Unit 1 Fundamental Concepts

In this unit you will learn:

- Radioactive material emits radiation.
- Biological effects of radiation.
- Techniques for reducing exposure.
- Purposes of the Radiological Protection System (RPS).

INTRODUCTION

This course is designed to help you understand and prepare for an event involving excessive exposures to nuclear radiation. To implement radiological incident management techniques effectively, basic concepts of radiation hazards must be understood. This unit explains the fundamental principles of radioactivity, describes the biological effects of radiation on individuals, and introduces the function of the Radiological Protection System.

It is important to remember that the biological effects to be discussed are "worst case", the result of very large amounts of nuclear radiation received in a very short period of time. The types of radiological emergencies, such as nuclear power plant accidents, transportation accidents, or radiological incidents may result in such amounts of radiation, but only in relatively small areas. "Worst case" amounts would typically be encountered over widespread areas only if we experienced a nuclear weapon detonation.

This unit is divided into four major sections: Radioactivity, Biological Effects of Radiation, Exposure Reduction Techniques, and the Radiological Protection System. Each of these sections contains information that can be used to help you keep yourself and others as safe as possible in the event of a radiological emergency.

The **Radioactivity** section describes the physics of radioactivity and the properties of the different types of nuclear radiation. Familiar radiation sources are also explored.

The **Biological Effects of Radiation** section describes both the immediate and long-term effects from exposure to radiation.

The **Exposure Reduction Techniques** section describes the three methods of reducing one's exposure to radiation: reducing the duration of exposure, increasing one's distance from the radiation source, and increasing the amount of shielding between oneself and the radiation source.

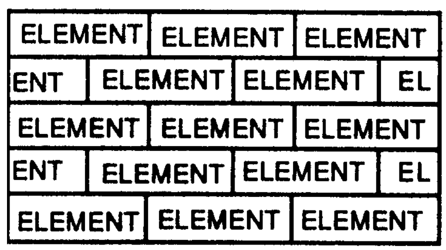
The **Radiological Protection System** section describes the program's design and purposes. The structure of the program and the respective roles of the federal, state and local governments are explained.

RADIOACTIVITY

Although radiation has always been present in our environment, it was not discovered until the late 1800s. To understand nuclear radiation, you need to know how radioactive atoms emit radiation and some of the terms used to express amounts of radiation present.

Elements and Atoms

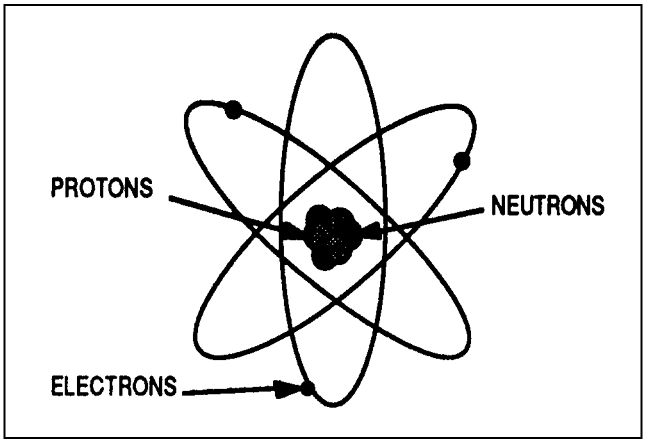
Elements are simple fundamental substances, commonly referred to as nature's building blocks. Although there are at least 106 known elements, 98% of the planet is made up of only six elements: iron, oxygen, magnesium, silicon, sulfur and nickel. The first 92 are naturally occurring elements; the remainder are man-made and radioactive.



Nature's Building Blocks

The smallest unit of an element is the atom. The atom has all the physical and chemical properties necessary to identify it as a particular element. Atoms are composed of smaller particles including protons, neutrons, and electrons. **Protons** and **neutrons** are heavy particles that are found in the center, or **nucleus**, of the atom. The basic difference between a proton and neutron is their associated electrical charge. Protons have a positive charge and neutrons have no charge. **Electrons** are even smaller, negatively charged particles.

Electrons orbit the nucleus producing what is often described as a “shell” around the atom. The extent of the orbits of the electrons determine the size of an atom. If an atom could be enlarged such that the nucleus would be the size of a baseball, the outer electrons would be tiny specks nearly a mile away.



Atom

Radioactivity and Nuclear Radiation

Everything in nature would prefer to be in a relaxed, or stable state. Unstable atoms undergo nuclear processes that cause them to become more stable. One such process involves emitting excess energy from the nucleus. This process is called radioactivity or **radioactive decay**.

The energy released from unstable (radioactive) atoms is called **nuclear radiation**. The terms "radiation" and "radioactive" are often confused. By keeping the following relationship in mind, these two terms can be distinguished: RADIOACTIVE ATOMS EMIT RADIATION.

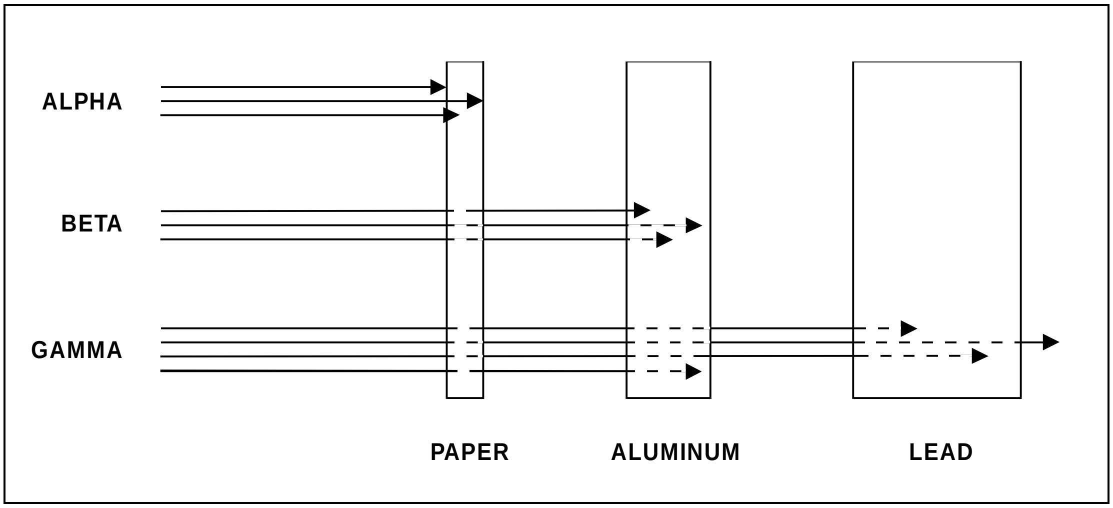
There are three main types of nuclear radiation emitted from radioactive atoms:

