RADIATION SAFETY TRAINING GUIDE

FOR RADIONUCLIDE USERS

Environmental Health and Safety
Florida Atlantic University

PART I

FUNDAMENTALS OF RADIOACTIVITY AND IONIZING RADIATION

1.0 REGULATIONS

The possession and use of radioactive materials in the United States is governed by strict regulatory controls. The primary regulatory authority for most types and uses of radioactive materials is the federal Nuclear Regulatory Commission (NRC). However, more than half of the states in the U.S. (including Florida) have entered into "agreement" with the NRC to assume regulatory control of radioactive material use within their borders. As part of the agreement process, the states must adopt and enforce regulations comparable to those found in Title 10 of the Code of Federal Regulations. Regulations for control of radioactive material use in Florida are found in Florida Administrative Code, Chapter 64E-5 Radiation Control.

For most situations, the types and maximum quantities of radioactive materials possessed, the manner in which they may be used, and the individuals authorized to use radioactive materials are stipulated in the form of a "specific" license from the appropriate regulatory authority. In Florida, this authority is the Department of Health, Bureau of Radiation Control. Certain institutions which routinely use large quantities of numerous types of radioactive materials, the exact quantities of materials and details of use may not be specified in the license. Instead, the license grants the institution the authority and responsibility for setting the specific requirements for radioactive material use within its facilities. These licensees are termed “broadscope” and require a Radiation Safety Committee and usually a full-time Radiation Safety Officer.

2.0 ATOMIC STRUCTURE

All matter contains atoms that are themselves composed of three primary particles; protons, neutrons, and electrons. Protons and neutrons are relatively massive compared to electrons and make up the dense core of the atom known as the nucleus. Protons are positively charged while neutrons, as their name implies, are neutral. The negatively charged electrons are found in an extended cloud surrounding the nucleus.

The number of protons within the nucleus defines the **atomic number**, designated by the symbol Z. In an electrically neutral atom, Z also indicates the number of electrons within the atom. The number of protons plus neutrons in the nucleus is termed the **mass number**, designated by the symbol A. For lighter elements, the number of neutrons in a stable nucleus approximately equals the number of protons.

The atomic number of an atom designates its specific elemental identity. For example, an atom with a Z of 1 is hydrogen, an atom with a Z of 2 is helium, and an atom with a Z of 3 is lithium. A given species of nucleus characterized by a particular atomic number and mass number is called a **nuclide**. A specific nuclide is represented by its chemical symbol with the mass number in superscript, e.g., ^{3}H, ^{14}C, ^{125}I or H-3, C-14, I-125. Nuclides with the same number of protons (i.e., the same Z) but different number of neutrons (i.e., different A) are called **isotopes** of that particular element. Isotopes of an element have for most practical purposes identical chemical properties. Figure 1 shows three naturally occurring isotopes of hydrogen.

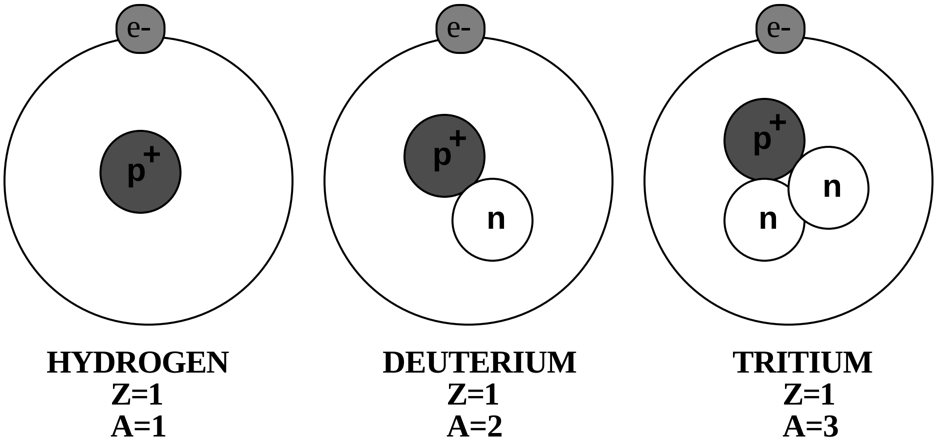

Figure 1. Isotopes of Hydrogen

3.0 RADIOACTIVE DECAY

Depending upon the ratio of neutrons to protons within its nucleus, an isotope of a particular element may be stable or unstable. Over time the nuclei of unstable isotopes spontaneously disintegrate, or transform, in a process known as **radioactive decay**. As part of this process, various types of ionizing radiation may be emitted from the nucleus and/or its surrounding electrons. Nuclides which undergo radioactive decay are called **radionuclides**. Any material which contains measurable amounts of one or more radionuclides is a **radioactive material**.

3.1 Activity

The quantity which expresses the degree of radioactivity or radiation producing potential of a given amount of radioactive material is **activity**. The special unit for activity is the curie (Ci) which was originally defined as that amount of any radioactive material which disintegrates at the same rate as one gram of pure radium. The curie has since been defined more precisely as a quantity of radioactive material in which 3.7×10^{10} atoms disintegrate per second. The International System (SI) unit for activity is the becquerel (Bq), which is that quantity of radioactive material in which one atom is transformed per second.

The activity of a given amount of radioactive material does not depend upon the mass of material present. For example, two one-curie sources of ^{137}Cs might have very different masses depending upon the relative proportion of non radioactive atoms present in each source. The concentration of radioactivity, or the relationship between the mass of radioactive material and the activity, is called the **specific activity**. Specific activity is expressed as the number of curies or becquerels per unit mass or volume.

3.2 Half-life

Each radionuclide decays at its own unique rate which cannot be altered by any chemical or physical process. A useful measure of this rate is the **half-life** of the radionuclide. The half-life is defined as the time required for the activity of any particular radionuclide to decrease to one-half of its initial value. Half-lives of radionuclides range from microseconds to billions of years.

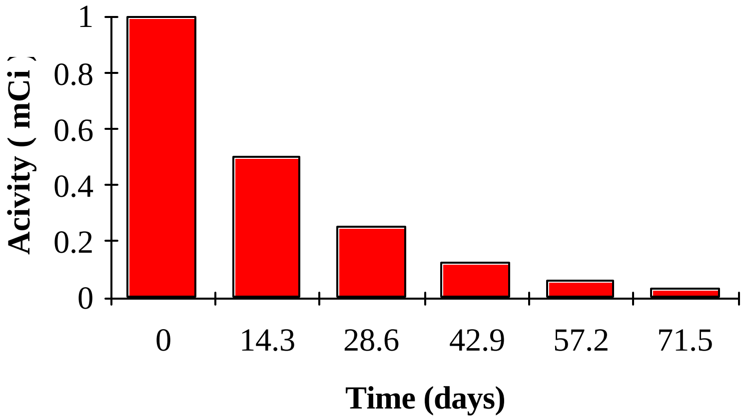

Figure 2. Half-life Decay Scheme of ^{32}P

3.3 Decay Law

The rate at which a quantity of radioactive material decays is directly proportional to the number of radioactive atoms present. This can be expressed mathematically by the equation:

$$-\frac{dN}{dt} = \lambda N \qquad \text{Eq. 1}$$

where dN/dt is the disintegration rate of the radioactive atoms, λ is the decay constant, and N is the number of radioactive atoms present at time t. Further mathematical treatment of this equation (i.e., by integration) yields:

$$N = N_0 e^{-\lambda t} \qquad \text{Eq. 2}$$

where N_0 is the initial number of radioactive atoms present and e is the base of the natural logarithms. Since activity (A) is proportional to N, the equation is often expressed as:

$$A = A_0 e^{-\lambda t} \qquad \text{Eq. 3}$$

It can be shown mathematically that the half-life ($T_{½}$) of a particular radionuclide is related to the decay constant (λ) as follows:

$$\lambda = \frac{0.693}{T_{½}} \qquad \text{Eq. 4}$$

Substituting this value of λ into Equation 3, one gets:

$$A = A_0 e^{-\left(\frac{0.693}{T_{½}}\right) t} \qquad \text{Eq. 5}$$

This is a very useful equation for determining the activity of a given radionuclide after a particular period of time.

Example 1: A researcher obtains 5 mCi of Phosphorus-32 ($T_{1/2}$ = 14.3 days). How much activity will remain after 10 days?

$$A_0 = 5 \text{ mCi}$$

$$\lambda = \frac{0.693}{14.3\text{d}} = 0.0048 \text{ d}^{-1}$$

$$t = 10 \text{ d}$$

$$A = A_0 e^{-\lambda t}$$

$$A = 5e^{-(0.0048)(10)} = 3.1 \text{ mCi}$$

4.0 TYPES IONIZING RADIATION

When an atom undergoes radioactive decay, it emits one or more forms of ionizing radiation, defined as radiation with sufficient energy to ionize (i.e., remove orbital electrons from) the atoms with which it interacts. Ionizing radiation can consist of high speed subatomic particles ejected from the nucleus or electromagnetic radiation (i.e., photons) emitted by either the nucleus or orbital electrons.

4.1 Alpha Particles

Certain radionuclides of high atomic mass (e.g., ^{226}Ra, ^{238}U, ^{239}Pu) decay by the emission of alpha particles. These alpha particles are tightly bound units of 2 neutrons and 2 protons each (i.e., ^{4}He nucleus). Emission of an alpha particle from the nucleus results in a decrease of two units of atomic number (Z) and four units of mass number (A). Alpha particles are emitted with discrete energies characteristic of the particular transformation from which they originate. In other words, all alpha particles from a particular radionuclide transformation will have identical energies.

4.2 Beta Particles

A nucleus with a slightly unstable ratio of neutrons to protons may decay through the emission of a high speed electron called a **beta particle**. This results in a net change of one unit of atomic number (Z). The beta particles emitted by a specific radionuclide range in energy from near 0 up to a maximum value characteristic of the particular transformation.

4.3 Gamma Rays

A nucleus which is in an excited state may emit one or more photons (i.e., particles of electromagnetic radiation) of discrete energies. The emission of these **gamma rays** does not alter the number of protons or neutrons in the nucleus but instead has the effect of moving the nucleus from a higher to a lower energy state. Gamma ray emission frequently follows beta decay, alpha decay, and other nuclear decay processes.

4.4 X-rays

X-rays are also part of the electromagnetic spectrum and are distinguished from gamma rays only by their source (i.e., orbital electrons rather than the nucleus). X-rays are emitted with discrete energies by electrons as they shift orbits following certain types of nuclear decay processes. A continuous energy spectrum of x-rays called **bremsstrahlung** may also be emitted by charged particles (e.g., beta particles) as they decelerate near atomic nuclei.

