Radiation Safety

For

Laboratory Workers

Radiation Safety Program
University Safety and Assurances

University of Wisconsin-Milwaukee
P.O. Box 413
Milwaukee, WI 53201
414-229-6339

January 2017

Table of Contents

Introduction i

Chapter 1 – Radiation and Radioisotopes

Atomic Structure 1
Radioactivity 2
Types of Emission 3
Energy 5
Activity 5
Decay Rate and Half-life 5
Interactions with Matter 6
Radiation Quantities and Units 6
Characteristics of Commonly Used Radionuclides 8

Chapter 2 – Radiation Detectors

Survey Meters 11, 16
Liquid Scintillation Counters 13, 18
Dosimeters 13
Radiation Detection and Measurement Techniques 16
Detector Efficiencies 20

Chapter 3 – Biological Effects of Radiation

Hazard Classification 22
External Radiation Exposure 22
Biological Effects 23
Internal Radiation Exposure 25
Radiation Exposure During Pregnancy 26
Biological Hazards from Radioactive Compounds 26

Chapter 4 – Current Standards and Dose Limits

Background Radiation 29
Current Exposure Limits 30
Radiation Exposure Risks 31
ALARA Program 32
Internal Doses 32

Chapter 5 – Reducing Radiation Exposure

Time 35
Distance 35
Shielding 36
Laboratory Practices 38

Chapter 6 – Current Regulations and Radiation Safety Procedures

Area Monitoring 41
Radioactive Material Ordering 42
Record Keeping 42
Waste Disposal 43
Iodine-125 45
Animals 46
Emergency Procedures 47

Self-Test Answers 52

Appendix A 53

Appendix B-1 54

Appendix B-2 55

Appendix B-3 61

Appendix C – Glossary 62

Introduction

This guide is for laboratory technicians, students and other persons who work with or around radioactive materials under the premise that every person working within a radionuclide lab should know the basics about radioisotopes and their effects. This guide will provide both the radiation and laboratory worker with basic information needed to protect himself/herself and to understand and comply with Federal, State and University regulations regarding the use of radioactive materials.

Topics covered in this document are:

- Nature and Characteristics of Radiation and Radioactivity
- Radiation Detection and Measurement
- Possible Hazards of Radiation Including Hazards to the Fetus
- Dose and Exposure Limits
- Safety Practices Which Can Reduce Radiation Exposure to Workers and the Environment
- Current Regulations and Emergency Procedures

In most cases the principles have been simplified and the rules summarized in this guide for easier understanding, but the concepts are correct. The self-test questions at the end of each chapter are an integral part of the guide, and are designed to help you decide whether or not you understand the material in the chapter. If you are not sure of the correct answer, look back in the chapter and then answer all the questions correctly before going on to the next chapter. The correct answers to the self-test questions are given in the back of the book. The glossary in the back of the guide will explain and further clarify any new words used in the text. Also associated with this guide is the "Radiation Safety Exam". This set of questions covers all the material discussed. If you don't know the answer to one of the questions, look it up in the proper chapter. After you have answered all the questions, turn in the "exam" to the Radiation Safety Program Office. This exam will serve as a permanent record of your basic radiation safety training. You should be able to answer all of the answers correctly. If you miss five or more answers you will be required to resubmit the exam.

The required depth and extent of knowledge you require for working with radioactivity depends on the amount, type, and chemical form of the radioisotope you work with, and the hazards associated with the radioactivity. Much of this information and additional instruction regarding specific lab procedures will need to be demonstrated to you in the laboratory. Documentation of that training should be made on the "Training and Instruction Checklist" (APPENDIX A) and submitted to the Radiation Safety Program Office as a part of your permanent training records. Individuals working with radioactive materials will need to complete all three sections. Individuals only working in radionuclide use areas who are **not** handling or using radioactive materials need only complete sections two and three. You are responsible for clarifying any questions regarding your working conditions with your supervisor.

If you routinely work with more than one millicurie of radioactive material or if you supervise workers who use these quantities, you should have a more thorough understanding of radiation safety and mandated procedures than is presented in this guide. The Radiation Safety Program can provide additional information and short training programs tailored to your specific safety needs. Please contact either your supervisor or the Radiation Safety Office to arrange such training.

