an organization which, in itself, had no official standing other than the technical competence of its work. It was indeed the case that these descriptions applied to the NCRPM.

b. This led to extensive discussions between representatives from the US Bureau of the Budget; the President's Science Advisor, and numerous others. There could be no disagreeing with the fact that if the Government wanted to take some official responsibility for radiation protection, it almost certainly had to have some kind of an organization of its own upon which to lean. The first thought was the possibility of having an interagency committee. There were questions as to whether it might be put in any one agency, but either the agency was basically unsuited or it had too strong a built-in bias of one kind or another. As a compromise, the Federal Radiation Council (FRC) was established and was directed to report to the President of the United States. The FRC has now been officially dissolved and its responsibilities have been assumed by the Environmental Protection Agency.

c. After an extended study made at the outset of its existence, the FRC adopted standards for radiation workers. Although expressed in slightly different phraseology, they were, in fact, the same standards proposed by the NCRPM. But, coming from the FRC, they could be used officially in any radiation areas subject to government control.

d. Another important standard the FRC adopted was for uranium miners. This standard was derived more directly from the American Standards Association, which had taken on this problem some years ago. The recommendations, in turn, related back to the basic radium protection standards that were proposed by the NCRPM about 1940.

2-15. FURTHER STUDIES

In the meantime, the Joint Committee on Atomic Energy had been continuing its well-planned, well-balanced public hearings. The areas of concern included Federal-state relations in the matters of radiation protection regulation, fallout radiation, workmen's compensation, radiation protection standards, protection of uranium miners, and so on. Most recently, the committee has been showing a proper and considerable concern for the problems of radiation in the environment, especially as this may be influenced by the expansion of our nuclear power program. It began considering problems of waste disposal some years ago; this would, of course, include effluents from power reactors. Special reference should be made to the Joint Committee hearings in 1960 and 1962 on Radiation Protection Criteria. It is in this set of hearings that you will find a complete collection of background information on the whole philosophy of radiation protection and radiation protection organization.

2-16. NATIONAL COUNCIL ON RADIATION PROTECTION AND MEASUREMENTS

a. Throughout the Joint Committee hearings, continued attention was drawn to the protection standards and work of the NCRPM. With the establishment of the Federal Radiation Council in 1959, there was a fear by some people that this would preempt the only nationally recognized radiation protection body that was not under Government control. Because of this, Representative Holifield, then Chairman of the Joint Committee on Atomic Energy, introduced a bill to give the NCRPM a Federal charter that would recognize its capability in the field and help to set it clearly apart from the Government. It is, in fact, something that the Council is extremely proud of, even though it does not vest it in any official position, special privilege, or special authority. Neither does it make the work of the organization, in any way, subject to Government control.

b. At the present time, the NCRPM is made up of 65 elected members, of which nine are further elected to act as a Board of Directors. In addition, it has over 250 members at any one time who participate in the work of its 50 scientific committees, covering just about every aspect of radiation protection and measurement. The organization now has its own secretariat and offices and is funded from a variety of sources, including some Government contracts, foundation support, and annual contributions from some 25 scientific organizations in this country.

c. Studies, usually aimed toward a published report, are generated mainly by recommendations by the members and they, in turn, try to be responsive to current needs. In a few instances, a specific study has been undertaken because of an outside request.

d. Reports prepared by standing or ad hoc committees are examined first by "critical reviewers," NCRPM members most knowledgeable in the area concerned. They are then submitted to the entire elected council for review and approval or rejection.

e. There are many and varied problems centered about the control of radiation exposure of workers or the general public. In 1953, in anticipation of these problems, the NCRPM began a study of radiation control by legislative and regulatory means and a report on the subject was published in 1955. It has formed the main pattern for Nuclear Regulatory Commission, state, and local regulations ever since.

2-17. DEPARTMENT OF ARMY RADIATION PROTECTION PROGRAM

Army programs are largely based on the recommendations and guidance of various advisory councils, Federal agencies, and Federal law. There are many regulations, technical bulletins, field manuals, technical manuals, and supply bulletins that deal with radiation protection. Some of the most frequently used in the AMEDD are discussed here.

a. AR 40-5, Preventive Medicine. This regulation has an entire section of Chapter 9 devoted to radiological hygiene. This regulation establishes responsibilities; provides guidelines for radiation workers; and details the film badge program, the records required, and actions to take in cases of overexposure.

b. AR 40-14, Occupational Ionizing Radiation Personnel Dosimetry. This document prescribes procedures for controlling and recording radiation exposure. Guidelines are based on the recommendations of the former Federal Radiation Council, whose functions are now carried out by the Environmental Protection Agency.

c. TB MED 525, Control of Hazards to Health from Ionizing Radiation Used by the Army Medical Department. This regulation implements the requirements of the Nuclear Regulatory Commission as they apply to radioactive materials controlled by the Nuclear Regulatory Commission.

d. AR 385-11, Ionizing Radiation Protection. This regulation applies to all use of radiation in the military except that used for medical purposes.

f. TB MED 521, Management and Control of Diagnostic X-Ray, Therapeutic X-Ray, and Gamma-Beam Equipment. This publication provides guidance to persons who use diagnostic/therapeutic x or gamma radiation equipment. It contains Federal performance standards and also provides information for radiation safety personnel.