4.5 Neutron

Neutrons are typically produced by one of three methods. Large amounts of neutrons are produced in nuclear reactors due to the nuclear fission process. High energy neutrons are produced by accelerating deuterons and causing them to interact with tritium nuclei. The third method of producing neutrons is by bombarding beryllium with alpha particles. Neutron sources can be made using the alpha-neutron reaction on beryllium by making a mixture of powered alpha emitter and beryllium and sealing it in a metal container. Early neutron sources used radium as the alpha emitter. Modern neutron sources typically use plutonium or americium as the alpha source. The radium-beryllium (RaBe) sources were also sources of large amounts of gamma radiation while the plutonium-beryllium (PuBe) sources and the americium-beryllium (AmBe) sources only produce small amounts of very low energy gamma radiation. Thus, as neutron sources, PuBe and AmBe sources tend to be less hazardous to handle. The older RaBe sources also had a tendency to develop leaks over time and give off radon gas, one of the products of radium decay.

5.0 INTERACTION OF IONIZING RADIATION WITH MATTER

As ionizing radiation moves from point to point in matter, it loses its energy through various interactions with the atoms it encounters. The rate at which this energy loss occurs depends upon the type and energy of the radiation and the density and atomic composition of the matter through which it is passing.

5.1 Mechanisms of Interaction

The various types of ionizing radiation impart their energy to matter primarily through **excitation** and **ionization** of orbital electrons. The term “excitation” is used to describe an interaction where electrons acquire energy from a passing charged particle but are not removed completely from their atom. Excited electrons may subsequently emit energy in the form of x-rays during the process of returning to a lower energy state. The term “ionization” refers to the complete removal of an electron from an atom following the transfer of energy from a passing charged particle. In describing the intensity of ionization, the term “specific ionization” is often used. This is defined as the number of ion pairs formed per unit path length for a given type of radiation.

5.2 Characteristics of Different Types of Ionizing Radiation

Because of their double charge and relatively slow velocity, alpha particles have a high specific ionization and relatively short range in matter (a few centimeters in air and only fractions of a millimeter in tissue). Beta particles have a much lower specific ionization than alpha particles and, generally, a greater range. For example, the relatively energetic beta particles from ^{32}P have a maximum range of 7 meters in air and 8 millimeters in tissue. The low energy betas from ^{3}H, on the other hand, are stopped by only 6 millimeters of air or 6 micrometers of tissue.

Gamma and x-rays are referred to as indirectly ionizing radiation since, having no charge; they do not directly apply impulses to orbital electrons as do alpha and beta particles. A gamma ray and x-ray instead proceeds through matter until it undergoes a chance interaction with a particle. If the particle is an electron, it may receive enough energy to be ionized whereupon it causes further ionization by direct interactions with other electrons. As a result, indirectly ionizing radiation (e.g. gamma and x-rays) can cause the liberation of directly ionizing particles (e.g. electrons) deep inside a medium. Because gamma and x-rays undergo only chance encounters with matter, they do not have finite ranges, but rather are attenuated in an exponential manner. In other words, a given gamma ray has a definite probability of passing through any medium of any depth.

Neutrons lose energy in matter by collisions which transfer kinetic energy. This process is called moderation and is most effective if the matter the neutrons collide with has about the same mass as the neutron. Thus, water, paraffin, or other materials with a high hydrogen content are very efficient moderators.

Once slowed down to the same average energy as the matter being interacted with (thermal energies), the neutrons have a much greater chance of interacting with a nucleus. Such interactions can result in material becoming radioactive or can cause radiation to be given off. An example of the process of activation in which material becomes radioactive is the reaction:

$$n + Na^{23} \rightarrow Na^{24}$$

Here natural sodium with atomic number 23 becomes activated to the radioactive sodium 24 (half-life of 15 hours) by absorbing a neutron.
An example of a neutron-nucleus interaction which results in radiation being given off is the reaction:

$$n + B^{10} \rightarrow Li^{7} + \alpha$$

In this case, boron-10 absorbs a neutron and gives off an alpha particle, leaving a lithium-7 nucleus. This process is often used to develop neutron detectors since the resulting alpha particle is relatively easy to detect.

5.3 Absorbed Dose

The absorbed dose is the quantity that expresses the amount of energy which ionizing radiation imparts to a given mass of matter. The special unit for absorbed dose is the rad (Radiation Absorbed Dose), which is defined as a dose of 100 ergs of energy per gram of matter. The SI unit for absorbed dose is the gray (Gy), which is defined as a dose of one joule per kilogram. Since one joule equals 10^7 ergs, and since one kilogram equals 1000 grams,

$$1 \text{ Gy} = 100 \text{ rad}$$

The size of the absorbed dose is dependent upon the strength (or **activity**) of the radiation source, the **distance** from the source to the irradiated material, and the **time** over which the material is irradiated. The activity of the source will determine the **dose rate** which can be expressed in rad/hr, mrad/hr, μGy/sec, etc.

PART II

MEASUREMENT OF IONIZING RADIATION

Ionizing radiation cannot be detected by the human senses. Its **detection** requires the identification of physical or chemical changes in a medium (gas, liquid, or solid) through which the radiation passes. **Measurement** of ionizing radiation requires the quantification of these physical or chemical changes. In general, detection and measurement methods can be categorized as being either active or passive.

1.0 ACTIVE DETECTION METHODS

Active radiation detection systems can be loosely defined as those that require an electrical power source for operation. Such detectors are generally used to characterize dose rates, count rates, etc. though some also have the capability of measuring cumulative dose. There are two principal types of active detectors; gas ionization and scintillation.

1.1 Gas Ionization Detectors

Most gas ionization detectors consist of a gas-filled chamber with a voltage applied such that a central wire becomes the anode and the chamber wall the cathode (See Figure 3). Any ion pairs produced by radiation interacting with the chamber move to the electrodes where they are collected to form an electronic pulse which can be measured and quantified. Depending upon the voltage applied to the chamber, the detector may be considered an **ion chamber**, a **proportional counter**, or a **Geiger-Mueller (GM) detector**.

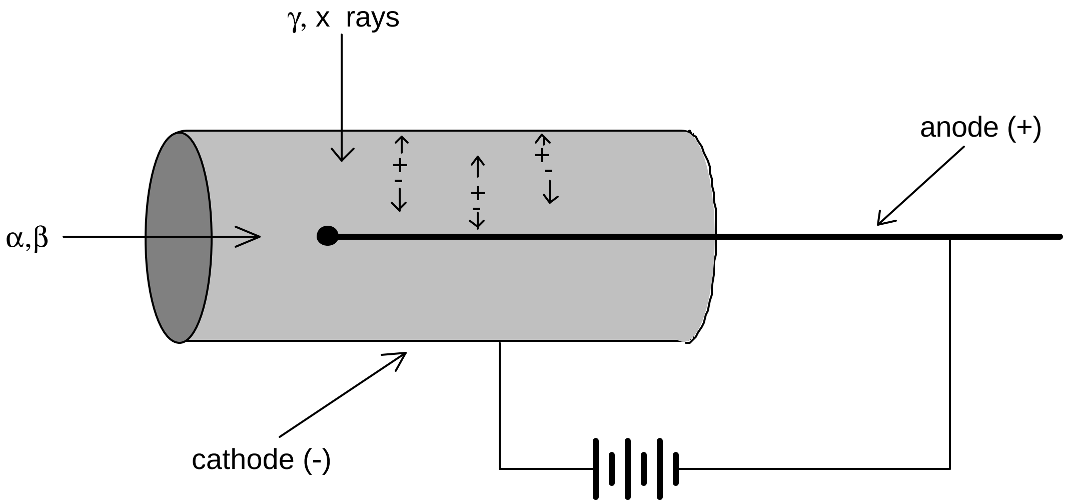

Figure 3. Diagram of a Gas Ionization Detector

Because of its versatility and dependability, the Geiger-Mueller detector is the most widely used portable survey instrument. It is particularly sensitive to medium-to-high energy beta particles (e.g., as from ^{32}P) yielding counting efficiencies of around 20 percent. The GM meter is also useful in detecting radiation levels near relatively large (e.g., at least mCi quantity) sources of medium-to-high energy gamma or x-rays.

The GM detector, however, is not particularly sensitive to low energy beta particles (such as those from ^{35}S and ^{14}C) yielding efficiencies of no more than 5 percent, nor is it very sensitive to low energy gamma and x-rays (such as from ^{125}I). In addition, neither the GM nor any other portable radiation meter is capable of detecting the very low energy beta particles from ^{3}H.

Unlike some other types of portable survey instruments, the GM detector does not actually "measure" exposure or dose rate. It instead "detects" the number of particles interacting in its sensitive volume per unit time. The GM should thus most appropriately be read-out in counts per minute (cpm), although it can be calibrated to approximate mrem/hr for certain situations.

1.2 Scintillation Detectors

Scintillation detectors are based upon the use of various phosphors (scintillators) which emit light in proportion to the quantity and energy of the radiation they absorb. The light flashes are converted to photoelectrons which are multiplied in a series of dynodes (i.e., a photomultiplier) to produce a large electrical pulse (See Figure 4). Because the light output and resultant electrical pulse is proportionate to the amount of energy deposited by the radiation, scintillators can be used in systems designed to identify the amount of specific radionuclides present.

Solid scintillation detectors are particularly useful in identifying and quantifying gamma and x-ray emitting radionuclides. The common gamma well-counter employs a large (e.g., 2"x2") crystal of Sodium Iodide (NaI) within a lead shielded well. The sample vial is lowered directly into a hollowed chamber within the crystal for counting. Such systems are extremely sensitive, but do not have the resolution of more recently developed semiconductor counting systems. Portable solid scintillation detectors are also widely used for conducting various types of radiation surveys. Of particular use to researchers working with radioiodines is the thin crystal (NaI) detector which is capable of detecting the emissions from ^{125}I with efficiencies nearing 20 percent (a GM detector is less than one percent efficient for ^{125}I).

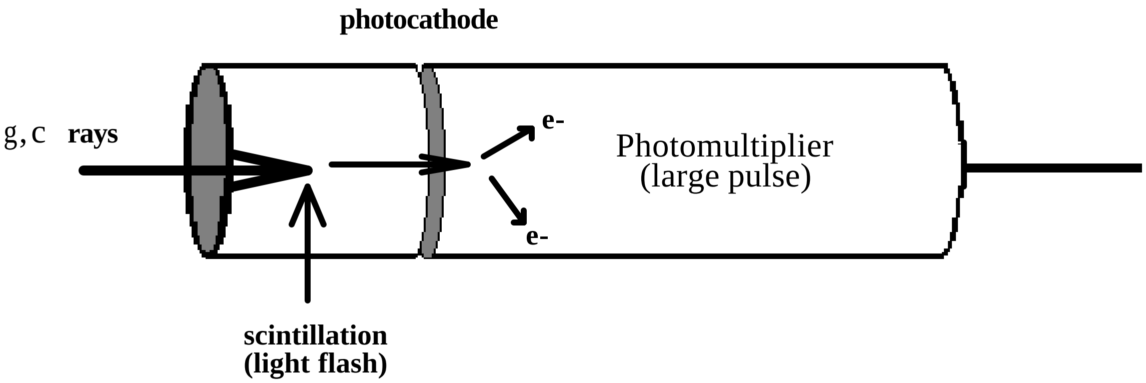

Figure 4. Diagram of a Scintillation Detector

The most common means of quantifying the presence of beta particle emitting radionuclides is through the use of liquid scintillation counting. In these systems, the sample and phosphor are combined in a solvent within the counting vial. The vial is then lowered into a well between two photomultiplier tubes for counting. Liquid scintillation counting has been an essential tool of research involving radionuclides such as ^{3}H and ^{14}C.