- Alpha.
- Beta.
- Gamma.

Alpha and beta radiation consist of actual particles that are electrically charged and are commonly referred to as alpha particles and beta particles. Gamma radiation, however, belongs to a class known as electromagnetic radiation. Electromagnetic radiation consists of energy transmitted in the form of waves. Other types of electromagnetic radiation include television and radio waves, microwaves and visible light. The only differences between gamma rays and these more familiar forms of electromagnetic radiation are that gamma rays are generally higher in energy and that gamma rays originate in the nuclei of atoms.

Alpha

Alpha particles are the heaviest and most highly charged of the nuclear radiations. Without additional energy input, these characteristics make alpha particles less penetrating than beta particles and gamma rays. Their energy is used up before they get very far. Alpha particles cannot travel more than four to seven inches (10 to 18 cm) in air and are completely stopped by an ordinary sheet of paper. Their energy is spent interacting with the charged protons and electrons they meet near any surface they strike.

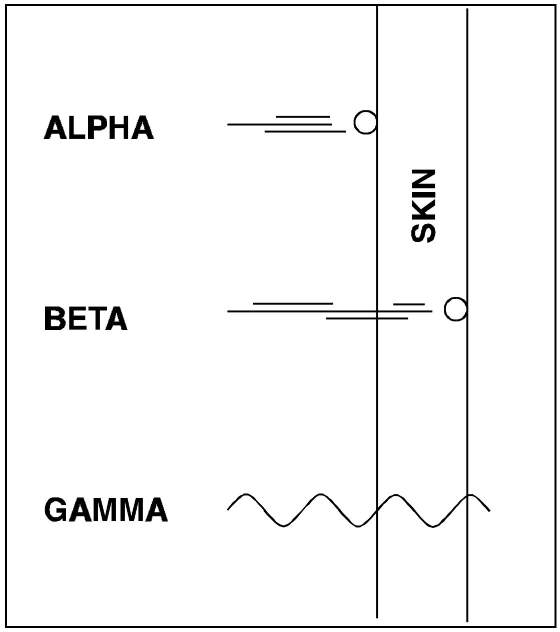


Penetrating Power of Alpha, Beta, and Gamma Radiation

Even the most energetic alpha particle from radioactive decay can be stopped by the outermost layer of dead skin that covers the body. Therefore, exposure to most alpha particles originating outside the body is not a serious hazard. On the other hand, if alpha emitting radioactive materials are taken inside the body, they can be the most damaging source of radiation exposure. The short range of the alpha particle causes the damaging effects of the radiation to be concentrated and in a very localized area.

Beta

Beta particles are smaller and travel much faster than alpha particles. They are physically similar to the electrons discussed earlier in this unit, but they are not in orbit around an atom. Since beta particles travel faster and have less charge than alpha particles, they penetrate further into any material or tissue. Typical beta particles can travel several millimeters through tissue, but they generally do not penetrate far enough to reach the vital inner organs. Beta particles may be a major hazard, however, when emitted by internally deposited radioactive material or when interacting with the lens of the eye.



Radiation Penetration Into Skin

Exposure to beta particles from outside the body is normally thought of as a slight hazard. However, if the skin is exposed to large amounts of beta radiation for long periods of time, skin burns similar to heat burns may result. If removed from the skin shortly after exposure, beta-emitting materials will not cause serious burns and will not pose a severe external hazard.

Like alpha particles, beta particles are considered to be an internal hazard if taken into the body by eating food, drinking water, or breathing air containing radioactive material. Beta emitting contamination can also enter the body through unprotected open wounds.

Gamma

Gamma rays are similar to medical x-rays. As discussed earlier, gamma rays are a type of electromagnetic radiation, energy transmitted through space in the form of waves. Physical characteristics of electromagnetic radiation include wavelength and frequency. Different types of electromagnetic radiation have unique wavelengths and frequency. By measuring these characteristics, the type of radiation can be identified. Short wavelength and high frequency are characteristic of radiations, such as gamma and x-rays.

Gamma rays are the most hazardous type of radiation from sources outside the body because they can travel much greater distances through air and all types of material. Gamma rays can travel up to a mile (1.6 km) in open air and may present a significant hazard even at fairly large distances. Since gamma rays penetrate more deeply through the body than alpha or beta particles, all tissues and organs can be damaged by sources outside of the body.

In many cases, some type of dense material is needed to reduce the hazard presented by gamma rays. Any material between the radiation source and the receptor is called **shielding**, because it absorbs some of the gamma ray energy before it can penetrate. For example, 2-1/2 inches (6 cm) of dense concrete will absorb approximately 50 percent of typical gamma rays. Five inches (13 cm) of water is just as effective.

All three types of nuclear radiation can be a hazard if they are emitted by radioactive material inside the body. Such material can get into your body by eating food with radioactive material in or on it, breathing air with radioactive material in it, or drinking water with radioactive material in it. If you keep radioactive material outside your body, you can use your knowledge of some of the radiation characteristics described in this unit to minimize the amount of radiation that penetrates your body.