Every person working with radioactive material has the right to inspect the current applicable regulations and a copy of the current DHS License. A person cannot be fired or discriminated against for asking questions about radiation safety procedures. A copy of the UWM DHS License is on file in the Radiation Safety Program office, and each laboratory should have a copy of the "Guide to the Safe Use of Radionuclides at the University of Wisconsin-Milwaukee". Every person who wears a dosimeter has the right to request the record of their annual exposure.

Chapter 1

Radiation and Radioisotopes

Radiation is simply the movement of energy through space or another media in the form of waves, particles, or rays. Radioactivity is the name given to the natural breakup of atoms which spontaneously emit particles or gamma/X energies following unstable atomic configuration of the nucleus, electron capture or spontaneous fission.

Atomic Structure

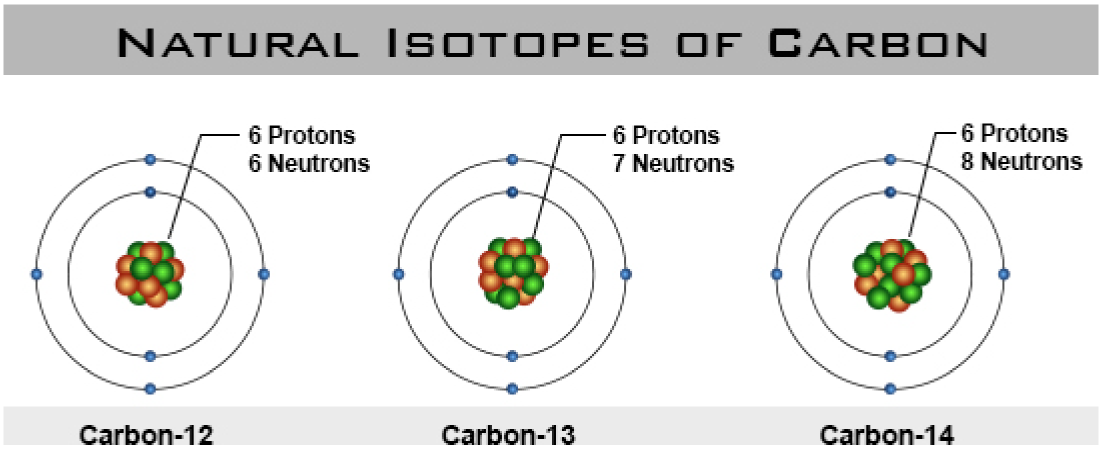
The universe is filled with matter composed of elements and compounds. **Elements** are substances that cannot be broken down into simpler substances by ordinary chemical processes (e.g., oxygen) while **compounds** consist of two or more elements chemically linked in definite proportions. Water, a compound, consists of two hydrogen and one oxygen atom as shown in its formula, H_2O. While it may appear that the atom is the basic building block of nature, the atom itself is composed of three smaller, more fundamental particles called **protons, neutrons, and electrons**. The **proton (p)** is a positively charged particle with a magnitude one charge unit (1.602×10^{-19} coulomb) and a mass of approximately one atomic mass unit (1 amu = 1.66×10^{-24} gram). The **electron (e^-)** is a negatively charged particle and has the same magnitude charge (1.602×10^{-19} coulomb) as the proton. The electron has a negligible mass of only 1/1840 atomic mass units. The **neutron (n)** is an uncharged particle that is often thought of as a combination of a proton and an electron because it is electrically neutral and has a mass of approximately one atomic mass unit. Neutrons are thought to be the "glue" which binds the nucleus together.

Combinations of the fundamental particles following certain strict natural laws result in the formation of atoms. In concept, the neutrons and protons form a dense, central core or nucleus around which the electrons rotate in various orbits. Nearly all of the atom's mass is located in the nucleus. Natural law specifies that each atom has the same number of protons as it has electrons. This means that the total positive charge in the nucleus is equal to the total negative charge of the orbiting electrons and this produces an electrically neutral atom.