1.3 Counting Efficiency

An active radiation detection system can never see 100 percent of the disintegrations occurring in a given radioactive sample. This is due to numerous factors related to both the particular counting system and the specific radionuclides in the sample. The counts per minute (cpm) displayed by the counter must therefore be distinguished from the disintegration rate (dpm) of the sample. The ratio of the count rate (cpm) to the disintegration rate (dpm) expressed as a percent is the efficiency of the counting system.

$$\frac{\text{cpm}}{\text{dpm}}\text{x}100\% = \text{efficiency} \qquad \text{Eq. 6}$$

Efficiencies of a particular radiation counting system for various radionuclides can be determined through calibration of the system with standards of these same radionuclides.

Because every counting system will register a certain number of counts from environmental radiation and electronic noise in the counter (referred to as the instrument's background), a more correct formula is:

$$\frac{\text{cpm}_{\text{sample}} - \text{cpm}_{\text{bkgd}}}{\text{dpm}_{\text{sample}}}\text{x}100\% = \text{efficiency} \qquad \text{Eq. 7}$$

Example 2: A sample containing a ^{14}C labeled amino acid is counted in a liquid scintillation counter. The sample count rate is 1200 cpm and the background is 30 cpm. If the counter is 85% efficient for ^{14}C, what is the activity within the sample?

$$= \frac{1200 - 30}{0.85}\text{dpm}$$

$$= 1376 \text{ dpm}$$

$$\underline{-\frac{1376\ \text{dpm}}{2.22\text{x}10^6\text{dpm}/\mu\text{Ci}} = 6.2\text{x}10^{-4}\mu\text{Ci}}$$

1.4 Instrument Operation and Calibration

Whether an active detection system is stationary or portable, it must be properly maintained and calibrated in order to provide valid measurements. The specific requirements in this area, in terms of calibration frequencies and procedures, are generally detailed in an institution's license application. Ideally, calibrations should involve the use of a National Institute of Standards and Technology (N.I.S.T.) traceable source with radiation of similar type and energy to that being monitored. The date of the most recent calibration, the date the next calibration is due, and the signature of the person who performed the calibration must be indicated by a sticker attached to each instrument (the sticker may also indicate the counting efficiencies determined for various radionuclides). In addition to these formal calibrations (which are generally done on at least an annual basis), a check of the instrument's response to radiation should be performed with a small radioactive source each time the instrument is operated. The range of acceptable response to this check source should also be listed on the instrument.

2.0 PASSIVE DETECTION METHODS

Radiation detection methods that do not require a power source are referred to as “passive” methods or systems. The detection medium is usually a solid and is used almost exclusively to characterize cumulative dose rather than dose rate or particle fluence rate (as is the case for many active detection systems). An important use for such detectors is as personnel dosimeters (i.e., devices used to assess an individual's cumulative external radiation exposure). The two principal types of personnel dosimeters are film badges and thermo-luminescent dosimeters (TLD). These are discussed in detail in Part V under "Personnel Monitoring".

PART III

BIOLOGICAL EFFECTS OF IONIZING RADIATION

1.0 CELLULAR EFFECTS

The energy deposited by ionizing radiation as it interacts with matter may result in the breaking of chemical bonds. If the irradiated matter is living tissue, such chemical changes may result in altered structure or function of constituent cells.

1.1 Mechanisms of Radiation Damage

Less than 20% of the energy deposited in cells by ionizing radiation is absorbed directly by macromolecules. This is due to the fact that such molecules make up a relatively small proportion of the cell's mass. More than 80% of the energy deposited in the cell is absorbed by water molecules which make up the majority of the cell's mass. This results in the formation of highly reactive free radicals:

$$H_2O \xrightarrow{\text{radiation}} H^0 + OH^0 \rightarrow H_2O_2$$

These radicals and their products (e.g., hydrogen peroxide) may initiate numerous chemical reactions which result in damage to macromolecules and a corresponding alteration of structure or function. Damage produced within the cell by the radiation induced formation of free radicals is described as being by **indirect action** of radiation.

1.2 Changes in Structure and Function

As a result of the chemical changes in the cell caused by the direct or indirect action of ionizing radiation, large biological molecules may undergo a variety of structural changes which lead to altered function. Some of the more common effects which have been observed are inhibition of cell division, denaturation of proteins and inactivation of enzymes, alteration of membrane permeability, and chromosome aberrations.

2.0 RADIOSENSITIVITY

The cell nucleus is the major site of radiation damage leading to cell death. This is due to the importance of the DNA within the nucleus in controlling all cellular function. Damage to the DNA molecule may prevent it from providing the proper template for the production of additional DNA or RNA. This hypothesis is supported by research which has shown that cells are most sensitive to radiation damage during reproductive phases (i.e., during DNA replication).

In general, it has been found that cell radiosensitivity is directly proportional to rate of cell division and inversely proportional to the degree of cell differentiation. Table 1 presents a list of cells which generally follow this principle.

TABLE 1. List of Cells in Order of Decreasing Radiosensitivity

Very radiosensitive	
lymphocytes	(cellular elements of lymph)
erythroblasts	(cells of red marrow that synthesize hemoglobin and that are an intermediate in the initial stage of red blood cell formation)
spermatogonia	(primitive male germ cells)
basal cells	(innermost cells of the deeper epidermis of the skin)
endothelial cells	(thin flattened cells that line the internal body cavities)

Moderately radiosensitive	
osteblasts	(bone-forming cells)
granulocytes	(polymorphonuclear white blood cells with granule-containing cytoplasm)
osteocytes	(cells characteristic of adult bone and isolated in small cavities of the bone substance)
sperm	(mature male germ cell)
erythrocytes	(red blood cells)
fibroblasts	(cells that produce the fibrous connective tissue)

Relatively radioresistant	
fibrocytes	(fibrous connective tissue cells)
chondrocytes	(cartilage tissue cells)
muscle cells	
nerve cells	

The considerable variation in the radiosensitivities of various tissues is due, in part, to the differences in the sensitivities of the cells that compose the tissues. Also important in determining tissue sensitivity are such factors as the site of nourishment of the cell, interactions between various cell types within the tissue, and the ability of the tissue to repair itself.

The relatively high radiosensitivity of tissues consisting of undifferentiated, rapidly dividing cells suggests that, at the level of the human organism, a greater potential exists for damage to the fetus or young child than to an adult for a given dose. This has, in fact, been observed in the form of increased birth defects following irradiation of the fetus and an increased incidence of certain cancers in individuals who were irradiated as children.

3.0 HUMAN HEALTH EFFECTS

The effects of ionizing radiation upon humans can be classified as being either **stochastic** or **non-stochastic**.

3.1 Stochastic Effects

Stochastic effects are those that occur by chance. They consist primarily of cancer and genetic effects. As the dose to an individual increases, the probability that cancer or a genetic effect will occur also increases. However, at no time, even for high doses, is it certain that cancer or genetic damage will result. Similarly, for stochastic effects, there is no threshold dose below which it is relatively certain that an adverse effect cannot occur. In addition, because stochastic effects can occur in unexposed individuals, one can never be certain that the occurrence of cancer or genetic damage in an exposed individual is due to radiation.

3.2 Non-Stochastic Effects

Unlike stochastic effects, non-stochastic effects are characterized by a threshold dose below which they do not occur. In addition, the magnitude of the effect is directly proportional to the size of the dose. Furthermore, for non-stochastic effects, there is a clear causal relationship between exposure and the effect. Examples of non-stochastic effects include sterility, erythema (skin reddening), and cataract formation. Each of these effects differs from the others in both its threshold dose and in the time over which this dose must be received to cause the effect (i.e., acute vs. chronic exposure).

4.0 FACTORS DETERMINING HEALTH EFFECTS

The occurrence of particular health effects from exposure to ionizing radiation is a complicated function of numerous factors including the size of the dose received, the rate at which dose was imparted, the specific tissues or parts of the body irradiated, and the type of radiation involved.

4.1 Dose vs. Dose Rate

Radiation effects in humans have been shown to be directly dependent upon the total dose received. For many types of effects, however, the rate at which a given dose is imparted has also been shown to be important. This has been particularly evident for non-stochastic effects. For example, a dose of 300 rads to the skin, given within one hour (i.e., an **acute** exposure), will likely exceed the threshold for erythema. If the same dose is spread over a period of five years (i.e., a **chronic** exposure), erythema will not occur. The most likely explanation for such results is that spreading the dose over longer periods allows cellular repair mechanisms sufficient time to operate, thus minimizing the effects of the radiation damage. This repair phenomenon is also believed to operate, to some extent, for stochastic effects such as cancer, although the current conservative philosophy is to assume that the risk of such effects depends solely on the total dose. In other words, for the previous example, the risk of skin cancer would be presumed to be identical in both exposure situations.

4.2 Portion of Body Irradiated

The effectiveness of a given dose of radiation in producing biological damage in humans is also dependent upon the portion of the body irradiated. This is due to the differences in the radiosensitivities of the various tissue types and organs within the body. For example, a given dose to the eye is more likely to result in an adverse health effect than is the same dose to the hand. Similarly, a given dose to the whole body has a greater potential for causing an adverse health effect than does the same dose to only a portion of the body.

4.3 Dose Equivalent

Although the biological effects of radiation are dependent upon the absorbed dose, some types of particles produce greater effects than others for the same amount of energy imparted. For example, for equal absorbed doses, alpha particles may be 20 times as damaging as beta particles. In order to account for these variations when describing human health risk from radiation exposure, the quantity, **dose equivalent**, is used. This is the absorbed dose multiplied by certain “quality” and “modifying” factors (QF) indicative of the relative biological damage potential of the particular type of radiation. The special unit for dose equivalent is the **rem** (Roentgen Equivalent Man). The SI unit for dose equivalent is the **sievert** (Sv). The relationship of these units to those of absorbed dose is as follows:

$$\text{rem} = \text{rad} \times \text{QF}$$

$$\text{sievert} = \text{gray} \times \text{QF}$$

For gamma and x-ray exposures and for most beta particles exposures, the numerical value of the rem or sievert is essentially equal to that for the rad or gray, respectively.

5.0 RADIATION RISK

The risk estimates of cancer or genetic effects from low doses of radiation are based upon conservative extrapolation of the risks associated with high doses. This is due to the fact that the risk is too small to give meaningful numbers using only low dose data.