As mentioned earlier, there are many other documents involved in radiation protection. Which ones apply depend on the type of radiation source and how it is to be used.

Continue with Exercises

EXERCISES, LESSON 2

REQUIREMENT. The following exercises are to be answered by marking the lettered response that best answers the question, by completing the incomplete statement, or by writing the answer in the space provided at the end of the question. After you have completed all the exercises, turn to "SOLUTIONS TO EXERCISES" at the end of the lesson and check your answers.

1. The greatest use of radiation sources is found in:

    a. Industry.

    b. Medicine.

    c. Agriculture.

    d. Research.

2. Which of the following is a source of natural background radiation?

    a. X-ray machines.

    b. Radiation from space.

    c. Nuclear medicine.

    d. Nuclear reactors.

3. The most common machine for producing radiation is the:

    a. Betatron.

    b. Linear accelerator.

    c. X-ray machine.

    d. Cyclotron.

4. As the frequency of an electromagnetic wave increases, the wavelength:

   a. Increases linearly.

   b. Remains unchanged.

   c. Increases geometrically.

   d. Decreases.

5. The difference between an x-ray and a gamma ray is the:

   a. Energy.

   b. Origin.

   c. Wavelength.

   d. Frequency.

6. Varying the current (mA) of an x-ray tube will result in a variation of:

   a. X-ray quantity.

   b. X-ray quality.

   c. X-ray energy.

   d. X-ray wavelength.

7. The most suitable target material presently used in x-ray tubes is:

   a. Copper.

   b. Lead.

   c. Tungsten.

   d. Platinum.

8. The characteristic x-ray is produced as a result of the impinging electron:

   a. Slowing down near the target nucleus.

   b. Knocking an electron from orbit in the target atom.

   c. Striking the target nucleus.

   d. Accelerating near the target nucleus.

9. The x-ray beam may be "hardened" by using:

   a. Filtration.

   b. Higher current.

   c. Different target.

   d. Larger target.

10. The amount of material required to reduce the exposure rate from an x-ray beam by one-half is the:

    a. Doubling layer.

    b. Attenuation layer.

    c. Half-value layer.

    d. Half layer.

11. The first protection standard was based on:

    a. An amount of radiation necessary to cause nausea.

    b. An amount of radiation necessary to cause a skin erythema.

    c. An amount of radiation necessary to darken a photographic film.

    d. An amount of radiation necessary to saturate an ion chamber.

12. The first radiation unit to be described and agreed upon internationally was the:

    a. Rem.

    b. Rep.

    c. Rad.

    d. Roentgen.

13. The Federal Radiation Council has been officially dissolved and its responsibilities have been assumed by:

    a. The Atomic Energy Commission.

    b. The Environmental Protection Agency.

    c. The Bureau of Radiological Health.

    d. The US Department of Health, Education, and Welfare.

14. One organization, the ______________has been given a Federal charter that recognizes its capabilities and contributions to the field of radiation health.

    a. International Atomic Energy Agency (IAEA).

    b. National Council on Radiation Protection and Measurements (NCRPM).

    c. International Commission on Radiological Protection (ICRP).

    d. International Commission on Radiological Units and Measurements (ICRUM).

15. What is the reference that implements NRC procedures for using radioactive materials for medical purposes?

a. AR 40-14.

b. TB MED 521.

c. AR 385-11.

d. TB MED 525.

Check Your Answers on Next Page

SOLUTIONS TO EXERCISES, LESSON 2

1. b. Medicine. (para 2-1b)

2. b. Radiation from space. (para 2-2a)

3. c. X-ray machine. (para 2-4a)

4. d. Decreases. (para 2-4b)

5. b. Origin. (para 2-4d)

6. a. X-ray quantity. (para 2-5b)

7. c. Tungsten. (para 2-5d)

8. b. Knocking an electron from orbit in the target atom. (para 2-5g)

9. a. Filtration. (para 2-5h)

10. c. Half-value layer. (para 2-5j)

11. b. An amount of radiation necessary to cause a skin erythema. (para 2-6e)

12. d. Roentgen. (para 2-7a)

13. b. The Environmental Protection Agency. (para 2-14b)

14. b. National Council on Radiation Protection and Measurements (NCRPM). (para 2-16a)

15. d. TB MED 525. (para 2-17c)

End of Lesson 2

LESSON ASSIGNMENT

LESSON 3	Nonionizing Radiation.
LESSON ASSIGNMENT	Paragraphs 3-1 through 3-14.
LESSON OBJECTIVES	After completing this lesson, you should be able to: 3-1 Identify the most commonly encountered sources of nonionizing radiation hazards. 3-2 Identify the basic principles of nonionizing radiation and the units of measurement used in discussing laser and microwave radiation. 3-3. Identify the physiological effects of and the methods of protection against nonionizing radiation.
SUGGESTIONS	After completing the assignment, complete the exercises at the end of this lesson. These exercises will help you to achieve the lesson objectives.