Each element has a unique number of protons (and corresponding neutrons) that determine its chemical properties. The number of protons in an atom is its **atomic number**, represented by the symbol **Z**. Thus, for carbon, which has 6 protons, Z=6. When the chemical symbol for an element is used with its atomic number, the atomic number is subscripted, e.g., ${}_6C$. Thus, all atoms with an atomic number of 1 are hydrogen atoms (${}_1H$); 2 are helium atoms (${}_2He$); 3 atoms are lithium (${}_3Li$); 4 are beryllium atoms (${}_4Be$); etc.

The chemical properties of an atom are determined by the number of protons contained in the nucleus. For example, every atom which has six protons in its nucleus is a carbon atom. However, while all the atoms of a particular element have the same number of protons, they may have different numbers of neutrons. For carbon, there can be five, six, seven, or eight neutrons. Each of these atoms is a different **isotope** of carbon. Figure 1 illustrates the natural isotopes of carbon. All the isotopes of carbon are chemically identical, because the chemical properties are dictated by the atomic number (number of protons) of the element. The term **nuclide** means any isotope of any element.

Figure 1



Stable **Stable** **Unstable**

Radioactivity

Naturally occurring elements often have several different isotopes. While most of these naturally occurring isotopes are stable, some are unstable. Usually an atom is unstable because the ratio of neutrons to protons produces a nuclear imbalance (i.e., too many protons or too many neutrons in the nucleus). These unstable atoms attempt to become stable by rearranging the number of protons and neutrons in the nucleus to achieve a more stable ratio. The excess energy from this rearrangement is ejected from the nucleus as kinetic energy. In this rearrangement, the isotope usually changes atomic number and sheds any excess energy by emitting secondary particles and or electromagnetic rays/photons. This change in the nucleus is called **nuclear disintegration**. The entire process of unstable isotopes disintegrating and emitting energy is called **radioactive decay or decay** and an isotope capable of undergoing radioactive decay is said to be **radioactive**.

Most of the isotopes encountered in nature are not radioactive. However, there are mechanisms to inject energy into an isotope's nucleus causing it to become unstable. To **activate** an isotope is to make it radioactive. This can be accomplished in a nuclear reactor where the nucleus can be bombarded by neutrons or in an accelerator where high speed electrons, protons, or larger particles can be injected into the nucleus. If something merely touches a radioisotope, it does not become radioactive, but it may become contaminated with radioactive material (see Chapter 6).

Unstable nuclei are radioactive. Unlike chemical processes which occur at the electron level and can be affected by external forces like heat, there is no known way to alter radioactive decay. Radioactive decay cannot be artificially accelerated or slowed down because radioactive instability involves extremely strong nuclear forces. Each isotope decays at a rate that is unique among all other nuclides. Additionally, the type and magnitude of the radioactive energy emitted depends upon the isotope. Thus, there are three parameters that uniquely identify any radionuclide: the type(s) of energy emitted, the magnitude of the energy, and the rate at which the isotope decays.

Types of Emission

When a radioisotope decays it normally emits one or more of four basic types of radiations: alpha particles, beta particles, X- or gamma rays, and neutrons. These radiations interact with atoms and molecules in the environment and deposit their energy. Table 1, at the end of this section, presents some properties of these decay types.

An **alpha (α) particle** is a massive particle on the atomic scale. It consists of 2 neutrons and 2 protons and carries an electrical charge of +2. It is identical to a helium nucleus. Because the alpha particle is massive and highly charged it has a very short **range** and travels less than 5 cm in air or 0.044 cm in tissue before expending its energy, stopping, and picking up two electrons to become a stable helium atom. Thus alpha particles are generally not a hazard to workers unless they get inside the body where they may cause much greater cellular damage than beta or gamma radiation.

A **beta (ß) particle** is a fast electron with a single charge. Depending on the isotope and mechanism of decay, the beta particle can have a negative or positive charge. The positively charged beta particle is called a **positron ($^{+}$ß)**. It usually results when the neutron:proton ratio is too low but when the alpha emission is not energetically possible. Positron emission produces a daughter nucleus which has the same atomic mass but is one less atomic number. The negatively charged beta particle is properly called an **electron (e^{-})** and, in every day usage the term beta radiation usually refers to the negative type, **-ß**. **Beta (-ß)** emission occurs when the neutron:proton ratio is too high.