In an average group of 10,000 people, we can expect about 1,833 to eventually die from cancer. A report from the National Research Council has stated that, if 10,000 workers were to each receive a radiation dose of 1 rem in a single exposure, we could estimate that 8 of those 10,000 will eventually die from cancer due to that radiation exposure. Thus, a single dose of 1 rem is seen to increase the risk of death due to cancer from 18.33% to 18.41%.

Another way of expressing the risk from exposure to radiation is by computing the average number of days of life expectancy lost due to various doses. These values can then be compared to life expectancy losses computed for other activities. (See Table 2). The estimates in Table 2 indicate that the health risks from occupational radiation exposure are no greater than the risks associated with many other activities and events encountered in life. It is also important to note that the average occupational exposure resulting from the types and quantities of radioactive materials used in typical research labs is much less than the 1 rem/year indicated in the table.

TABLE 2. Estimated Loss of Life Expectancy from Various Activities

Health Risk	Estimates of Days of Life Expectancy Lost, Average
Smoking 20 cigarettes/day	2410 (6.6 years)
Overweight (by 20%)	985 (2.7 years)
All accidents combined	366 (1.0 years)
Alcohol consumption (U.S. average)	365 (1.0 years)
Auto accidents	207
Home accidents	74
Safest jobs (such as teaching)	30
Drowning	14
Natural background radiation, calculated	8
Medical X-rays (U.S. average), calculated	6
All catastrophes (earthquake, etc.)	3.5
0.1 rem/yr for 30 years, calculated	9.9
1 rem/yr for 30 years, calculated	51

* From Bernard L. Cohen, "Catalog of Risks Extended And Updated," Health Physics, Vol. 61, Sept. 1991.

PART IV

HUMAN EXPOSURE TO IONIZING RADIATION

1.0 SOURCES OF EXPOSURE

Human exposures to ionizing radiation can be classified broadly according to whether they result from sources within the work environment (i.e., occupational exposures) or from sources outside the work environment (i.e., non-occupational exposures).

1.1 Occupational Exposures

Occupational exposures are those received by individuals as a result of working with or near radiation sources (i.e., radioactive material or radiation-producing devices). Occupational exposures differ from non-occupational exposures in that they are generally received during the course of a 40 hour work week as opposed to a 168 hour week for natural exposures. In addition, whereas the non-occupational exposure received by a given individual is largely unknown, an individual's occupational exposure is closely monitored and controlled.

1.2 Non-Occupational Exposures

Non-occupational exposures can be divided into one of two categories: those originating from **natural** sources and those resulting from **human-made** sources.

All individuals are continuously exposed to ionizing radiation from various natural sources. These sources include cosmic radiation and naturally occurring radionuclides within the environment and within the human body. The radiation levels resulting from natural sources are collectively called "natural background." Natural background (and the associated dose it imparts) varies considerably from one location to another in the United States. Historically, the estimated value for the average whole body dose equivalent from natural background in the United States. has been about 100 mrem/person/year. More recently, this figure has been revised upward to between 250 to 300 mrem/person/year to account for the dose contribution from indoor radon.

The primary source of human-made radiation exposures is medical irradiation, particularly diagnostic x-ray and nuclear medicine procedures. Such procedures contribute an average 55 mrem/person/year in the United States. All other sources of human-made exposures such as nuclear weapons fallout, nuclear power plant operations, and the use of radiation sources in industry and universities contribute an average of less than one mrem/person/year in the United States.

2.0 ROUTES OF EXPOSURE

There are two principal routes by which humans are exposed to ionizing radiation, **external** and **internal**.

2.1 External Exposures

External exposures are those which are due to sources located outside of the body which emit radiation of a type and energy sufficient to reach and penetrate the body. Examples of penetrating radiations include gamma rays, x-rays, and high energy beta particles (e.g., as from ^{32}P). External exposures cannot result from sources which emit only alpha particles or low energy beta particles since these radiations do not penetrate the dead outer cell layer of the skin.

As with all radiation exposures, the size of the dose resulting from an external exposure is a function of: (1) the **activity** of the source; (2) the **time** or duration of the exposure; (3) the **distance** from the source to the tissue being irradiated; and (4) the amount of **shielding** between the source and the tissue. In contrast to the situation for internal exposures, these factors can be altered for a particular external exposure situation with a resultant increase or decrease in the dose received.

2.2 Internal Exposures

Internal exposures are those that result from radioactive material which has been taken up by the body as a result of **ingestion**, **inhalation**, **injection**, or **absorption** through the skin. Such exposures are of concern for all radioactive materials regardless of the type of ionizing radiation emitted. Of particular concern, however, are radioactive materials which emit alpha and beta particles. These radiations cause significant damage to tissue when depositing their energy along highly localized paths.

In contrast to the situation for external exposures, the source-to-tissue distance, exposure duration, and source strength cannot be altered for internal sources. Instead, once a quantity of radioactive material has been taken up by the body, an individual is essentially "committed" to the dose which will result from the quantities and forms of the particular radionuclides involved.

In general, radionuclides taken up by the body do not distribute equally throughout the body's tissues. Often a radionuclide concentrates in a particular organ or tissue type. For example, ^{131}I and ^{125}I concentrate in the thyroid, ^{45}Ca and ^{32}P in the bone, and ^{59}Fe in the spleen. In such cases, the affected tissue or organ sustains a correspondingly greater amount of dose than the body as a whole.

The dose committed to a particular organ or tissue depends, in part, upon the time over which these areas are irradiated by the radionuclide. This, in turn, is determined by the radionuclide's physical and biological half-lives (i.e., the effective half-life). The **biological half-life** of a radionuclide is defined as the time required for one half of a given amount of the radionuclide to be removed from the body by normal biological turnover.

3.0 EXPOSURE LIMITS

Concern over the biological effects of ionizing radiation began shortly after the discovery of x-rays in 1895. From that time to the present, numerous recommendations regarding occupational exposure limits have been proposed and modified by various radiation protection groups, the most important being the International Commission on Radiological Protection (ICRP). These guidelines have, in turn, been incorporated into regulatory requirements for controlling the use of materials and devices emitting ionizing radiation.

3.1 Basis of Recent Guidelines

In general, the guidelines established for radiation exposure have had as their principal objectives: (1) the prevention of acute radiation effects (e.g., erythema, sterility, etc.); and (2) the limiting of the risks of late stochastic effects (e.g., cancer and genetic damage) to "acceptable" levels. Numerous revisions of standards and guidelines have been made over the years to reflect both changes in the understanding of the risk associated with various levels of exposure and changes in the perception of what constitutes an "acceptable" level of risk. The current annual occupational dose limits have been established at a level where the risk of death from radiation induced cancer should not exceed the risk of accidental death to an average worker in a safe, non-nuclear industry.

Current guidelines for radiation exposure are based upon the conservative assumption that there is no safe level of exposure. In other words, even the smallest exposure is assumed to have some probability of causing a late effect such as cancer or genetic damage. This assumption has led to the general philosophy of not only keeping exposures below recommended levels or regulatory limits, but of also maintaining all exposures "as low as is reasonably achievable" (**ALARA**). This is a fundamental tenet of current radiation safety practice and is a regulatory requirement to be followed by all occupational users of radioactive materials and radiation producing devices.

3.2 Regulatory Limits for Occupational Exposure

Many of the recommendations of the ICRP and other radiation protection groups regarding radiation exposure have been incorporated into regulatory requirements by various countries. In the United States, the annual radiation exposure limits are found in Title 10, Part 20 of the Code of Federal Regulations (10CFR20), or equivalent state regulations. These limits are based on external, internal, and external plus internal exposures. To better understand the annual occupational exposure limits set by the appropriate regulatory agency, the definitions of these limits need to be discussed. These definitions are presented in this section.

EXTERNAL DOSE

Shallow-Dose Equivalent (SDE) is the external dose to the skin of the whole-body or extremity from an external source of radioactive material. This value is the dose equivalent at a tissue depth of 0.007 cm. (7 mg/cm^2) averaged over an area of 1 cm^2.
Eye Dose Equivalent (LDE) is the dose equivalent to the lens of the eye from an external source of radioactive material. This value is the dose equivalent at a tissue depth of 0.3 cm. (300 mg/cm^2).
Deep-Dose Equivalent (DDE) is the external whole-body dose from an external source of radioactive material. This value is the dose equivalent at a tissue depth of 1 cm. (1000 mg/cm^2).

INTERNAL DOSE

Committed Dose Equivalent (CDE) is the dose equivalent to organs or tissue that will be received from an intake of radioactive material.
Committed Effective Dose Equivalent (CEDE) is the dose equivalent for the whole-body from an intake of radioactive material.

EXTERNAL PLUS INTERNAL DOSE

Total Organ Dose Equivalent (TODE) is the dose equivalent to the maximally exposed organ or tissue from external and internal sources of radioactive material combined.

TODE = DDE + CDE

Total Effective Dose Equivalent (TEDE) is the dose equivalent to the whole-body from the combination of external and internal sources of radioactive material.

TEDE = DDE + CEDE

Table 3 provides a summary of the current annual occupational dose limits for external and internal exposures.

TABLE 3. Annual Occupational Dose Limits for Adult Workers

	Limit
Shallow Dose Equivalent, Whole-body	50 rem
Shallow Dose Equivalent, Max. Extremity	50 rem
Eye Dose Equivalent to the Lens of the eye	15 rem
Total Organ Dose Equivalent	50 rem
Total Effective Dose Equivalent	5 rem

In addition, internal exposure limits are addressed in the 10CFR20 through the establishment of "annual limits on intake" (**ALI**). These values represent the activity which, if taken up by the body during the course of the year (in either single or multiple events), would result in the individual receiving a committed effective dose equivalent of 5 rem or a committed dose equivalent of 50 rem. Table 4 lists ALI for some commonly used radionuclides.

TABLE 4. Annual Limits on Intake for Ingestion of Selected Radionuclides

Radionuclide	ALI (mCi)
^{3}H	80
^{14}C	2
^{32}P	0.6
^{35}S	10
^{45}Ca	2
^{125}I	0.04

One of the significant changes in the revised 10CFR20 effective January 1, 1994 is that it requires that an individual worker's total external and internal dose equivalents for a year be summed, and that this total be maintained $\leq$5 rem for the total effective dose equivalent (TEDE) and $\leq$50 rem for the total organ dose equivalent (TODE).

3.3 Regulatory Limits for Minors

A minor is anyone under 18 years of age. The annual occupational dose limits for minors are 10% of the annual occupational dose limits specified for adult workers in section 3.2.

3.4 Regulatory Limits for Exposure of Declared Pregnant Workers

Because of the increased susceptibility of the human embryo and fetus to damage from ionizing radiation, the National Council on Radiation Protection and Measurement (NCRP) recommends that the whole body radiation dose received by a female worker during the 9 months of her pregnancy not exceed 500 mrem (i.e., 10 percent of the normal annual occupational dose limits). The Nuclear Regulatory Commission has published Regulatory Guide 8.13 that details potential health risks of prenatal exposures and suggests precautions and options for the pregnant worker. The 10CFR20 and related state regulations have adopted the NCRP recommendations. These regulation allow a worker to **voluntarily** inform her employer, **in writing**, of her pregnancy and the estimated conception date. The "Declaration of Pregnancy" form is to be used to declare her pregnancy.