Neutron

In addition to the three types of nuclear radiation already discussed, there is another type that has much different properties. This type is **neutron radiation**. Neutron radiation consists of neutrons in motion. These are the same as the neutrons you learned about earlier, except they are not contained in the nucleus of an atom. They are traveling through space by themselves and, in open air, neutrons can travel up to 3,000 feet (900 m). Neutrons lose their energy mostly by colliding with protons in the nucleus of hydrogen atoms. When a neutron has lost enough energy, it can be "captured" by a nucleus making the target atom radioactive. The radioactive atoms then emit alpha, beta or gamma radiation in their attempt to become more stable. Certain elements have a high affinity for capturing slowed down neutrons. Such elements are used in control rods in commercial nuclear reactors as will be discussed in Unit 3.

Practice Exercise

1. The type of radiation which is only a hazard if it originates from radioactive material inside the body is ________________.

2. The type of radiation which may cause skin burns if it originates from radioactive material located on the skin for extended periods of time is __________________.

3. The type of radiation which presents the greatest hazard from radioactive materials outside the body is _________________.

Radiation Measurement Terms

Since nuclear radiation affects people, we must be able to measure its presence. We also need to relate the amount of radiation received by the body to its physiological effects. Two terms used to relate the amount of radiation received by the body are **exposure** and **dose.** When you are exposed to radiation, your body absorbs a dose of radiation.

As in most measurement quantities, certain units are used to properly express the measurement.

Roentgen

Roentgen is the unit used to express the amount of gamma radiation exposure an individual receives. In writing exposures, roentgen is usually abbreviated with a capital "R," which follows immediately after the amount of gamma radiation received. An exposure of 50 roentgens would then be written "50 R." Milliroentgen is a subunit of the roentgen (one thousandth of a roentgen), and is abbreviated "mR."

The **roentgen** is independent of the time over which the exposure occurs. For instance, if a man is exposed to 5 R of gamma rays on one occasion, and 6 R on another, the sum of the two, 11 roentgens, is his cumulative gamma radiation exposure.

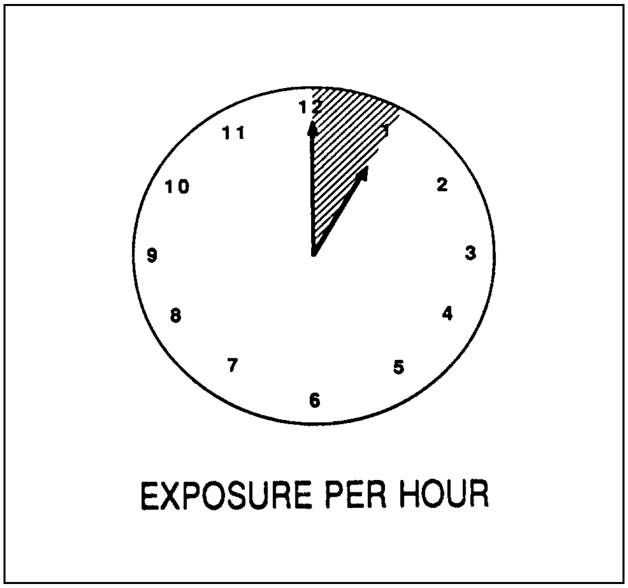
Rad (radiation absorbed dose)

Different materials that receive the same exposure may not absorb the same amount of energy. The rad was developed to relate the different types of radiation (i.e., alpha, beta, gamma and neutron) to the energy they impart in materials. It is the basic unit of the absorbed dose of radiation. The dose of one rad indicates the absorption of 100 ergs (an erg is a small but measurable amount of energy) per gram of absorbing material. One roentgen of gamma radiation exposure results in about one rad of absorbed dose. To indicate the dose an individual receives in the unit rad, the word "rad" follows immediately after the magnitude, for example, "50 rads." One thousandth of a rad is abbreviated "mrad."

Rem (roentgen equivalent man)

Some types of nuclear radiation produce greater biological effects than others for the same amount of energy imparted. The rem is a unit that relates the dose of any radiation to the biological effect of that dose. Therefore, to relate the absorbed dose of specific types of radiation, a "quality factor" must be multiplied by the dose in rad. To indicate the dose an individual receives in the unit rem, the word "rem" follows immediately after the magnitude, for example, "50 rem." For gamma rays and beta particles, 1 rad of exposure results in 1 rem of dose. For alpha particles, 1 rad of exposure results in approximately 20 rem of dose. For neutrons, 1 rad of exposure results in approximately 10 rem of dose. One thousandth of a rem is abbreviated as "mrem."

Another quantity measured is the rate at which an individual is exposed to radiation. This is often measured on a per-hour basis, and is called the **exposure rate**. Exposure rates are expressed in terms of roentgen or milliroentgen per hour. An exposure rate of sixty roentgen per hour would be written "60 R/hr." "R" stands for Roentgen, a "/" is used in place of "per," and "hr" is used for the word "hour."



Exposure Rate Usually Expressed "Per Hour"

Standard international (SI) units which may be used in place of the rem and the rad are the sievert (Sv) and the gray (Gy). These units are related as follows:

- 1 Sv = 100 rem.
- 1 Gy = 100 rad.

SI units must be used on transportation labels. Many radiation meters in use utilize R/hr for measuring dose rate. To convert R/hr to Sv/hr divide by 100. (For example: 60 R/hr ÷ 100 = .6 Sv/hr.)

Radioactivity Measurement Terms

The radioactivity of a given material is a measure of the rate at which the material undergoes radioactive decay. The unit used to measure radioactivity is the curie (Ci) where one curie equals 3.7×10^{10} radioactive disintegrations per second (dps). The SI unit which may be used in place of the curie is the becquerel (Bq). These units are related as follows:

- 1 Ci = 3.7×10^{10} dps = 3.7×10^{10} Bq.
- 1 Bq = 1 dps**.**

Another useful quantity is the amount of radioactivity per unit mass. This quantity, called **specific activity**, is typically measured in units of curies per gram (Ci/g).