Figure 2. Beta Decay Spectrum

$$ {}^{18}_{9}\mathrm{F} \text{ -------> } {}^{18}_{8}\mathrm{O} + {}^{0}_{+1}\beta + \nu $$

positron ($^{+}$ß)

$$ {}^{32}_{15}\mathrm{P} \text{ -------> } {}^{32}_{16}\mathrm{S} + {}^{0}_{-1}\beta + \nu $$

electron ($^{-}$ß)

Because beta radiation is a small particle with only a single charge, a beta particle has a much greater range than an alpha particle with the same energy. Low energy beta particles, energies less than 200 keV, are easily shielded and only pose a potential hazard if they get inside the body. Thus, the beta particle emitted from ^{3}H with a maximum energy of 18 keV only travels about 6 mm in air and less than 0.00052 cm in tissue. Beta particles with energy less than 70 keV will not penetrate the protective layer of skin. Of the beta particles emitted from ^{14}C or ^{35}S (E_{max} ~ 160 keV), only 11% are capable of penetrating the dead layer of skin (0.007 cm thick). On the other hand, high energy beta particles have longer ranges. The range of beta particles in air is approximately 12 ft per MeV. Therefore, the beta from ^{32}P ejected with a maximum energy of 1.7 MeV could travel up to 20 feet in the air and 95% of the beta particles can penetrate the dead layer of skin, so ^{32}P may pose a potential radiation hazard even from outside the body. Shielding large quantities of high energy beta particle emitters is usually done with plastic or plexiglass because when the beta particles are shielded with dense materials like lead, **bremsstrahlung** xrays (see Chapter 5) are produced.

A **gamma (γ)** ray is an electromagnetic ray emitted from the nucleus of an excited atom following radioactive disintegrations. Unlike beta particles, which are emitted in a spectrum of energies, gamma rays are emitted at discrete energies and provide a mechanism for the excited nucleus to rid itself of the residual decay energy that was not carried off by the particle emitted in its decay. Thus, many isotopes which decay by beta emission also have gamma rays (or photons) associated with the disintegration. Gamma rays are similar to light but of shorter wavelength and higher energy. Consider activities greater than 1 mCi a radiation hazard and shield with thick, dense material such as lead.

Figure 3. Gamma Ray Decay

$$^{22}_{11}\mathrm{Na} \text{------>} \; ^{22}_{10}\mathrm{Ne} + \, ^{0}_{+1}\beta + \nu + ?$$

An **X-ray** is an electromagnetic ray, identical to a gamma ray in all respects except for the point of origin. Gamma rays are emitted from the nucleus as part of the nuclear decay process. X-rays originate from outside the nucleus normally as part of the electron orbital changes.

A **neutron (n)** is an elementary nuclear particle with a mass approximately the same as that of a proton and is electrically neutral. Normally the neutron decays to a proton. Except when bound in the nucleus, the neutron is not a stable particle. A free neutron decays to a proton with the emission of a $^{-}$ß and an antineutrino. This decay process takes on the average of about 12 minutes. There are few naturally occurring neutron emitters. Aside from nuclear-fission reactions, the only way to produce neutron sources is through bombardment of the nuclei with high energy radiation (both particles and rays). Because a neutron is uncharged, it easily passes through the electron cloud and can interact with the nucleus of the atom, often making the atom radioactive.

Table 1. Decay Types

Name	Symbol	Range	Shielding Requirements
Alpha Particle	α	Short	None
Beta Particle	ß	Moderate	Low Density Material, e.g. Plastic
Gamma/X-rays	γ/X	Long	High Density Material, e.g. Lead
Neutron	N	Long	Hydrogenous Material, e.g. Paraffin