A TEDE of 500 mrem must not be exceeded by the declared pregnant worker throughout her entire pregnancy. If the worker has received greater than 500 mrem since the conception date, but prior to her declaration, she may not receive a TEDE of more than 50 mrem for the duration of her pregnancy. The declared worker may, at any time, revoke her declaration of pregnancy.

DECLARATION OF PREGNANCY

Name of Individual ____

Social Security Number ____

Date of Conception (Mo/Yr) ____

By providing this information to my immediate supervisor, in writing, I am declaring myself to be pregnant as of the date shown above. Under the provisions of 10 CFR Part 20.1208, FAC 64E-5, I understand that my exposure will not be allowed to exceed 500 mrem (5 mSv) during my entire pregnancy from occupational exposure to radiation. I understand this limit includes exposure I have already received. If my estimated exposure since the above date of conception has already exceeded 500 mrem (5 mSv), I understand that I will be limited to no more than 50 mrem (0.5) mSv for the remainder of my pregnancy. When the pregnancy has ended I will inform my supervisor and the Radiation Safety Officer (RSO) as soon as practical. I also understand I have the right to revoke this declaration of pregnancy at any time and such revocation must be made in writing to the RSO.

Signature of Individual ____

Date Signed ____

RECEIPT OF DECLARATION OF PREGNANCY

Name of Supervisor ____

I have received notification from the above named individual that she is pregnant. I have explained to her the potential risks from exposure to radiation as provided in Regulatory Guide 8.13, Revision 3. I have evaluated her prior exposure and established appropriate limits to control the dose to the developing embryo/fetus in accordance with limits in 10 CFR Part 20.1208, FAC 64E-5. I have explained to her options for reducing her exposure to as low as reasonably achievable (ALARA).

Signature of Supervisor ____

Date Signed ____

Send this completed form to the Radiation Safety Officer. The information furnished on this form will be used and maintained pursuant to 5 U.S.C. 552a (e) (3), enacted into law by Section 3 of the Privacy Act of 1974 (Public Law 93-579).

3.4 Regulatory Limits for dose to an Embryo/fetus

The dose to the embryo/fetus during the entire pregnancy, due to occupational exposure of a declared pregnant worker, must not exceed 500 mrem. The dose will be the sum of the deep dose equivalent (DDE) to the declared pregnant worker and the dose to the embryo/fetus from radionuclides in the embryo/fetus and radionuclides in the declared pregnant worker. The records of dose for the embryo/fetus will be permanently kept in the declared pregnant worker's dosimetry files.

3.5 Regulatory Limits for dose to an Individual Members of the Public

In general, the limits for dose to non-radiation workers and members of the public are 2 percent of the annual occupational dose limits. For the whole body dose, this would equal a TEDE of 100 mrem/year. This would be in addition to the 300 mrem/year received on average by individuals in the United States. from natural background radiations plus an average of 55 mrem/person/year from man-made radiation sources.

PART V

RADIATION SAFETY FOR LABORATORY USE OF RADIONUCLIDES

1.0 PHILOSOPHY OF CURRENT RADIATION SAFETY PRACTICE

Current regulatory limits for radiation dose have been conservatively set to prevent all acute effects of radiation dose and to limit the risk of chronic effects, such as cancer, to very low levels. As a primary objective, then, radiation safety practice attempts to ensure that all doses are below these limits. The accomplishment of this objective, however, is not the ultimate aim of current radiation safety practice. An overriding principle of radiation protection philosophy is that all doses must be maintained "**a**s **l**ow **a**s is **r**easonably **a**chievable": (**ALARA**). Thus, even if a given dose to an individual is within regulatory limits, it will not be acceptable if the dose could have been limited further by "reasonable" means. This unit describes the standard practices and procedures which constitute the means for ensuring doses are **ALARA**.

2.0 EXTERNAL RADIATION PROTECTION

High energy beta particles, gamma rays and x-rays are often referred to as "penetrating" radiations because of their ability to pass through considerable thicknesses of matter. Because of this ability, penetrating radiation can originate from sources external to the body and still impart a significant dose to living tissue. Radionuclides which emit such radiations thus pose an "external" radiation hazard. Examples of such radionuclides which are used in radiotracer research are the beta emitter, ^{32}P, and the gamma/x-ray emitter, ^{125}I.

Certain gamma emitters (e.g., ^{137}Cs, ^{60}Co) which are routinely encapsulated as sealed sources can also pose significant external hazards. On the other hand, such commonly used radionuclides as ^{3}H, ^{14}C, and ^{35}S are primarily internal radiation hazards since the beta particles they emit do not have sufficient energy to penetrate the skin (although if applied directly to the skin's surface in sufficiently large quantities, ^{14}C or ^{35}S can cause damage to living skin cells).

The dose resulting from a given exposure situation depends upon the duration of the exposure, the distance from the source to the tissue, and the strength of the source. For external exposures, these factors can be controlled to determine the total dose received.

2.1 Minimizing Exposure Time

In general, the dose (D) received from a particular exposure situation is the product of the dose rate ($\dot{D}$) and the exposure time (t):

$$D = \dot{D} \times t \qquad \text{Eq. 8}$$

It follows, then, that any reduction in the time (t) spent in radiation field ($\dot{D}$) will decrease the total dose received.

Example 3: A biochemist is working with a micro cap vial of 50 µCi of ^{32}P in a 1 ml solution. The dose rate to the researcher's thumb when holding the vial (a source to tissue distance of 1 cm) is 3.2 mrem/sec. If the researcher works 5 days per week all year with this type of sample, what is the maximum time per day she can handle the vial and not exceed her shallow dose equivalent limit to her hand?

daily maximum = 50,000 mrem/yr divided by 250 work days/yr

daily maximum = 200 mrem/day

$$t = \frac{D}{\dot{D}}$$

t = 200 mrem/day divided by 3.2 mrem/sec

t = 62.5 sec/day

This example clearly illustrates the substantial doses which an individual's hand can receive in a short period of time when he or she is working with relatively high specific activity ^{32}P solutions. If the individual added some shielding or just increased the distance by a few centimeters the dose would be greatly reduced as we shall see in the next examples.

2.2 Maximizing Distance from the Source

If one assumes that a source of gamma or x-rays occupies a single point, it can be shown mathematically that the dose rate at distance d from the source $\{\dot{D}(d)\}$ varies inversely with the square of the distance from the source:

$$\dot{D}(d) = \frac{\dot{D}(1)}{d^2} \qquad \text{Eq. 9}$$

where $\dot{D}(d)$ is the dose rate at distance d from the source and $\dot{D}(1)$ is the dose rate at a distance of 1 unit (meters, feet, etc.) from the source. From this equation, it is apparent that doubling the distance from a radiation source decreases the dose rate by a factor of 4. Increasing the distance by a factor of 3 decreases the dose rate by a factor of 9, etc.

The inverse square equation can also be used to approximate the dose rate from high energy beta particle emitters over short distances (e.g., less than 0.5 meters). At distances greater than this, beta particle dose rates decrease even more rapidly than predicted by the equation due to attenuation in air.

Example 4: The same researcher as in the previous example wants to increase the amount of time per day which she can handle the vial of 50 μCi of ^{32}P. She places the vial in a test tube rack and holds the rack at a distance of 10 cm from the vial for most manipulations. How much time per day can she now spend handling the vial without exceeding her annual dose limit to the hand?

$$\dot{D}(10\text{ cm}) = \frac{3.2\text{ mrem/sec}}{(10\text{ cm})^2}$$

$$= .032\text{ mrem/sec}$$

$$= 1.9\text{ mrem/min}$$

$$t = \frac{200\text{ mrem / day}}{1.9\text{ mrem / min}}$$

$$= 105.3\text{ min/day}$$

(as opposed to 62.5 sec for the previous example)

This example illustrates the usefulness of small amounts of distance in dramatically reducing external hazards.

2.3 Shielding the Source

The dose from a particular exposure situation can also be reduced by decreasing the source strength (i.e., dose rate) through the use of shielding. Shielding is any material which is placed around or in front of a radiation source to reduce its accessible dose rate. The amount by which a given shield reduces the dose rate from gamma or x-rays is given by the following equation:

$$\dot{D}_2 = \dot{D}_1 e^{-mx} \qquad \text{Eq. 10}$$

where $\dot{D}_2$ = dose rate from source shielded by thickness x
$\dot{D}_1$ = dose rate from source without shielding
x = absorber (i.e., shield) thickness
e = base of natural logarithms
μ = attenuation coefficient

Example 5: A researcher is temporarily storing several millicuries of ^{131}I waste solution within the fume hood. The dose rate at the face of the hood is 20 mrem/hr. If the researcher wraps several sheets of lead (total thickness of 1 cm) around the container, what will be the new dose rate at the face of the hood?

$\mu = 2.31\ \text{cm}^{-1}$ (for ^{131}I)

$x = 1$ cm

$\dot{D}_1 = 20$ mrem/hr

$\dot{D}_2 = ?$

$\dot{D}_2 = 20e^{-(2.31)(1)}$

$\dot{D}_2 = 2$ mrem/hr

Utilizing the same thickness of lucite, instead of lead:

$\mu = 0.12\ \text{cm}^{-1}$

$\dot{D}_2 = 20e^{-(0.12)(1)}$

$\dot{D}_2 = 18$ mrem/hr

This illustrates the effectiveness of lead over lucite in shielding gamma rays.

Because beta particles have finite ranges, they do not strictly follow the shielding equation (i.e., Eq. 8). According to equation 8, no amount of shielding can totally absorb all gamma rays emitted by a given source. However, for any beta emitting source, there is a particular amount of shielding material that will absorb all beta particles emitted.

As a secondary problem, the process by which beta particles are absorbed in matter results in the emission of x-rays known as bremsstrahlung radiation. The production of bremsstrahlung is much greater for high atomic number shields than for low atomic number shields. For example, as much as 8 percent of the energy from 1.5 MeV beta particles (e.g., as from ^{32}P) is converted to bremsstrahlung when these particles are absorbed in lead whereas less than one percent of the energy of these particles is converted to x-rays when they are absorbed in lucite. The ideal material for shielding beta particles, then, is one that is thick enough to stop all the beta particles but with an atomic number low enough to minimize the production of bremsstrahlung. For shielding ^{32}P beta particles, a 1 cm thickness of lucite or plexiglas is commonly used.

3.0 INTERNAL RADIATION PROTECTION

Any radionuclide, whether it is an alpha, beta, or gamma emitter, poses a potential hazard to health if incorporated into the body. Once within the body, the radionuclide will continue to irradiate living tissue until it is removed by natural processes. Because there is no easy way of increasing the rate of these processes, it is essential that radionuclides be prevented from being taken into the body in the first place.