LESSON 3

NONIONIZING RADIATION

Section I. MICROWAVE RADIATION

3-1. GENERAL

a. Microwave/radio frequency radiation, a form of nonionizing radiation, has been with us for many years now. We are all exposed to this type of radiation every day without giving it much thought. However, there is increasing concern about the exposure to radiation in the microwave region.

b. When discussing the electromagnetic spectrum and the radiations thereof, we use some descriptive terms to define the radiation. These terms are frequency and wavelength.

c. Frequency (υ) defines the number of waves that pass a given point in one second. The old term for this was cycles per second. It was replaced by the Hertz (Hz).

$$1 \text{ Hz} = 1 \text{ cycle/second}$$

d. Wavelength (λ) is a measure of distance and is expressed in meters, centimeters, etc. An old term that is used infrequently is the angstrom unit.

$$1 \text{ Å} = 10^{-10} \text{ meter}$$

e. In the case of microwaves, frequency is the descriptive term commonly used. Microwave frequencies range from 100 Megahertz (MHz) to 300,000 MHz.

3-2. MICROWAVE RANGE

a. The microwave band (frequency range) includes frequencies normally used by radar and communication facilities.

b. Other subregions in the microwave band include the following:

(1) AM broadcast (535 to 1,605 MHz)

(2) Medical diathermy (271.2 to 406.8 MHz)

(3) Microwave ovens (915 and 2,450 MHz)

3-3. MICROWAVE GENERATION

a. There are many pieces of equipment available today that are capable of producing microwave radiation. To produce microwave radiation, specially designed electron tubes must be employed. Magnetron tubes and travelling waves may be used to produce lower frequency microwaves, such as those used for heat production. Microwave radiation higher frequencies, such as radar, may be produced by a Klystron tube.

b. In all cases, the radiation field of a microwave generator is made up of an electric field (E field) and a magnetic field (H field), which vary together in intensity but whose directions are at right angles to one another in space, and both of which are at right angles to the antennae from which they were emitted (Figure 3-1). Each field supports the other and neither can exist by itself without setting up the other. Together they are termed the "electromagnetic field."

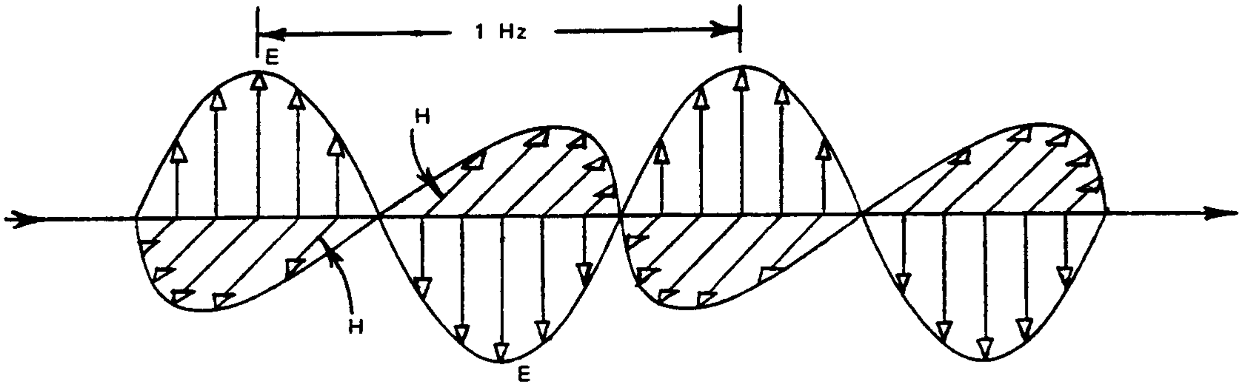


Figure 3-1. Relationship of E and H fields.

3-4. USES

The major stumbling blocks to the large scale industrial, military, and home use of microwave radiation have been high cost, size of equipment, and maintenance. These three problems are of particular interest in any attempt to provide microwave systems for home use. The recent advent of solid-state microwave equipment, with its reduction in size, and the latest technological advances which have simplified the operation and maintenance of microwave systems, have made possible many uses for microwaves which were not feasible just a few years ago. The primary uses of microwave radiation can be subdivided into two distinct categories. The first category utilizes the heating effect of microwave radiation and involves only microwave generators. The second category utilizes microwave radiation as a means of conveying information, such as radar and communications systems, and therefore requires a generator (known as a "transmitter") and some type of receiver.

3-5. BIOLOGICAL EFFECTS

a. Experimental work indicates that the average power output of the microwave generator is more closely related to the biological effect than is the peak power output of the generator. Therefore, at present, the "dosage unit" is described in terms of watts per square centimeter (W/cm^2), referring to the average power density per unit cross-sectional area of the radiation beam.

b. The biological effects associated with the propagation of microwave energy are as follows.

(1) Thermal effects. The electromagnetic radiation of microwaves does not possess sufficient energy to produce ionization; however, it can cause excitation of atoms. Thus, when the radiation is absorbed in matter, there is a rise in temperature of the object or organism. The depth of heating is frequency dependent. For example:

(a) Frequencies less than 1,000 MHz produce heat in deep tissues.