Natural and Man-made Radiation Sources

Before we discuss the biological effects of nuclear radiation, it is important to remember the many sources of natural and man-made radiation that surround us. Individuals are exposed to minute amounts of radiation from the environment daily. This natural background radiation comes from three main sources:

- **Cosmic radiation:** Cosmic radiation reaches the earth primarily from the sun. It is composed of a very wide range of penetrating radiations which undergo many types of reactions with the elements they encounter in the atmosphere. The atmosphere acts as a shield and considerably reduces the amount of cosmic radiation reaching the earth's surface. The average dose rate in the U.S. from cosmic radiation is approximately 0.3 mSv/year or 30 mrem/year. Much higher doses (up to 140 mrem/year or 1.4 mSv/year) are received by individuals living in higher elevation areas such as Denver.

- **Terrestrial sources:** The environment we live in is filled with radioactive materials. For example, the rocks and soil of the earth contain small quantities of the natural radioactive elements uranium and thorium. The concentration of these and other radioactive elements varies considerably depending on the type of rock formation. Thus, the dose rate from this source depends on the geographical location. In the U.S., the dose rate to the body may vary between approximately 15 and 140 mrem/year (0.15 and 1.4 mSv/year). The average is approximately 40 mrem/year (0.4 mSv/year).

- **Radioactivity in the body:** The human body contains very small quantities of radioactive carbon and potassium. This radioactive material gets incorporated into tissues and organs throughout the body. The radioactive carbon originates in the atmosphere and results in a dose of approximately 1 mrem/year (0.01 mSv/year) in the soft tissue. Radioactive potassium is naturally occurring and contributes approximately 20 mrem/year (0.2 mSv/year) to the testes or ovaries.

In addition to the natural background radiation, there are many sources of man-made radiation which may contribute daily to radiation exposure for humans. These sources include:

- **Diagnostic radiology:** Diagnostic radiology is the use of radiation (e.g., x-rays) to determine a patient's condition. It has been estimated that 75 to 90 percent of the total exposure of the population from medical uses of radiation comes from the diagnostic use of x-rays.

- **Therapeutic radiology:** Therapeutic radiology is the use of radiation to treat a patient. The average dose to the overall population from therapeutic radiology is much less than that from diagnostic radiology. Although quite large exposures may be used in certain treatments such as cancer radiotherapy, only a small number of people are involved and exposures are limited to small, precise areas.

Table 1-1
Annual Whole Body Radiation Dose Rates in the United States*

Source	Average Annual Dose		% of Total
	mSv/year	mrem/year	
Natural background (cosmic, terrestrial, internal)	0.82	82	44.6
Medical radiation	0.77	77	41.8
X-rays			
Radiopharmaceuticals	0.14	14	7.6
Fallout (weapons testing)	0.04-0.05	4-5	2.4
Nuclear industry	<0.01	<1	<0.5
Research	<<0.01	<<1	<<0.5
Consumer products	0.03-0.04	3-4	1.9
Airlines			
Travel	0.005	0.5	0.3
Transport of radiopharmaceuticals	0.0001	0.01	0.005
	1.84	184	100%

*Adapted from BEIR (1980), pp. 66-67.

- **Fallout from weapons testing:** Some of the radioactive materials created during a nuclear test were injected into the highest region of the atmosphere and carried around the earth several times. They gradually returned to the earth over a period of a few years and consequently gave doses to the population. The dose reached a peak shortly after each weapon test. For some population, minute amounts of radioactive strontium atoms concentrated in the body's skeleton and radioactive cesium atoms were distributed throughout the body.

- **Occupational exposure:** Occupational exposure is exposure to individuals such as nuclear energy workers, industrial users of radioactive materials, and medical personnel who encounter radioactive materials as part of their jobs. Because the number of these individuals is limited, the dose from all occupational exposure is very small (approximately 0.5 mrem/year or 0.005 mSv/year) when averaged over the entire population.

Practice Exercise

4. Cosmic radiation and radioactive potassium in the body are examples of ________________.

5. The roentgen (R) is a unit of _____________________.

6. The roentgen per hour (R/hr) is a unit of ___________________.

BIOLOGICAL EFFECTS OF RADIATION

Nuclear radiation is the most-studied environmental hazard in the world. The effects on people caused by exposure to very large amounts of radiation is well known.

In this section, you will learn about the biological effects of very large radiation doses received in a relatively short period of time. An exposure received within a short period of time is called **acute exposure**. Generally, a large acute exposure can result in observable effects, such as radiation sickness or death, shortly after exposure. The severity of these immediate effects depends on the amount of radiation dose. Large acute exposures can also result in effects such as cancer that show up after a number of years. The probability of these delayed effects also depends on the amount of radiation dose.

A continuous or repetitive exposure is called a **chronic exposure**. Natural background radiation, an example of chronic exposure, exposes individuals to relatively small amounts of radiation over a long time. Small chronic exposures, such as exposure to background radiation, have no immediately observable effects, but may result in the same types of delayed effects that are associated with acute exposures.

To understand the types of biological effects resulting from exposure to nuclear radiation, it is important to understand how radiation interacts with the body. Remember, radiation is a form of energy in motion. When alpha, beta and gamma radiation enter the body, some or all of their energy is lost in collisions with the body's atoms. The major characteristic of these atomic interactions is the stripping away of electrons from atoms in the body. This removal of electrons is called **ionization.** For this reason, alpha, beta, and gamma radiation is often called **ionizing radiation**.

The biological effects of radiation are caused by these ionizations and their effects on cells. The body cells depend on individual atoms working together. The body is accustomed to repairing many types of cell damage. Usually, the body is able to handle cell damage through its repair mechanisms. The immediate and delayed biological effects seen from radiation occur when the body either improperly repairs the damage, or when the body has so much repair to perform that it can't overcome the damage quickly enough.