In order to adequately protect against the uptake of radionuclides, it is important to understand the ways in which radionuclides enter the body. The four primary routes of uptake are: (1) ingestion; (2) inhalation; (3) absorption through the skin; (4) injection.

3.1 Protection Against Ingestion

By far the most common route of uptake of radionuclides is ingestion. Incorporation of radionuclides into the body by this pathway generally results from the researcher eating, drinking, or smoking with contaminated hands. This serves to emphasize the importance of observing strict contamination control measures in the laboratory including the monitoring of hands, clothing, and work areas after each procedure involving the use of radioactive material.

3.2 Protection Against Inhalation

Certain chemical forms of particular radionuclides volatilize easily and thus pose a hazard through inhalation. Examples of these include tritiated water and radioiodines in solution as NaI. Because of the volatility of these materials, procedures involving their use should always be carried out within a fume hood.

3.3 Protection Against Absorption

Many of the same types of radioactive materials that pose inhalation hazards also pose a hazard by absorption through the skin. Both tritiated water and various chemical forms of radioiodine are readily absorbed through the skin. In addition, such materials have been shown to diffuse fairly quickly through the thickness of a single rubber glove. For this reason, it is important that two pairs of gloves be worn and that the outer pair be changed frequently during procedures using these materials.

3.4 Protection Against Injection

Accidental puncture with contaminated syringes or other “sharps” is also a common route of uptake of radioactive material as well as biologically and chemically hazardous materials. For this reason, extra care should be practiced during manipulations or transfers where punctures are possible. In addition, all sharps should be disposed of in a designated sharps container.

4.0 RADIATION MONITORING

In order to ensure that internal and external doses to radiation are kept **ALARA**, it is essential that: (1) all radioactive materials remain confined to designated storage and work locations; and that (2) radiation levels resulting from the storage and use of these materials are adequately known and controlled. These objectives can only be met through the routine practice of various radiation monitoring activities.

4.1 Contamination Surveys

The undesired or uncontrolled presence of radioactive material on any surface is referred to as “contamination”. Radiation monitoring procedures designed to assess the locations and extent of such contamination are referred to as contamination surveys.

Depending upon the types and quantities of radioactive materials in use, contamination surveys may be made directly with portable survey instruments or indirectly by wiping surfaces (approximately 100 cm^2) with a filter paper and counting the wipes in a liquid scintillation counting system.

Contamination consisting of ^{3}H, ^{14}C, or ^{35}S is best detected through the use of wipes and liquid scintillation counting, since the beta emissions from these radionuclides are not sufficiently energetic to be efficiently detected by portable survey instruments (e.g., ^{3}H cannot be detected at all by such instruments). The use of wipes may also be appropriate when attempting to detect contamination in areas with higher than background radiation levels. For example, the use of a GM survey meter to detect ^{32}P contamination on the lip of a hood would not be practical if radiation levels at that point were already elevated from ^{32}P stored within the hood.

When radiation levels in an area are at normal background levels, portable survey instruments can be quite effective in detecting certain types of radioactive contamination. Most GM meters can detect ^{32}P with efficiencies exceeding 20%. ^{125}I can be detected at efficiencies nearing 20% with a thin crystal NaI scintillation probe.

4.2 Dose Rate Surveys

In addition to contamination monitoring, it is also important to assess external dose rates resulting from the storage and use of relatively large quantities of high energy beta particles or gamma ray emitters. This information is important in planning and evaluating the control of the factors of **time**, **distance** and **shielding** for the particular situation in order to minimize doses to personnel. In most situations, a properly calibrated GM meter can give a reasonable estimate of the dose rate.

4.3 Facility Audits by the RSO

In order to ensure that safety rules are observed and that radioactive materials have been adequately controlled, the radiation safety staff conduct routine audits of radionuclide laboratories. During the course of each audit, both external radiation levels and surface contamination levels are monitored. Also reviewed at this time are the investigator's radionuclide inventory and contamination survey records. Any problems encountered by the radiation safety staff during the audit are normally discussed with the laboratory supervisor and, when necessary, with the principal investigator.

4.4 Basic Procedures, Practices, and Rules for the Safe Use of Radioactive Materials.

In general, both internal and external exposures to ionizing radiation can be maintained As Low As is Reasonably Achievable (ALARA) through the adherence by radioactive material users to a number of standard procedures, practices, and rules:

1. Smoking, eating or drinking shall not be permitted in radionuclide laboratories.

2. Food, beverages and their containers shall not be permitted in the laboratory.

3. Pipetting by mouth shall not be permitted in radionuclide laboratories.

4. Microwave ovens in radionuclide laboratories shall not be used for heating food or beverages for personal use.

5. Individuals who have not been approved for radionuclide use shall not work with or handle radioactive materials.

6. A "Caution-Radioactive Material" sign shall be conspicuously posted at each entrance (e.g. on the door) of a radionuclide laboratory. Such signs or labels shall also be affixed at locations within the laboratory where radionuclides are used or stored (e.g. hoods, refrigerators, microwave ovens, etc.). Also posted within the laboratory in a conspicuous place shall be a copy of "Emergency Rules" and the "Notice to Employees."

7. Radionuclide work areas shall be clearly designated and should, to the extent possible, be isolated from the rest of the laboratory. The work area shall be within a hood if the radioactive material to be used is in a volatile form.

8. All work surfaces shall be covered with absorbent paper which should be changed regularly to prevent the build-up of contamination.

9. Work involving relatively large volumes or activities of liquid radioactive material should be performed in a spill tray lined with absorbent paper.

10. Procedures involving radioactive materials should be well planned and, whenever possible, practiced in advance using non-radioactive materials.

11. Protective clothing which is appropriate for the work conditions shall be worn when working with radioactive materials. This includes laboratory coats, gloves, and safety

glasses. Appropriate footwear must always be worn (sandals **cannot** be worn when working with radioactive materials).

12. Dosimeters shall be worn when working with relatively large quantities of radionuclides which emit penetrating radiation.

13. All containers of radioactive materials and items suspected or known to be contaminated shall be properly labeled (i.e. with tape or tag bearing the radiation logo and the word "radioactive").

14. All contaminated waste items shall be placed in a container specifically designated for radioactive waste. Sharp items such as needles or razor blades shall be placed in a cardboard box, glass bottle or "sharps" container.

15. A radiation survey shall be performed by the radionuclide user at the end of each procedure involving radioactive materials (the survey may be made using a portable survey instrument, wipes, or both depending on the radionuclides used). All items found to be contaminated shall be placed either in the radioactive waste container or an appropriately designated area. Any surfaces found to be contaminated shall be labeled and decontaminated as soon as possible. **The survey should always include a check of personnel for possible contamination. The RSO shall be notified immediately if extensive contamination is found within the laboratory or if any personnel are found to be contaminated.**

16. A record of the types and quantities of radionuclides possessed by each principal investigator at a given time shall be maintained.

17. Radioactive materials shall be protected from unauthorized removal or access at all times

5.0 PERSONNEL MONITORING

The assessment of an individual's cumulative dose from external and/or internal radiation exposure is based upon the use of various procedures and devices for monitoring these exposures.

5.1 Dosimeters

Devices use to measure an individual's cumulative external radiation dose are called “dosimeters”.

The most commonly used dosimeter in research laboratories is the **film badge**. This consists of a small piece of radiation-sensitive film placed in a special holder containing various filters. The film badge is worn by the researcher (e.g., usually on the upper torso near the lapel) whenever working with or near radioactive materials emitting penetrating radiations (i.e., energetic beta particles or gamma rays). On a periodic basis, the film in the badge is replaced and the exposed film forwarded to the vendor's laboratory for analysis. The amount of darkening of the film can then be measured and used to determine the dose received.

TLDs are small chips of material (e.g., LiF or CaF_2) which, when heated after an exposure to penetrating radiation, give off light in proportion to the dose received. In research laboratories, TLDs are commonly used within rings worn by individuals handling relatively large quantities of energetic beta or gamma emitting radionuclides (e.g., ^{32}P, ^{125}I).

5.2 Bioassays

Assessing the dose from internal radiation exposure is far more difficult than the determination of the dose from an external exposure. Procedures for this purpose are collectively termed "bioassays". For many water soluble compounds of low energy beta emitting radionuclides (e.g... ^{3}H. ^{14}C), the bioassay consists of a urinalysis utilizing liquid scintillation counting. For radioiodines, internal doses are best assessed by using a NaI scintillation probe to externally measure the radiation coming from the thyroid.

5.3 Recording of Monitoring Data

The federal and state regulations require monitoring of any radiation worker who could possibly receive 10% of any annual occupational dose limit in normal job duty. Annual reports of occupational doses must be given to those individuals meeting this monitoring requirement. A report of annual occupational doses must be given to the monitored individual upon termination or upon request by that individual.

All monitored personnel must receive an annual occupational dose report, whether or not they meet the aforementioned monitoring requirement. This report normally is the Nuclear Regulatory Commissions' **NRC Form 5**.

6.0 EMERGENCY AND DECONTAMINATION PROCEDURES

Despite the strict adherence to all laboratory safety rules, it is possible that accidents involving radioactive material will occur on occasion. For this reason, it is important that radioactive material users are aware of the proper procedures to follow for various types of accidents.

6.1 Minor Spills

Incidents involving the release or spillage of less than 100 microcuries of a radionuclide in a nonvolatile form can generally be regarded as minor. In such cases:

1. Notify all other persons in the room at once.
2. Clear the room of all persons except those needed to deal with the spill.
3. Confine the spill immediately.

   Liquids: Drop absorbent paper or chemical (e.g. calcium bentonite) on the spill.

   Solids: Dampen thoroughly, taking care not to spread contamination. Use water, unless a chemical reaction would release air contaminants; otherwise use oil.

4. Notify the laboratory supervisor.
5. Notify the Radiation Safety Officer or Staff.

6.2 Major Spills or Releases

An incident which occurs outside of the hood and involves the release of more than 100 microcuries of a radionuclide in a nonvolatile form, or the release of any amount of a radionuclide in a volatile form, should be considered "major." In such cases:

1. Evacuate the room immediately shutting doors and windows on the way out.
2. Notify the laboratory supervisor.
3. Notify the Radiation Safety Officer or Staff.
4. Post the laboratory door with a "Keep Out" sign.
5. Assemble those persons who were present in the laboratory near the entrance.
6. Wait for assistance.

6.3 Accidents Involving Personal Injury

For any accident involving personal injury, medical treatment or assistance will always be the first priority. This may involve administering first aid and/or calling 911 for emergency medical assistance. For accidents involving radioactive materials, contamination control and exposure control are also important but should never delay or impede medical assistance. If radioactive materials are involved, the RSO must be notified as soon as possible. After the injured person is treated and removed from the accident site, the previously described procedures should be followed as appropriate.