(b) Frequencies greater than 3,000 MHz heat superficial (skin) tissue.

(c) Between 1,000 and 3,000 MHz combinations of deep and superficial heating occur. The critical organs affected thermally are the eye and the testicle. The eye is susceptible to thermal damage, since it has an inefficient vascular system to circulate blood and exchange heat to the surrounding tissues. The accumulation of heat in the lens of the eye can result in the coagulation of lens protein and an irreversible opacity can be formed. The threshold for this effect has not been determined. It is for this reason that the eye is considered the most critical organ. The testicle is extremely sensitive to heat because of its physical location relative to body surfaces and its poor ability to dissipate heat by means of its vascular system. The effects of whole body increase in temperature are the same as those experienced with a naturally occurring fever. These whole body thermal effects are reversed by removing the individual from the microwave field.

(2) Athermal effects. Various events can be demonstrated experimentally, namely, pearl chain formations or lining up of particles of matter, inactivation of certain enzymes, and change in root tips of garlic. However, to date none of these have clinical application to man. Following are a few examples.

(a) Unexplained response of man to radar. Epigastric distress and/or nausea may occasionally occur at levels as low as five to 10 mw/cm^2 and are most commonly associated with the frequency range from 8,000 to 12,000 MHz.

(b) Auditory response. Certain people can hear a buzz when exposed to microwave radiation. The sensation of sound is probably not the microwave frequency but the pulse repetition frequency.

(c) Sensory nerve response. A feeling of warmth will be experienced when the heating effect occurs on the skin. This phenomenon is most commonly associated with the frequency range 8,000 MHz to 26,000 MHz.

c. Recent information on research done by the Soviet Union and some Warsaw Pact countries has indicated a need for further research in the bioeffects of microwave radiation.

3-6. STANDARDS

a. The necessity for exposure controls has been long recognized by the military. The military has had exposure standards in effect for a number of years.

b. With the enactment of Public Law 90-602, Radiation Control for Health and Safety Act of 1968, effective 6 October 1971, a performance standard was imposed on all microwave ovens used in homes, restaurants, food vending, etc.

c. It is important to recognize the difference between an exposure standard and a performance standard. The performance standard is placed on the equipment, restricting the hazard that can be experienced from a piece of equipment. The burden, therefore, is on the manufacturer. The exposure standard, on the other hand, limits the amount of exposure to a particular hazard an individual should experience, thereby placing the responsibility on the individual or operator, but not the manufacturer.

3-7. EXPOSURE STANDARDS

a. Exposure standards apply to all microwave sources not covered by Public Law 90-602. Past research indicated that a power density of 0.2 watts per square centimeter (W/cm^2) was required to produce sufficient damage. The instrumentation for this research was questionable and it was decided that the power density used in the research could have been as low as 0.1 W/cm^2**.** The presence of assorted minute quantities of radiation from incidental sources at various frequencies was taken into consideration and a safety factor of 10 is settled upon. Thus, the 1958 Tri-Service Committee established the limit of 0.01 W/cm^2 average power density for either continuous or intermittent exposures at all frequencies. However, this limit does not consider the following factors:

(1) Time of exposure.

(2) Frequency of radiation.

(3) Multi-frequency exposure.

(4) Air currents.

(5) Sensitivity of organ.

(6) Reflected radiation.

(7) Ambient temperature.

This limit of 0.01 W/cm^2 was established based on thermal effects of microwave radiation. The current official Army standards (adopted in 1965) permit exposure to power densities greater than 0.01 W/cm^2 but not greater than 0.01 W/cm^2 for periods of time in accordance with the formula:

$$T = \frac{60}{w}$$

Where: T = Stay time in minutes
w = Power density in mW/cm^2

It is not considered feasible to control personnel stay time for periods of less than two minutes; therefore, it was recommended that the formula not be applied to power densities greater than 50 mW/cm^2. A detailed discussion may be found in TB MED 523, Control of Hazards to Health from Microwave Radiation and Radiofrequency and Ultrasound Radiation.

b. To determine whether or not the exposure standards are being complied with, the power density of the microwave field must be measured. Instrumentation is available to the field, but in most cases these measurements will be made during the periodic survey performed by the Laser Microwave Division of the US Army Environmental Hygiene Agency (USAEHA).

3-8. PERFORMANCE STANDARDS

a. The performance standard for microwave ovens promulgated by Public Law 90-602 says that "power density of the microwave radiation emitted by a microwave oven shall not exceed one milliwatt per square centimeter at any point five centimeters or more from the external surface of the oven, measured prior to acquisition by a purchaser, and thereafter, five milliwatts per square centimeter at any point five centimeters from the external surface of the oven."

b. The establishment of this standard was based on the increased exposure of the general public to microwave cooking sources.

c. The absence of data to substantiate or refute a threshold effect for eye damage from microwave energy necessitates the protection of the public to the limits of our technical ability.

3-9. ARMY PROGRAM

a. Department of Defense Instruction 6055.11, Protection of DOD Personnel from Exposure to Radio Frequency Radiation and Military Exempt Lasers. The intent of this instruction is to limit personnel RF exposure to permissible exposure limits specified in the Institute of Electrical and Electronic Engineers (IEEE)/American National Standards Institute (ANSI) C95.1 "Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz".

b. Memorandum, U.S. Army Health Professional Support Agency, SGPS-PSP, 30 October 1991, subject: Microwave Oven Radiation Control Program.