Acute Effects

The body's natural defenses against radiation damage have developed in the naturally radioactive environment we live in. These defenses are overwhelmed by **acute exposures**. For example, if a large group of people received an acute exposure of 450 R (0.12 C/kg), half of them would probably die within a month without medical care. However, if this same group were exposed to 450 R over an extended period of time, far fewer would die as a result. If the exposure was protracted over many years, no radiation sickness would be observed, although the delayed effects might be statistically observable. Therefore, **chronic**

exposures received over an extended period of time can be tolerated by the body with much less biological effect than **acute exposures**.

Biological Factors

Although the effects of exposure to large groups can be predicted, each individual's body differs. These differences can mean that, except at extremely high acute doses, two people exposed to the same amount of nuclear radiation may experience different symptoms. Biological factors which may influence the effect of radiation on an individual include age, sex, diet, body temperature, and health.

Biological Symptoms

The symptoms discussed below are those caused by large short-term (acute) exposures of gamma radiation. We will relate some general symptoms to specific amounts of exposure. These classifications must be general because, as previously stated, radiation effects are somewhat variable among individuals.

Two visible, potential signs of radiation sickness are nausea and vomiting. Since shock or pain can also cause nausea and vomiting, they are not necessarily an indication of radiation sickness. The symptoms must be weighed against the dose received to determine whether they indicate radiation sickness. Another symptom is a high fever. All three of these symptoms resemble those of many common illnesses, including the "flu" and the common cold.

Radiation sickness symptoms may appear shortly after exposure, then disappear for a few days only to reappear in a much more serious form in a week or so. This "latent" period is related to the amount of the exposure. When the symptoms recur, they are sometimes accompanied by swelling in the passages of the nose, mouth, and throat.

Acute Radiation Sickness

As stated, acute radiation doses occur when an individual is exposed to a large amount of radiation within a relatively short period. The effects of acute radiation doses greater than approximately 1 Sv (100 rem) are collectively known as **acute radiation sickness**. Acute radiation sickness symptoms include:

- Changes in blood cells.
- Vascular changes (blood vessels).
- Skin irritation.
- Gastrointestinal system effects.
- Radiation sickness (diarrhea, nausea, vomiting, high fever).
- Hair loss (epilation).
- Burns.

The severity and course of the acute radiation sickness depends on how much total dose is received, how much of the body is exposed and the radiosensitivity of the exposed individual. The symptoms of acute doses usually appear within the first one or two weeks after the radiation is received. The effects of acute radiation exposure are described below.

Any organism will die if it is exposed to too much radiation. For some people, exposures above .05 C/Kg (200 R) to the whole body may be lethal. At .09 C/Kg (350 R), perhaps 5 percent of the exposed group would die within a month without medical attention. At .12 C/Kg (450 R), as stated earlier, half of the exposed group would probably die without medical attention. At .17 C/Kg (650 R), most would die without intense medical care.

Hair loss results from the destruction of hair follicles in the skin. Hair loss may be temporary or permanent depending on the dose.

Skin irritation is another effect likely to occur from acute exposures to radiation. A tingling sensation of the skin and some reddening may persist for a couple of days after exposure. This response is typical of a sunburn and the dead skin cells are obvious from the peeling of skin after the burn. But unlike sunburn, the irritation will return after some time has passed and persist for about 3 weeks. More severe skin burns and blistering occurs after higher exposures.

Severity Levels

The severity and the time of onset of early radiation sickness after exposure are important indicators in the determination of what the later symptoms of the acute radiation sickness will be, especially if the absorbed dose is not known. Nausea, vomiting, diarrhea and anorexia are common symptoms of early radiation sickness. Later symptoms may include:

- Malaise (a vague feeling of illness and depression).
- Fatigue.
- Drowsiness.
- Weight loss.
- Fever.
- Abdominal pain.
- Insomnia (sleeplessness).
- Restlessness.
- Blisters.

Changes in the formation or production of blood cells may occur when individuals are exposed to large amounts of radiation such as 300 to 500 R. Some smaller (sublethal) doses may generate blood changes detectable in laboratories with no overt patient symptoms. The individual initially suffers from nausea and vomiting and may appear to recover in about three days. At this level of exposure, blood cells essential for fighting infections are greatly reduced in number. In two to three weeks, symptoms including chills, fatigue, and ulceration of the mouth will appear. Susceptibility to secondary infection is greatly increased during this period and may cause death, even with medical care.

If an individual receives over 500 R of acute radiation dose, damage to the stomach lining and/ or intestine may occur. The high doses of radiation may cause structural changes to the gastrointestinal tract including decreased absorption, ulceration, and dehydration. If the individual suffers from severe infection, fluid loss, blood loss or circulatory collapse, death may occur within 7 days.

Acute doses of over 1000 R cause irreparable damage to the central nervous system cells. Terminal symptoms may include over excitability, lack of coordination, breathing difficulty, and occasional periods of disorientation. At these doses, death occurs within hours to days.

Table 1-2 shows the effects of various large doses in the weeks after exposure.

Table 1-2
Clinical Symptoms of Acute Radiation Sickness in Relation to Postexposure Time and Dose

Time after Exposure	Sublethal Dose (100-250 rem)	Lethal Dose (250-450 rem)	Supralethal Dose (>650 rem)
First Week	Nausea and occasional vomiting within hours	Nausea, vomiting, extreme paleness within a few minutes or hours	Nausea, vomiting, extreme paleness within a few minutes Shock, unconsciousness, diarrhea, abdominal pains and cramps, fever, severe skin irritation, burns or blisters, insomnia, restlessness
Second Week		Weight loss, general malaise, fatigue, stomatitis Fever, anorexia, abdominal pains, severe skin irritation	Death certain (without medical attention) within a few hours to a few days
Third Week	General malaise, anorexia, mild skin irritation, diarrhea, fatigue, drowsiness Hair loss	Hair loss, internal bleeding	
Fourth Week and Later	Recovery probable Changes in blood cells detectable in laboratory	Menstrual irregularities in females 50% chance of death from changes in blood cells if not treated	

Treatments

As discussed, individuals exposed to radiation may suffer from a full range of injuries from invisible blood change effects at low doses to superficial burns caused by beta particles, to serious radiation sickness at high doses. Whatever the injury, a medical doctor should treat the individual. By examining blood microscopically, a medical doctor can diagnose radiation exposure before other effects appear or after an exposure not great enough to cause more severe symptoms. Treatment depends upon the nature and seriousness of injury. Beta burns, for example, may be treated just like any other burn.