6.4 Decontamination Procedures

In the event that surfaces or equipment within the laboratory are suspected or determined to be contaminated with radioactive material, the radionuclide user must initiate and complete appropriate decontamination procedures. For most relatively minor contamination incidents, the following general steps should be taken upon discovery of the contamination:

1. Mark the perimeter of the contaminated area.

2. Notify the RSO of the contamination so that their staff can more accurately assess the extent of the contamination and advise and assist in the decontamination effort.

3. Assemble cleaning supplies such as paper towels, detergent in water, plastic bags and plastic gloves.

4. Proceed with scrubbing the area from the borders to the center, cleaning small areas at a time.

5. Periodically monitor the effectiveness of the decontamination effort with surface wipes and instrument surveys.

6. Place all contaminated cleaning materials such as paper towels, rags, and gloves in a plastic bag and label as radioactive waste.

7. Notify the RSO upon completion of the decontamination effort so that a follow-up contamination survey can be made.

Glossary

Absorbed Dose - the amount of energy imparted to matter by ionizing radiation per unit mass of irradiated material. The unit of absorbed dose is the rad, which is 100 ergs/gram.

Absorption - the phenomenon by which radiation imparts some or all of its energy to any material through which it passes.

Activation - the process of making a material radioactive by bombardment with neutrons, protons, or other nuclear radiation.

Activity - the rate of disintegration or transformation or decay of radioactive material. The units of activity are the becqueral (bq) and the curie (Ci).

Acute Exposure - the absorption of a relatively large amount of radiation (or intake of radioactive material) over a short period of time.

Acute Health Effects - prompt radiation effects (those that would be observable within a short period of time) for which the severity of the effect varies with the dose, and for which a practical threshold exists.

Adult - an individual 18 or more years of age.

Agreement State - any state with which the U.S. Nuclear Regulatory Commission has entered into an effective agreement concerning the licensing of by-product material. Iowa is an agreement state and regulates the safe uses of radiation and by-product material within its boundary.

ALARA (acronym for As Low As Reasonably Achievable) - making every reasonable effort to maintain exposures to radiation as far below the dose limits as is practical, consistent with the purpose for which the licensed activity is undertaken, taking into account the state of technology, the economics of improvements in relation to state of technology, the economics of improvements in relation to benefits to the public health and safety, and other societal and socioeconomic considerations, and in relation to utilization of nuclear energy and licensed materials in the public interest.

Alpha Particle - a strongly ionizing particle emitted from the nucleus during radioactive decay having a mass and charge equal in magnitude to a helium nucleus, consisting of 2 protons and 2 neutrons with a double positive charge.

Annual Limit on Intake (ALI) - the derived limit for the amount of radioactive material taken into the body of an adult worker by inhalation or ingestion in a year. ALI is the smaller value of intake of a given radionuclide in a year by a reference person that would result in a committed effective dose equivalent of 5 rem (0.05 Sv) or a committed effective dose equivalent of 50 rem (0.5 Sv) to any individual organ or tissue.

Atom - smallest particle of an element which is capable of entering into a chemical reaction.

Attenuation - the process by which a beam of radiation is reduced in intensity when passing through some material. It is the combination of absorption and scattering processes and leads to a decrease in flux density of the beam when projected through matter.

Background Radiation - ionizing radiation arising from radioactive material other than the one directly under consideration. Background radiation due to cosmic rays and natural radioactivity is always present. There may also be background radiation due to the presence of radioactive substances in other parts of the building, in the building material itself, etc.

Beta Particle - charged particle emitted from the nucleus of an atom during radioactive decay. A negatively charged beta particle is identical to an electron. A positively charged beta particle is called a positron.

Bioassay - the determination of kinds, quantities or concentrations and, in some cases, the locations of radioactive material in the human body, whether by direct measurement (*in vivo* counting) or by analysis and evaluation of materials excreted or removed from the human body.

Body Burden - the amount of radioactive material which if deposited in the total body will produce the maximum permissible dose rate to the critical organ.

Bremsstrahlung - electromagnetic (x-ray) radiation produced by the deposition of charged particles in matter. Usually associated with energetic beta emitters, e.g., phosphorus - 32.

Calibration - determination of variation from standard, or accuracy, of a measuring instrument to ascertain necessary correction factors.

Charged Particle - an ion. An elementary particle carrying a positive or negative electric charge.

Chronic Exposure - the absorption of radiation (or intake of radioactive materials over a long period of time), i.e., over a lifetime.

Committed Dose Equivalent - the dose equivalent to organs or tissues of reference that will be received from an intake of radioactive material by an individual during the 50-year period following the intake.

Committed Effective Dose Equivalent - the sum of the products of the weighting factors applicable to each of the body organs or tissues that are irradiated and the committed dose equivalent to these organs or tissues.

Contamination, Radioactive - deposition of radioactive material in any place where it is not desired, and particularly in any place where its presence may be harmful. The harm caused may be a source of excessive exposure to personnel or the validity of an experiment or a procedure.

Controlled Area - an area, outside of a restricted area but inside the site boundary, access to which can be limited by the licensee for any reason.

Coulomb - the meter-kilogram-second unit of electric charge, equal to the quantity of charge transferred in one second by a constant current of one ampere.

Count - the external indication of a device designed to enumerate ionizing events. It may refer to a single detected event or to the total registered in a given period of time. The term is often erroneously used to designate a disintegration, ionizing event, or voltage pulse.

Critical Organ - the organ or tissue, the irradiation of which will result in the greatest hazard to the health of the individual or his descendants.

Curie - the quantity of any radioactive material in which the number of disintegrations is 3.7×10^{10} per second. Abbreviated Ci.

Daughter Products - isotopes that are formed by the radioactive decay of some other isotope. In the case of radium-226, for example, there are ten successive daughter products, ending in the stable isotope lead-206.

Decay, Radioactive - disintegration of the nucleus of an unstable nuclide by the spontaneous emission of charged particles and/or photons.

Declared Pregnant Woman - a woman who has voluntarily informed her employer, in writing, of her pregnancy and the estimated date of conception.

Decontamination - the reduction or removal of contaminating radioactive material from a structure, area, object, or person. Decontamination may be accomplished by (1) treating the surface to remove or decrease the contamination, (2) letting the material stand so that the radio-activity is decreased as a result of natural decay, and (3) covering the contamination to shield or attenuate the radiation emitted.

Deep Dose Equivalent - applies to external whole-body exposure and is the dose equivalent at a tissue depth of one centimeter (1000 mg/cm 2).

Department of Transportation (DOT) - a governmental agency responsible for promoting the safe transportation of hazardous materials by all modes. (land, air, water).

Disintegration - see decay, radioactive.

Dose or Radiation Dose - a generic term that means absorbed dose, dose equivalent, effective dose equivalent, committed dose equivalent, committed effective dose equivalent, or total effective dose equivalent, as defined in other paragraphs of this section.

Dose Rate - the radiation dose delivered per unit of time. Measured, for example, in rem per hour.

Dosimeter - a portable instrument for measuring and registering the total accumulated exposure to ionizing radiation. (see dosimetry.)

Dosimetry - the theory and application of the principles and techniques involved in the measurement and recording of radiation doses. Its practical aspect is concerned with the use of various types of radiation instruments with which measurements are made. (see film badge; thermo luminescent dosimeter; Geiger-Mueller counter.)

Effective Dose Equivalent - the sum of the products of the dose equivalent to the organ or tissue and the weighting factors applicable to each of the body organs or tissues that are irradiated.

Efficiency - (radiation detection instrument) a measure of the probability that a count will be recorded when radiation is incident on a detector. Usage varies considerably so be aware of which factors (window, transmission, sensitive volume, energy dependence, etc.) are included in a given case. Efficiency refers to the percent of total activity present for a given nuclide detected by the radiation detection instrument being used.

Electron - negatively charged elementary particle which is a constituent of every neutral atom. Its unit of negative electricity equals 4.8 x 10 -19 coulombs. Its mass is 0.00549 atomic mass units.

Electron Volt - a unit of energy equivalent to the amount of energy gained by an electron in passing through a potential difference of 1 volt. Abbreviated eV. Radioisotopic energy is typically measured in MeV. (million electron volts)

Erg - the unit of energy or work in the centimeter-gram-second system; the work performed by a force acting over a distance of one centimeter so as to result in a one gram mass being accelerated at a rate of one centimeter per second each second.

Exposure - (1) being exposed to ionizing radiation or radioactive material. (2) a measure of the ionization produced in air by x or gamma radiation. It is the sum of the electrical charges on all ions of one sign produced in air when all electrons liberated by photons in a volume element of air are completely stopped in air, divided by the mass of air in the volume element. The special unit of exposure is the Roentgen.

Extremity - hand, elbow, arm below the elbow, foot, knee, or leg below the knee.

Eye Dose Equivalent - applies to the external exposure of the lens of the eye and is taken as the dose equivalent at a tissue depth of 0.3 centimeter (300 mg/cm 2).

Film Badge - a packet of photographic film used for the approximate measurement of radiation exposure for personnel monitoring purposes. The badge may contain two or more films of differing sensitivity, and it may contain filters which shield parts of the film from certain types of radiation.

Fission- the splitting of a nucleus into at least two other nuclei and the release of a relatively large amount of energy. Two or three neutrons are usually released during this type of transformation.

Gamma Ray - very penetrating electromagnetic radiation of nuclear origin. Except for origin, identical to x-ray.

Geiger-Mueller - (G-M) Counter a radiation detection and measuring instrument. It consists of a gas-filled tube containing electrodes, between which there is an electrical voltage but no current flowing. When ionizing radiation passes through the tube, a short, intense pulse of current passes from the negative electrode to the positive electrode and is measured or counted. The number of pulses per second measures the intensity of radiation.

Gray (Gy) - the SI unit of absorbed dose. One Gray is equal to one joule per kilogram (100 rad).

Half-Life, Biological - time required for the body to eliminate 50 % of a dose of any substance by the regular processes of elimination. This time is approximately the same for both stable isotopes and radionuclides of a particular element.

Half-Life, Effective - time required for a radioactive nuclide in a system to be diminished by 50 % as a result of the combined action of radioactive decay and biological elimination.

Effective half-life = Biological half-life x Radioactive half-life / Biological half-life + Radioactive half-life

Half-Life, Radioactive - time required for a radioactive substance to lose 50 % of its activity by decay. Each radionuclide has a unique half-life.

Half Value Layer - the thickness of any specified material necessary to reduce the intensity of an x-ray or gamma ray beam to one-half its original value.

Health Physics - a term in common use for that branch of radiological science dealing with the protection of personnel from harmful effects of ionizing radiation.

High Radiation Area - an area, accessible to individuals, in which radiation levels could result in an individual receiving a dose equivalent in excess of 100 mrem (1 mSv) in one hour at thirty centimeters from the radiation source or from any surface that the radiation penetrates.

Hot Spot - the region in a radiation/contamination area in which the level of radiation/contamination is noticeably greater than in neighboring regions in the area.