(1) This memorandum revokes the initial and periodic comprehensive survey requirement for new or in-service microwave ovens. The visual inspections combined with radio frequency leakage measurements were performed by trained 91S personnel. Training to perform these surveys was provided to 91S personnel at the Academy of Health Sciences. As a result of a review and evaluation of the entire Microwave Oven Radiation Protection Program, comprehensive surveys of microwave ovens are no longer required. Additional requirements to (1) maintain records of comprehensive surveys, (2) maintain a comprehensive inventory of microwave ovens, and (3) post radio frequency radiation warning signs for cardiac pacemaker users were also revoked.

(2) Comprehensive surveys shall be performed on microwave ovens offered for resale to the public. Use USAEHA TG No. 153, April 1987, Guidelines for Controlling Potential Health Hazards from Radio Frequency Radiation for guidance.

(3) Units that have qualified individuals and the necessary equipment are encouraged to perform surveys of microwave ovens upon request. Units should not purchase equipment to perform these surveys. Those without the capability to perform requested surveys may request assistance from: Commander, USACHPPM, ATTN: MCHB-TS-ORF, 5158 Blackhawk Road, Aberdeen Proving Ground, MD 21010-5403.

Section II. LASER RADIATION

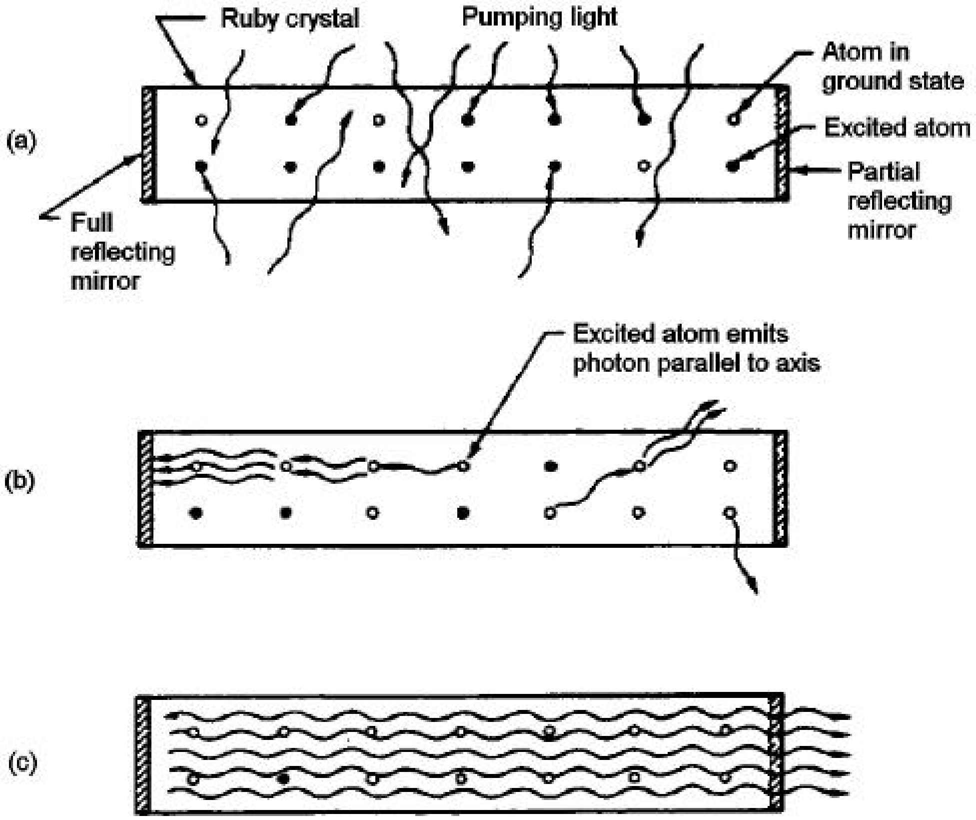
3-10. GENERAL

Laser light differs from ordinary light in that it is much more intense, directional, monochromatic, and coherent (that is, the same color and in phase). The light emitted by an ordinary source--such as a candle or an incandescent lamp--consists of uncoordinated waves of different length, that is, it is incoherent and more or less white. The waves of laser light are coordinated in space and time and have nearly the same length. This color purity and intensity of the laser light result from the fact that excited atoms are stimulated to radiate excess energy cooperatively.

3-11. LASER OPERATION AND USES

a. How does the light amplification by the stimulated emission of radiation (laser) work? We must obtain a lasing material, an energy source to excite the atoms, a fully reflecting mirror, and a partially reflecting mirror before we can put our laser into operation.

b. Looking at the figure below (Figure 3-2), we show a laser crystal containing many atoms in a ground state (white dots) and a few in the excited state (black dots). The pumping light, or energy source (wavy arrows in A), raises most of the atoms to the excited state, creating a population inversion--that is, more atoms in the excited state than the ground state.