Long-term Effects

The probability of experiencing long-term effects increases as the level of exposure increases. However, at occupational exposure levels such as 0.5 R/year, the probability of these effects occurring to an individual is very small.

Cancer

One of the most serious delayed effects of exposure to nuclear radiation is the increased risk of cancer. Although widely thought of as a cause of cancer, acute radiation exposure contributes only a limited increase to cancer risk. For example, of 82,000 Japanese atomic bomb survivors receiving an average of approximately 28 rads (0.28 Gy), only an estimated 185 or 0.2 percent experienced a radiation induced cancer. The danger of cancer caused by acute radiation exposure is clearly less than the danger presented by the short-term acute radiation effects discussed previously in this unit.

Low-level radiation exposure, although also widely thought of as a cause of cancer, is an even less potent cancer causing agent. Measurable increases in cancer rates are not observed but are generally assumed to exist due to the known cancer causing effect of the much higher, acute doses. When responding to radiological accidents such as most transportation accidents or a nuclear power plant accident as severe as that at Three Mile Island, it will be this assumed low-level radiation exposure risk that will be a factor.

Table 1-3 compares the risk of radiation exposure with other common risks.

Table 1-3
Risk Comparisons

Condition	Average Lifespan Reduction (Days)
Being an unmarried male	3,500
Cigarette smoking (male)	2,250
Being 30 percent overweight	1,300
Motor vehicle accidents	207
Alcohol (U.S. average)	130
Accidents in the home	95
Accidents on the job (average)	74
Occupational radiation exposure (5 rem/year or 0.05 Sv/year)	32
Illicit drugs (U.S. average)	18
Natural radiation	8
Medical x-rays	6
Occupational radiation exposure (0.5 rem/year or 0.005 Sv/year)	3
Diet drinks	2
Average radiation dose from a nuclear reactor accident	0.2-2

Cataracts

The fibers that comprise the lens of the eye are specialized to transmit light. Damage to these fibers, and particularly to the developing immature cells that give rise to them, can result in dark spots in the lens called cataracts which can interfere with vision. Acute exposure of 200 rads (2 Gy) or more can induce the formation of vision-impairing cataracts. Exposure to 1,000 rads (10 Gy) over a period of months can also cause cataracts.

Life-Shortening

The evidence regarding life-shortening is derived mainly from animal experiments where radiation has been demonstrated to shorten lifespan. The aging process is complex and largely obscure; and the exact mechanisms involved in it are yet uncertain. Irradiated animals in these investigations appear to die of the same diseases as nonirradiated animals, but they do so at an earlier age. How much of the total effect is due to premature aging and how much to an increased incidence of radiation-induced diseases is still unresolved. However, data from the populations of Hiroshima and Nagasaki indicate that, if life-shortening occurs it is very slight, less than 1 year per 100 R.

Table 1-4 shows typical latent periods between exposure and effect.

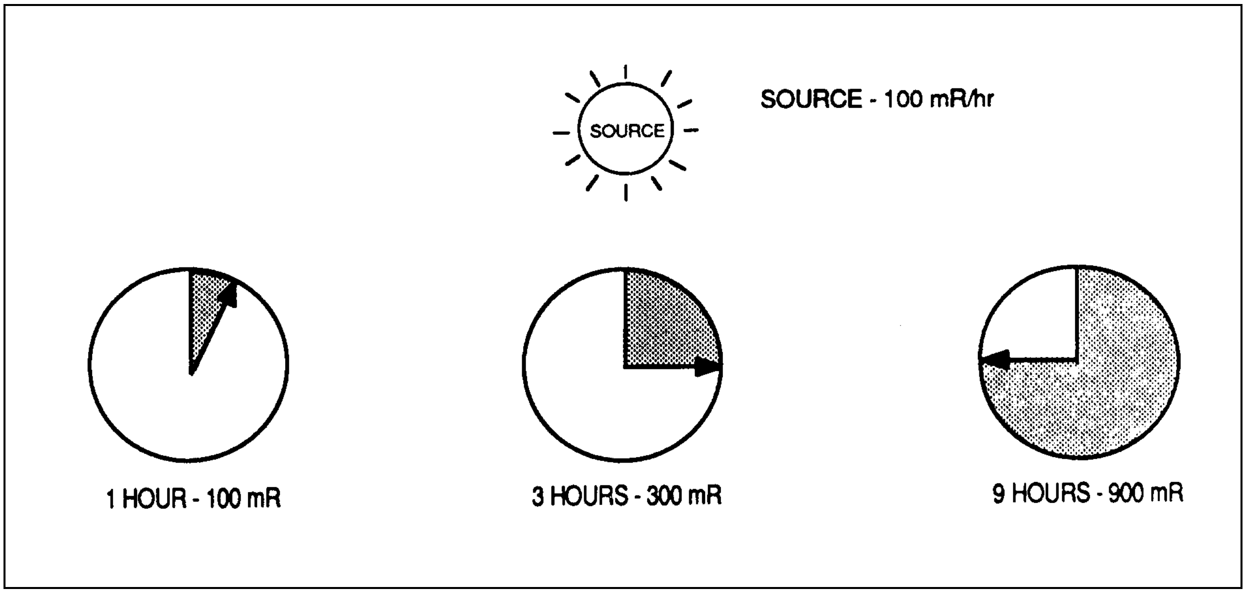
Table 1-4
Long-Term Effects of Radiation