Individual Monitoring Devices - devices designed to be worn by a single individual for the assessment of dose equivalent such as film badges, thermoluminescent dosimeters (TLDs), pocket ionization chambers, and personal air sampling devices.

Inverse Square Law - the intensity of radiation at any distance from a point source varies inversely as the square of that distance. For example: if the radiation exposure is 100 R/hr at 1 inch from a source, the exposure will be 0.01 R/hr at 100 inches.

Ion - an atom that has too many or too few electrons, causing it to be chemically active; such as an electron that is not associated (in orbit) with a nucleus. Ions may be positively or negatively charged, and vary in size.
Ionization the process by which a neutral atom or molecule acquires either a positive or a negative charge.
Ionization Chamber an instrument designed to measure the quantity of ionizing radiation in terms of the charge of electricity associated with ions produced within a defined volume.

Ionizing Radiation - alpha particles, beta particles, gamma rays, x-rays, neutrons, high speed electrons, high speed protons, and other particles or electromagnetic radiation capable of producing ions.

Isotopes - nuclides having the same number of protons in their nuclei, and hence having the same atomic number, but differing in the number of neutrons, and therefore in the mass number. Almost identical chemical properties exist between isotopes of a particular element.

Joule - the meter-kilogram-second unit of work or energy, equal to the work done by a force of one Newton when its point of application moves through a distance of one meter in the direction of the force.

Labeled Compound - a compound consisting, in part, of labeled molecules. By observations of radioactivity or isotopic composition this compound or its fragments may be followed through physical, chemical or biological processes.

Licensed Material - source material, special nuclear material, or byproduct material received, possessed, used, transferred or disposed of under a general or specific license issued by the Nuclear Regulatory Commission or an Agreement State.

Licensee - the holder of the license.

Limits - the permissible upper bounds of radiation exposures, contamination or releases.

Member of the Public - an individual, except when that individual is receiving an occupational dose.

Microcurie (µCi) - a one-millionth part of a curie. (1/1,000,000th), (.000001 Ci), (see curie.)

Millicurie (mCi) - a one-thousandth of a curie. (1/1000th), (.001 Ci), (see curie.)

MilliRoentgen (mR) - a sub multiple of the Roentgen equal to one-thousandth (1/1000th) of a Roentgen. (see Roentgen.)

Minor - an individual less than 18 years of age.

Monitoring - the measurement of radiation levels, concentrations, surface area concentrations or quantities of radioactive material and the use of the results of these measurements to evaluate potential exposures and doses.

NARM - naturally occurring or accelerator-produced radioactive material. It does not include by-product, source, or special nuclear material.

Natural Radiation - ionizing radiation, not from manmade sources, arising from radioactive material other than the one directly under consideration. Natural radiation due to cosmic rays, soil, natural radiation in the human body and other sources of natural radioactivity are always present. The levels of the natural radiation vary with location, weather patterns and time to some degree.

Neutron - elementary particle with a mass approximately the same as that of a hydrogen atom and electrically neutral. It has a half-life in minutes and decays in a free state into a proton and an electron.

Non-Removable Contamination - contamination adhering to the surface of structures, areas, objects or personnel and will not readily be picked up or wiped up by physical or mechanical means during the course of a survey or during decontamination efforts.

NORM - naturally occurring radioactive materials.

Nuclear Regulatory Commission (NRC) - an independent federal regulatory agency responsible for licensing and inspecting nuclear power plants, universities and other facilities using radioactive materials.

Nucleus - the small, central, positively charged region of an atom that carries essentially all the mass. Except for the nucleus of ordinary (light) hydrogen, which has a single proton, all atomic nuclei contain both protons and neutrons. The number of protons deter-mines the total positive charge, or atomic number; this is the same for all the atomic nuclei of a given chemical element. The total number of neutrons and protons is called the mass number.

Nuclide - a species of atom characterized by its mass number, atomic number, and energy state of its nucleus, provided that the atom is capable of existing for a measurable time.

Occupational Dose - the dose received by an individual in the course of employment in which the individual’s assigned duties involve exposure to radiation and to radioactive material from licensed and unlicensed sources of radiation, whether in the possession of the licensee or other person. Occupational dose does not include dose received from background radiation, as a patient from medical practices, from voluntary participation in medical research programs, or as a member of the general public.

Photon - a quantum (or packet) of energy emitted in the form of electromagnetic radiation. Gamma rays and x-rays are examples of photons.

Pig - a container (usually lead) used to ship or store radioactive materials. The thick walls protect the person handling the container from radiation. Large containers are commonly called casks.

Pocket Dosimeter - a small ionization detection instrument that indicates radiation exposure directly. An auxiliary charging device is usually necessary.

Positron - particle equal in mass, but opposite in charge, to the electron; a positive charge.

Principal Investigator (P.I.) - a faculty member, assistant professor or higher (no visiting faculty), employed by the licensee, who has been approved through the Radiation Safety Committee for the purchase and use of radioactive materials. Principal investigators seeking approval must fill out applications describing the isotopes and activities to be used as well as the procedures, survey equipment and techniques and other pertinent information prior to approval.

Protective Barriers - barriers of radiation absorbing material, such as lead, concrete, plaster and plastic, that are used to reduce radiation exposure.

Proton - an elementary nuclear particle with a positive electric charge located in the nucleus of an atom.

Public Dose - the dose received by a member of the public from exposure to radiation and to radioactive material released by a licensee, or to another source of radiation either within a licensee's controlled area or in unrestricted areas. It does not include occupational dose or doses received from background radiation, as a patient from medical practices, or from voluntary participation in medical research programs.

Quality Factor - a modifying factor that is used to derive dose equivalent from absorbed dose. It corrects for varying risk potential due to the type of radiation.

Rad - the special unit of absorbed dose. One rad is equal to an absorbed dose of 100 ergs/gram.

Radiation Area - an area, accessible to individuals, in which radiation levels could result in an individual receiving a dose equivalent in excess of 0.005 rem (0.05 mSv) in one hour at thirty centimeters from the radiation source or from any surface that the radiation penetrates.

Radiation Worker - an individual who uses radioactive materials under the licensees' control. Individuals must be trained and have passed a radiation safety examination prior to beginning work with radioactive materials.

Radiography - the making of shadow images on photographic film by the action of ionizing radiation.

Radioisotope - a nuclide with an unstable ratio of neutrons to protons placing the nucleus in a state of stress. In an attempt to reorganize to a more stable state, it may undergo various types of rearrangement that involve the release of radiation.

Radiology - that branch of medicine dealing with the diagnostic and therapeutic applications of radiant energy, including x-rays and radioisotopes.

Radionuclide - a radioactive isotope of an element.

Radiosensitivity - the relative susceptibility of cells, tissues, organs, organisms, or other substances to the injurious action of radiation. Radiotoxicity term referring to the potential of an isotope to cause damage to living tissue by absorption of energy from the disintegration of the radioactive material introduced into the body.

Relative Biological Effectiveness - for a particular living organism or part of an organism, the ratio of the absorbed dose of a reference radiation that produces a specified biological effect to the absorbed dose of the radiation of interest that produces the same biological effect.

REM - the special unit of dose equivalent. The dose equivalent in rems is equal to the absorbed dose in rads multiplied by the quality factor. (1 rem = .001 sievert)

Removable Contamination - contamination deposited on the surface of structures, areas, objects or personnel that can readily be picked up or wiped up by physical or mechanical means during the course of a survey or during decontamination efforts.

Restricted Area - an area, access to which is limited by the licensee for the purpose of protecting individuals against undue risks from exposure to radiation and radioactive materials. Restricted area does not include areas used as residential quarters, but separate rooms in a residential building may be set apart as a restricted area.

Roentgen (R) - the quantity of x or gamma radiation such that the associated corpuscular emission per 0.001293 gram of dry air produces, in air, ions carrying one electrostatic unit of quantity of electricity of either sign. Amount of energy is equal to 2.58 x 10 -4 coulombs/kg air. The Roentgen is a special unit of exposure.

Scintillation Counter - a counter in which light flashes produced in a scintillator by ionizing radiation are converted into electrical pulses by a photomultiplier tube.

Sealed Source - radioactive material that is permanently bonded or fixed in a capsule or matrix designed to prevent release and dispersal of the radioactive material under the most severe conditions which are likely to be encountered in normal use and handling.

Seivert - the SI unit of any of the quantities expressed as doe equivalent. The dose equivalent in Seivert is equal to the absorbed dose in Gray multiplied by the quality factor. (1 Sv = 100 rem)

Shallow Dose Equivalent - applies to the external exposure of the skin or an extremity and is taken as the dose equivalent at a tissue depth of 0.007 centimeter (7 mg/cm 2) averaged over an area of one square centimeter.

Shielding Material - any material which is used to absorb radiation and thus effectively reduce the intensity of radiation, and in some cases eliminate it. Lead, concrete, aluminum, water and plastic are examples of commonly used shielding material.

SI - the abbreviation for the International System of Units.

Site Boundary - that line beyond which the land or property is not owned, leased, or otherwise controlled by the licensee.

Smear - (smear or swipe test) a procedure in which a swab, e.g., filter paper or cotton tipped applicator, is rubbed on a surface and its radioactivity measured to determine if the surface is contaminated with loose (removable) radioactive material.

Specific Activity - total radioactivity of a given nuclide per gram of a compound, element or radioactive nuclide.

Stable Isotope - an isotope that does not undergo radioactive decay. Survey an evaluation of the radiological conditions and potential hazards incident to the production, use, transfer, release, disposal or presence of radioactive material or other sources of radiation. When appropriate, such an evaluation includes a physical survey of the location of radioactive material and measurements or calculations of levels of radiation, or concentrations or quantities of radioactive material present.

Thermoluminescent Dosimeter (TLD) - crystalline materials that emit light if they are heated after being they have been exposed to radiation.

Total Effective Dose Equivalent - the sum of the deep dose equivalent (for external exposures) and the committed effective dose equivalent (for internal exposures).

Tracer, Isotopic - the isotope or non natural mixture of isotopes of an element which may be incorporated into a sample to make possible observation of the course of that element, alone or in combination, through a chemical, biological, or physical process. The observations may be made by measurement of radioactivity or of isotopic abundance.

Unrestricted Area - an area, access to which is neither limited nor controlled by the licensee.

Unstable Isotope - a radioisotope.

Very High Radiation Area - an area accessible to individuals, in which radiation levels could result in an individual receiving an absorbed dose in excess of 500 rads (5 grays) in one hour at one meter from a source of radiation or from any surface that the radiation penetrates.

X-Rays - penetrating electromagnetic radiation having wave lengths shorter than those of visible light. They are usually produced by bombarding a metallic target with fast electrons in a high vacuum. In nuclear reactions it is customary to refer to photons originating in the nucleus as gamma rays, and those originating in the extranuclear part of the atom as x-rays. These rays are sometimes called Roentgen rays after their discoverer, W.C. Roentgen.

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