A - Pumping light raises many atoms to excited state.

B - Lasing begins when a photon is spontaneously emitted along the axis of the crystal. This stimulates other atoms in its path to emit.

C - The resulting wave is reflected back and forth many times between the ends of the crystal and builds in intensity until finally it flashes out of the partially silvered end.

Figure 3-2. Sequence of operations in a solid crystal laser.

c. Lasing begins when an excited atom spontaneously emits a photon parallel to the axis of the crystal (B). (Photons emitted in other directions merely pass out of the crystal.) The photon stimulates another atom in its path to contribute a second photon, in step, and in the same direction. This process continues as the photons are reflected back and forth between the ends of the crystal. (We might think of lone soldiers falling into step with a column of marching men.) The beam builds up until, when amplification is great enough (C), it flashes out through the partially silvered mirror at the right--a narrow, parallel, concentrated, coherent beam of light, ready for many applications.

d. Applications that might be encountered in military use are target acquisition, range finding, and research. Lasers are also found in many locations in the hospital.

e. Laser equipment available today will operate in one of the following configurations.

(1) Continuous wave (CW). A continuous beam of light is produced.

(2) Pulsed laser. A class of laser characterized by operation in a pulsed mode, i.e., emission occurs in one or more flashes of short duration (pulse length).

(3) Q-switched laser (also known as Q-spoiled). A pulsed laser capable of extremely high peak powers for very short durations (typical pulse length of 5 to 50 billionths of a second).

f. The output of a laser is measured in either watts or joules, depending on the operating configuration. Units of power are used primarily to rate CW lasers since the energy delivered per unit time remains relatively constant (output measured in watts). However, pulsed lasers have a peak power significantly greater than their average power and produce effects, which may best be categorized by energy output per pulse. The output of low power CW lasers is usually expressed in milliwatts (mW = 1/1,000 watts, pulsed lasers in kilowatts (kW = 1,000 watts), and Q-switched pulsed lasers in megawatts (MW = million watts) or gigawatts (GW = billion watts). Pulsed energy output is usually expressed in joules. The joule is a unit of energy used in describing a single pulsed output of a laser. It is equal to one watt-second or 0.239 calories.

3-12. BIOLOGICAL EFFECTS

a. Laser radiation should not be confused with ionizing radiation (such as x and gamma rays). The biologic effects of the laser beam are essentially those of visible, ultraviolet, or infrared energy upon tissues. However, the intensity of the light is of magnitudes that could previously be approached only by the sun, nuclear weapons, burning magnesium, or arc lights. This is one of the important properties that make lasers potentially hazardous.

b. A laser beam striking tissue will be reflected, transmitted, and/or absorbed. The degree to which each of these reactions occurs depends upon various properties of the tissue involved. Absorption is selective, as in the case of visible light; darker material such as melanin or other pigmented tissue absorbs more energy.

c. Skin effects may vary from mild reddening (erythema) to blistering and charring, depending upon the amount of energy transferred.

d. The effect upon the retina may be a temporary reaction without residual pathologic changes or it may be more severe with permanent pathologic changes, which may heal by fibrosis. The mildest observable reaction may be simple reddening--as the energy is increased, lesions may occur which progress in severity from edema to charring with hemorrhage and additional tissue reaction around the lesion. Very high energies will cause gases to form, which may disrupt the retina and may alter the physical structure of the eye. Portions of the eye other than the retina may be selectively injured, depending upon the region where the greatest absorption of the specific wavelength of the laser energy occurs and the relative sensitivity of tissue affected.

e. Infrared light produces heat with its characteristic effect on tissue and the lens of the eye. Some residual energy may reach the retina. Ultraviolet light can produce symptoms similar to those observed in arc welders. It may cause severe acute inflammation of conjunctiva and usually does not reach the retina. Light in the far infrared, such as the 10 micron wavelength from the carbon dioxide lasers, is absorbed by the cornea and conjunctiva and may cause severe pain and destructive effects (see Figure 3-3).

3-13. CLASSES OF LASER

Because of the biological hazard, lasers are divided into classes. Hazard controls vary depending on the type of laser being used and the manner of its use. Most control measures depend upon the laser's classification.