Effect	Mean Latent Period (years)	Evidence
Leukemia	2-4	Atomic bomb casualties Medical x-ray treatment
Bone cancer	15	Radium luminous dial painters
Thyroid cancer	15-30	Atomic bomb casualties Medical treatment
Lung cancer	10-20	Mine workers
Life-shortening	Not applicable	Experiments with mice
Cataract formation	1-5	Atomic bomb casualties

EXPOSURE CONTROL TECHNIQUES

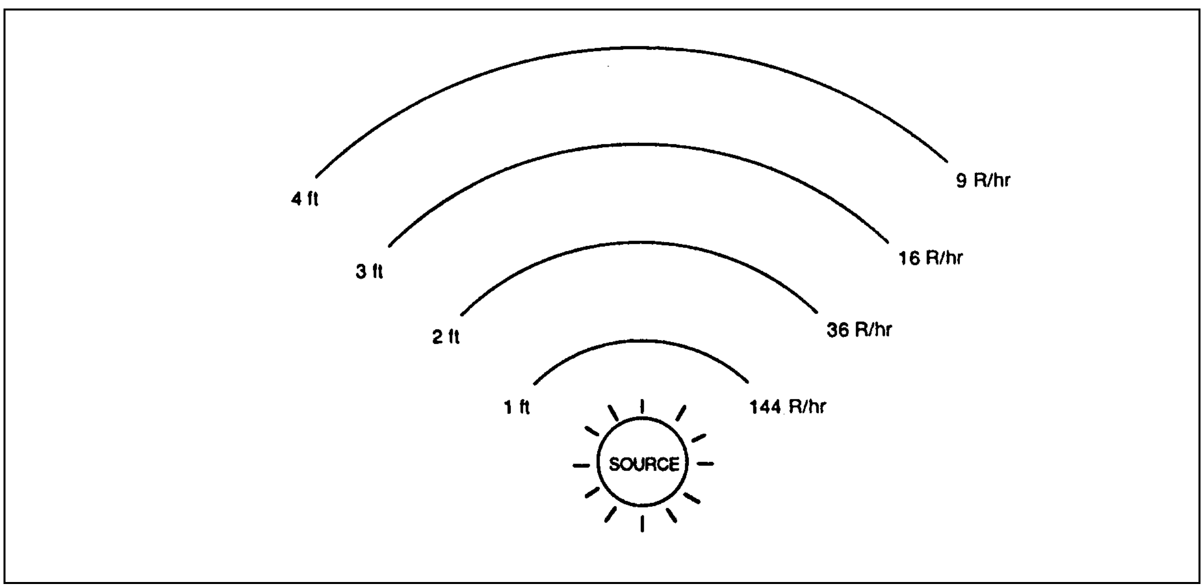
There are three important factors in protecting individuals from radiation: **time**, **distance**, and **shielding**.

The time factor means that the less time an individual remains in a radiation field, the less exposure that individual will receive. The figure below shows the effect of time spent in a field of 100 mR/hr. If you remain in a 100 mR/hr field of radiation for 1 hour, you will be exposed to 100 mR. If you remain in the same 100 mR/hr field for 3 hours, you will be exposed to 300 mR (3 x 100).



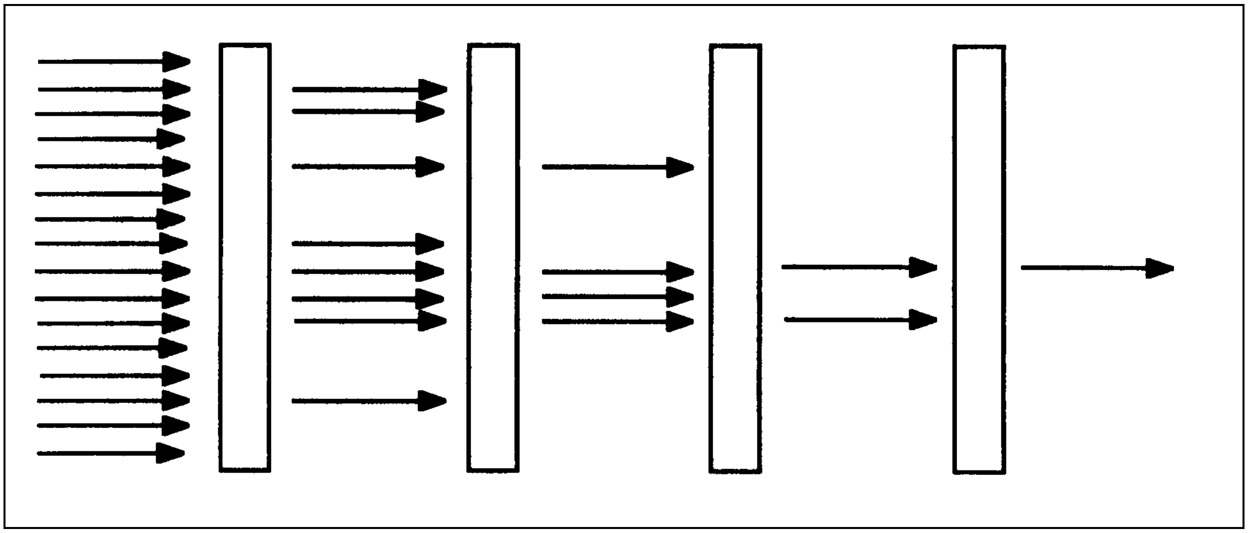
Effect of Exposure Rate and Time On Total Exposure

The **distance** factor means that the further an individual remains from a radiation source, the less exposure that individual will receive. The intensity of a radiation field decreases as the distance from the source increases. The figure below shows the effect of distance on gamma exposure rates. If the exposure rate at one foot (30.5 cm) away from the source is 1,000 mR/hr, the exposure rate at two feet (61 cm) away will be 250 mR/hr. The 250 mR/hr is 1/4 of the exposure rate at one foot.