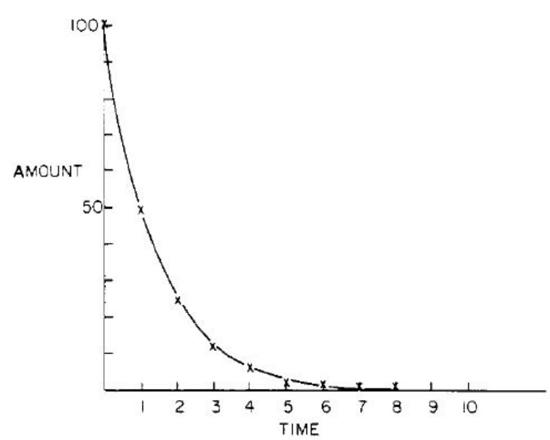
Energy
The energy carried away by radiation is expressed in units of **electron volts (eV)**. The electron volt is a very small quantity of energy ($1.6x10^{-19}$ Joule). Most radiations are ejected with energies of many thousand or millions of electron volts, listed as either **keV (kiloelectron volts – 1000 eV)** or **MeV (megaelectron volts – 1,000,000 eV)**. The amount of energy involved and the type of radiation emitted determines the penetrability of the radiation and consequently the shielding thickness and type required to protect workers from radiation. All things being equal, the higher the energy, the more penetrating the radiation. For example, gamma rays have higher decay energy and need more shielding than alpha or beta particles which have lower decay energies.

Activity
The decay of a radioactive sample is statistical. Just as it is not possible to change a specific isotope's rate of decay, it is impossible to predict when a particular atom will disintegrate. Rather, one measures **activity** as the number or radioactive nuclei that change or decay per unit time (e.g., second). The special unit of activity is the **curie (Ci)** where 1 curie represents 37 billion ($3.7x\ 10^{10}$) nuclear disintegrations (decays) per second (dps) or alternately, $2.22x10^{12}$ disintegrations per minute (dpm). Sub-multiples of the curie are the **millicurie (mCi)** which represents one-thousandth ($3.7x10^7$ dps) of a curie and the **microcurie (µCi)** which represents one-millionth ($3.7x10^4$ dps) of a curie. As will be discussed later in this section, everywhere except in the U.S., the curie unit has been replaces by the **bequerel (Bq)** unit where 1 Bq is 1 nuclear disintegration or decay per second.

Decay Rate and Half-Life
Radioisotopes are always in a state of decay, emitting energy. Therefore, the amount of radioactivity remaining is continually decreasing. Each radioisotope has a unique decay rate and that decay rate is the **physical half-life ($T_{½}$)** of the radioisotope. Half-life describes the length of time required for the amount of radioactivity present to decrease to half of its original amount. This decrease in material is not linear. Figure 4 shows a plot of the decay of a radioisotope having a half-life of 1 day so you can see how rapidly the amount decreases.

Figure 4. Half-Life

Referring to Figure 4, if we start with 100 microcuries of material, by the end of the second day (two half-lifes) we will have only 25 microcuries of material, and at the end of the fourth day only 6.25 microcuries will remain. However, there are still over one quarter million disintegrations per second remaining, even after four half-lives.



From Figure 4, you can see that the greater the number of radioactive atoms that are initially present, the greater the number of nuclei that will decay during a half-life (e.g., if 100 radioactive atoms are present, 50 will decay in one half-life, if 1000 radioactive atoms are present, on average 500 will decay in one half-life). The decay rate or activity of a radioactive sample is proportional to the number of unstable nuclei that are initially present. This relationship is expressed by the universal decay equation where A_0 is the original radioactivity of the sample, A_t is the amount of radioactivity remaining after the elapsed time, t, and $T_{1/2}$ is the (physical) half-life of the radioisotope. The **decay constant, λ**, expresses the rate of decay as a factor of the radioactive half-life ($T_{½}$), where **$\lambda = \ln 2/T_{½}$.**