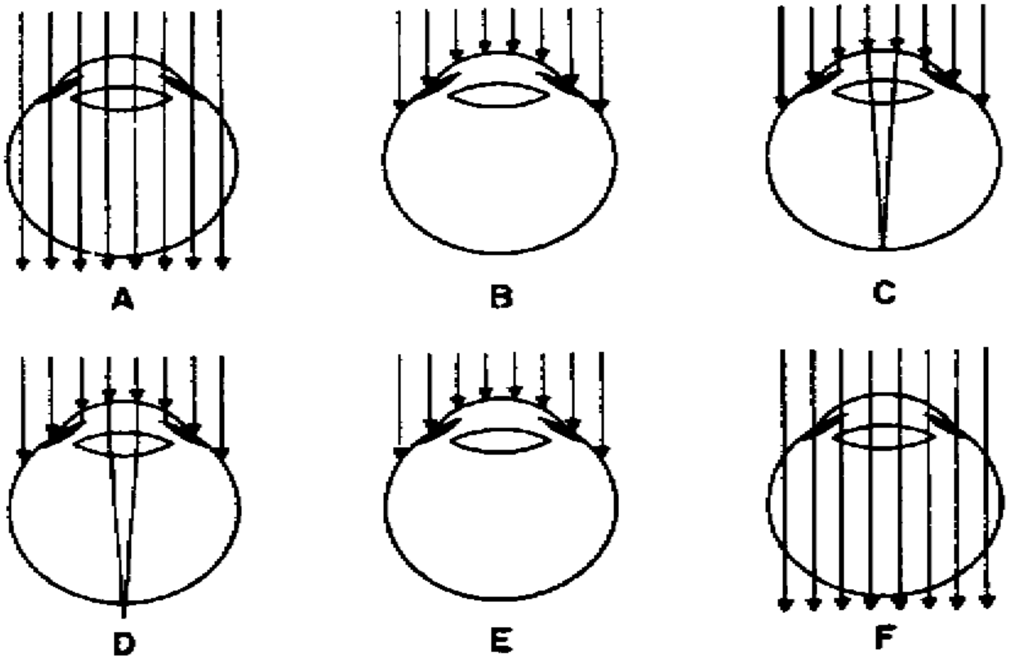
a. In general, a Class I Exempt Laser Device is one that is considered to be incapable of producing damaging radiation levels and is, therefore, exempt from any control measures or other forms of surveillance.

b. A Class II Low Power Laser Device may be viewed directly, but must have a cautionary label warning against continuous intrabeam viewing affixed to the device.

c. A Class III Medium Power Laser Device requires control measures that shall prevent viewing of the direct beam.

d. A Class IV Laser or High Power Laser System requires the use of controls, which shall prevent exposure of the eye and skin to the direct and diffusely reflected beam.

e. A Class V Laser is either a Class II, Class III, or Class IV laser contained in a protective housing and operated in such manner as to be incapable of emitting hazardous radiation from the enclosure. A stringent control system shall be installed and maintained from any laser system to qualify for this classification.



A - Most higher energy x-rays and gamma rays pass completely through the eye.
B - For short ultraviolet, absorption occurs principally at the cornea.
C - Long ultraviolet and visible light is refracted at the cornea and lens and absorbed at the retina.
D - Near infrared energy is absorbed in the ocular media and at the retina.
E - Far infrared absorption is localized at the cornea.
F - Microwave radiation is transmitted through the eye, although a large percentage may be absorbed.

Figure 3-3. Absorption properties of the eye for electromagnetic radiation.

3-14. LASER PROTECTION

a. Lasers rated class II and above are potentially hazardous. The hazard to the eye, the most sensitive organ to visible laser radiation, can be reduced by the use of protective goggles designed to filter out the light frequencies emitted by the laser of interest.

b. There are general safety rules that should be followed in all laser installations:

(1) Contain the beam.

(2) Avoid reflective surfaces.

(3) Control access.

(4) Wear eye protection.

(5) Never look into the beam.

(6) Conduct periodic examinations.

(7) Maintain a safe distance.

If operated within these guidelines, the laser can be used safely.

c. Lasers are rapidly coming into the Army inventory and it is necessary for preventive medicine personnel to have a thorough knowledge of the hazards involved and the means of protection against these hazards.

Continue with Exercises

EXERCISES, LESSON 3

REQUIREMENT. The following exercises are to be answered by marking the lettered response that best answers the question, by completing the incomplete statement, or by writing the answer in the space provided at the end of the question. After you have completed all the exercises, turn to "SOLUTIONS TO EXERCISES" at the end of the lesson and check your answers.

1. What is the unit used to describe microwave radiation frequency?

    a. CPS.

    b. Joule.

    c. Hertz.

    d. Hectare.

2. Microwave applies to an arbitrary range of frequencies from:

    a. 100 Hz to 100,000 Hz.

    b. 300 Hz to 300,000 Hz.

    c. 100 MHz to 300,000 MHz.

    d. 300 Hz to 300,000 MHz.

3. Which of the following is outside of the microwave band?

    a. Ultraviolet light.

    b. AM broadcast.

    c. Radar.

    d. Diathermy.

4. High frequency microwaves are produced by which of the following type tube?

   a. Magnetron tube.

   b. Traveling wave.

   c. TV tube.

   d. Klystron tube.

5. A major use for microwave systems is:

   a. Cooling.

   b. Lighting.

   c. Photography.

   d. Communication.

6. From which of the following microwave frequencies would you expect deep tissue heating?

   a. 400 MHz.

   b. 1,465 MHz.

   c. 2,450 MHz.

   d. 10,000 MHz.

7. Performance standards applied to microwave cooking ovens place responsibility for compliance on the:

   a. Federal Government.

   b. Manufacturer.

   c. Owner.

   d. State government.

8. An exposure standard restricts the amount of radiation that:

   a. A piece of equipment can emit.

   b. May occur at an individual location.

   c. A piece of equipment can emit in an hour.

   d. An individual may experience.