Effect of Gamma Exposure Rate and Distance On Total Exposure

The **shielding factor** means that the more material placed between an individual and a radiation source, the less exposure that individual will receive. The intensity of a radiation beam is reduced by absorption and scattering processes with the material. For gamma radiation, dense material such as lead is most effective as a shield. Beta radiation can be shielded by relatively thin amounts of wood or plastic. Alpha is shielded by virtually any material.



Effect of Shielding Layers On Exposure Rate

All of the above mentioned factors may be accomplished by an adequate shelter. The shelter provides distance away from the radiation located outside. The shelter acts as shielding and can help prevent inhalation of radioactive material.

Practice Exercise

7. Some visible or measurable signs of radiation sickness are _______________.

8. The amount of acute radiation exposure which will kill approximately 50% of the individuals exposed (if not medically treated) is______________________.

9. The factors which protect an individual from exposure to radiation are,_____________________, ______________________, and _________________.

EMERGENCY MANAGEMENT AND THE RADIOLOGICAL PROTECTION SYSTEM

In the United States, emergency management at the Federal, state, and local level is designed to minimize the effects of all hazards on the civilian population. The Radiological Protection System (RPS) is one element of emergency management. This system of public protection provides plans and trained personnel to respond to any situation involving the release or potential release of radioactive materials. The RPS may be activated by transportation accidents, problems at nuclear power plants or other fixed facilities, natural disaster damage to facilities that use radioactive materials in industry, research or medicine, or terrorist use of a nuclear weapon or conventional weapon containing nuclear material.

Key elements of emergency management are **preparedness**, **response**, **recovery** and **mitigation** measures:

- Preparedness includes training, exercising, public information programs, and administration of government emergency management programs. The federal government, through the Federal Emergency Management Agency, establishes program guidelines and the establishment of state and local programs.

- Response includes the implementation of plans and procedures for dealing with any type of hazard. These plans and procedures include the protective measures for both the general public and emergency workers or responders.

- Recovery is returning the community back to normal as much as possible.

- Mitigation includes measures taken by both the public and government to lessen the impact and effects of a hazard.

The radiological protection system conducts preparedness, response, recovery and mitigation activities as related to events that could result in public exposure to radiation.

Preparedness: use Federal guidelines for state and local planning and training. Includes maintenance of radiation detection instruments.

Response: to all types of radiation events -- protection for public includes State radiological health, local responders, local and state emergency managers.

Recovery: decontamination, monitoring of food and water supply, returning people to homes.

Mitigation: public education (re: nuclear power plants and general effects of radiation, notification systems, Emergency Planning Zone (EPZ) plans, and evacuation routes).

Practice Exercise

10. The system designed to minimize the effects of a radiological hazard on the population is called ________________________________.

UNIT 1 REVIEW

This unit described Radioactivity, the Biological Effects of Radiation, Techniques for Reducing Exposure, and the RPS.

Radioactive atoms emit radiation. There are three main types of nuclear radiation emitted from radioactive atoms: alpha, beta and gamma. Neutrons are a fourth type of nuclear radiation. When you are exposed to radiation, your body absorbs a dose of radiation. There are both natural and man-made sources of radiation in our environment. Radiation is the most studied environmental hazard in the world.

The biological effects of radiation exposure are dependent on the type of exposure (acute or chronic), the level of exposure, and certain biological factors. The acute biological symptoms due to radiation exposure are not unique except at very high levels of exposure. The long-term effects of high doses of radiation include increased risk of cancer and cataracts with a possibility of life-shortening. Measurable effects of low-level radiation exposure have not been observed but are generally assumed to exist due to the known cancer causing effect of much higher, acute doses.

Protective measures can be used to reduce an individual's radiation exposure. The use of time, distance, and shielding principles are especially important in reducing exposure to radiation.

The Radiological Protection System (RPS), a part of the overall Emergency Management Program, is an organized effort designed to minimize the effects of nuclear radiation (from all sources) on people and their property.

UNIT 1 REVIEW QUESTIONS

Answer the following questions to review your knowledge of the Fundamental Concepts unit. Read each question carefully and circle the correct answer.

1. The greatest hazard from radioactive material outside the body is from:

    a. Alpha particles

    b. Beta particles

    c. Gamma rays

2. The type of radiation totally absorbed by the body when emitted by radioactive material inside the body is:

    a. Alpha particles

    b. Gamma rays

    c. Both gamma rays and beta particles

3. The amount of radiation absorbed per hour is the:

    a. Dose rate

    b. Radiation effect

    c. Exposure rate

4. If a man was exposed to .2 C/Kg of gamma rays on one occasion and .5 C/Kg on another, his total exposure would be:

    a. 2.5 C/Kg

    b. .25 C/Kg

    c. .7 C/Kg

5. Cosmic radiation, terrestrial radiation sources and radioactive potassium in the body are all examples of:

   a. Radioactive contamination

   b. Natural background radiation

   c. Man-made radiation

6. One example of man-made radiation which may contribute to routine human exposure is:

   a. Therapeutic radiology

   b. Cosmic radiation

   c. Terrestrial sources

7. Some visible or measurable signs of radiation sickness are:

   a. Nausea, vomiting, fever

   b. Diarrhea, jaundice, nervousness

   c. Burns, backache, headache

8. Most individuals receiving an acute radiation exposure of 500 R will:

   a. Probably experience no noticeable effects

   b. Probably be ill and likely die if medical treatment is not received

   c. Be certain to die almost immediately

9. One example of a potential long-term effect from chronic low level radiation exposure is:

   a. Hair loss

   b. Cataracts

   c. Nausea

10. Identify the three factors that are important in protecting individuals from radiation exposure of any type.

    a. Time, shielding and dose rate

    b. Dose rate, shielding and distance

    c. Time, distance and shielding

UNIT 1
REVIEW ANSWER KEY

1. c
2. a
3. c
4. c
5. b
6. a
7. a
8. b
9. b
10. c