9. The power density of microwave radiation source is measured in:

   a. Joules.

   b. Watts.

   c. Watts/CM2.

   d. Joules/CM2-

10. The exposure standard established by the Tri-Service Committee considers which of the following factors?

    a. Thermal effects.

    b. Ambient temperature.

    c. Frequency of radiation.

    d. Reflected radiation.

11. A population inversion of excited atoms in a laser medium is accomplished by:

    a. Adding energy to system.

    b. Proper use of mirrors.

    c. Spontaneous emission.

    d. Stimulated emission.

12. Which of the following classes of lasers presents the greatest hazard?

    a. Class II.

    b. Class III.

    c. Class IV.

    d. Class V.

13. The organ of the human body <u>most</u> sensitive to laser emissions is the:

    a. Skin.

    b. Eye.

    c. Testicle.

    d. Brain.

14. There are three basic modes of laser operation, CW, pulsed, Q-switched. Pulsed laser energy is usually measured in:

    a. Watts.

    b. Volts.

    c. Neutrons.

    d. Joules.

Check Your Answers on Next Page

SOLUTIONS TO EXERCISES, LESSON 3

1. c. Hertz. (para 3-1c)
2. c. 100 MHz to 300,000 Hz. (para 3-1e)
3. a. Ultraviolet light. (para 3-2b)
4. d. Klystron tube. (para 3-3a)
5. d. Communication. (para 3-4)
6. a. 400 MHz. (para 3-2b)
7. b. Manufacturer. (para 3-6c)
8. d. An individual may experience. (para 3-6c)
9. c. Watts/cm2. (para 3-5a)
10. a. Thermal effects. (para 3-7a)
11. a. Adding energy to system. (para 3-11b)
12. c. Class IV. (para 3-13d)
13. b. Eye. (paras 3-12d, e)
14. d. Joules. (para 3-11f)

End of Lesson 3

GLOSSARY

Angstrom Unit	A unit of measurement for expressing wavelength. 1 Å = 1/10,000th microns (µ) or 1/100,000,000th centimeters.
Athermal	The absence of heat.
Brachytherapy	A method of radiation therapy in which an encapsulated source is utilized to deliver gamma or beta radiation at a distance up to a few centimeters either by surface, intracavitary, or interstitial application.
Curie (Ci)	The basic unit to describe the intensity of radioactivity in a sample of material. The curie is equal to 37 billion disintegrations per second.
Electromagnetic Radiation	Radiation consisting of associated and interacting electric and magnetic waves that travel at the speed of light. Examples: light, radio waves, gamma rays, and x-rays.
Electron	An elementary particle with a unit negative electrical charge and a mass 1/1837 that of the proton. Electrons surround the positively charged nucleus and determine the chemical properties of the atom.
Electron Volt (ev or eV)	The amount of energy gained by an electron when it is accelerated through an electric potential difference of one volt. It is equivalent to 1.603×10^{-12} erg.
Erg	A small unit of energy which can exert a force of one dyne (gm-cm/sec^2) through a distance of one centimeter.
Frequency	The number of cycles per second of an alternating electric current.
Ionization	The process of removing one or more electrons from atoms or molecules, thereby creating ions.

Isotope	One of two or more atoms with the same atomic number (the same chemical element) but with different atomic weights.
Joule	A unit of work or energy equal to 10^7 ergs.
Neutron	An uncharged elementary particle with a mass slightly greater than that of the proton and found in the nucleus of every atom heavier than hydrogen.
Power Density	The intensity of electromagnetic radiation power per unit area expressed as watts/cm^2.
Proton	An elementary particle with a single positive electrical charge and a mass approximately 1,837 times that of the electron.
Radioactivity	The spontaneous decay or disintegration of an unstable atomic nucleus, usually accompanied by the emission of ionizing radiation.
Radioisotope	A radioactive isotope. An unstable isotope of an element that decays or disintegrates spontaneously, emitting radiation.
Radiation	The products of radioactivity such as gamma rays, beta particles, and alpha particles.
Teletherapy	The treatment of disease with gamma radiation from a source located at a distance from the patient.
Watt	A unit of power equal to one joule per second.
Wavelength	The distance between any two similar points of two consecutive waves for electromagnetic radiation.

COMMENT SHEET

SUBCOURSE MD0180 Radiological Health EDITION 100

Your comments about this subcourse are valuable and aid the writers in refining the subcourse and making it more usable. Please enter your comments in the space provided. ENCLOSE THIS FORM (OR A COPY) WITH YOUR ANSWER SHEET **ONLY** IF YOU HAVE COMMENTS ABOUT THIS SUBCOURSE..

FOR A WRITTEN REPLY, WRITE A SEPARATE LETTER AND INCLUDE SOCIAL SECURITY NUMBER, RETURN ADDRESS (and e-mail address, if possible), SUBCOURSE NUMBER AND EDITION, AND PARAGRAPH/EXERCISE/EXAMINATION ITEM NUMBER.

PLEASE COMPLETE THE FOLLOWING ITEMS:

(Use the reverse side of this sheet, if necessary.)

1. List any terms that were not defined properly.

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2. List any errors.

<u>paragraph</u> <u>error</u> <u>correction</u>

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3. List any suggestions you have to improve this subcourse.

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