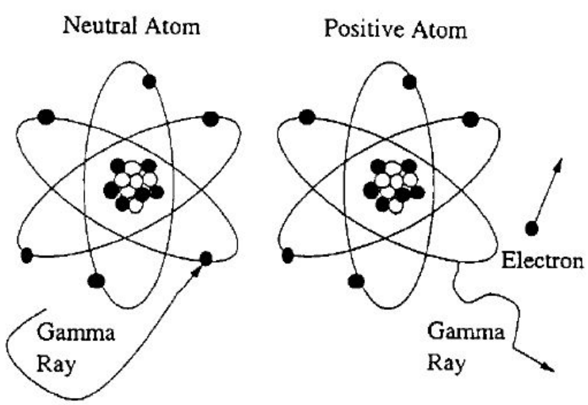
Figure 5. Universal Decay Equation

$$A_t = A_0\, e^{-\lambda t} = A_0\, e^{-\ln 2/T_{½}\, t}$$

Interaction with Matter

When alpha, beta or gamma radiation passes through matter it interacts with atoms and molecules, depositing energy in the matter until it has spent its kinetic energy and comes to rest or is absorbed. Ionizing radiation interacts at the orbital electron level and results in ionization and excitation of the atoms in the matter. Ionization (Figure 6) is the process where the electrons are knocked out of their orbits producing ion pairs (i.e., a free electron and a positively charged atom or molecule). If sufficient energy is deposited an orbital electron may be excited and on returning to ground state, emit low energy radiation.

Figure 6. Ionization



Radiation Quantities and Units

A **quantity** is some physically measureable entity (e.g., length, mass, time electric current, etc.) that needs to be measured. A **unit** is the amount of quantity to be measured. Units for various quantities are formulated when needed by national or international organizations such as the National Institute of Science and Technology (NIST) or the international General Conference on Weights and Measures (CGPM). Traditional units were formulated by these organizations.

Traditional units used to measure and quantify radioactive materials were developed during late 1800's during early research into radioactive materials. That early research showed that the number of ion pairs produced in a physical substance is related to the amount of radiation energy deposited in the substance. The oldest, still used, radiation unit, the **roentgen (R)**, is based on the number of ion pairs produced in a volume of air traversed by x- or gamma radiation. This unit of x-/γ radiation exposure in air, is defined to be the collection of 2.58×10^{-4} coulombs per kilogram of air. Since each electron carries a charge of 1.6×10^{-19} coulomb, this represents 1,610,000,000,000,000,000 ion pairs in a kilogram of air. Submultiples, the **milliroentgen (mR)** and the **microroentgen (μR)** are also frequently used.

Early radiation researchers also investigated the effects of radiation energy on matter. Initially the roentgen was widely used, but because it is limited to x-/γ radiation in air, a second unit, the **rad**, was defined to be the unit of absorbed dose in any matter. The rad equals 100 ergs of energy deposited per gram of matter. Although the roentgen is a unit of radiation exposure in air and a rad is a unit of exposure in tissue, the two units are very close in magnitude. They are correlated by the fact that 1 roentgen produces 0.96 rad in biological tissue. An easy method for defining rad, think of it as the acronym for **radiation absorbed dose**.

Investigating the effects of radiation at the cellular level, researchers found that for the same quantity of absorbed dose, different types of radiations produced different amounts of cellular damage. For example, the cellular damage from an absorbed dose of 100 rad from alpha particles was significantly more severe than the damage caused by 100 rad from gamma rays. The "quality" of the alpha particle's deposited energy, at the cellular level, is greater than the "quality" of the gamma ray's deposited energy. The **rem** is the unit of radiation dose equivalence used to equalize the biological effectiveness of the various types of radiation. The radiation absorbed dose in rad, multiplied by the radiation's **quality factor, Q**, which varies from 1-20 (Table 2), produces the dose equivalent, in rem, of the radiation exposure (i.e., rem=rad x Q). Thus, an absorbed dose of 1 rad to tissue from a radionuclide deposition produces a dose equivalence of 1 rem if the radionuclide is ß/γ emitter and a dose equivalence of 20 rem if the radionuclide is an α emitter. An easy method for defining a rem is to think of it as the acronym for **roentgen equivalent man**.

Table 2. Quality Factors

Type of Radiation	**Q**
X-/Gamma Rays	1
Beta Particles, electrons	1
Thermal Neutrons	2-3
Fast Neutrons, protons	10
Alpha Particles	20

In the 1970's an international agreement was developed to make all physical constants convertible by multiplying by units of "1" alone. This system of measurement is called the international system of units of SI (Le Systeme International d' Unites). SI units are based on the MKS (meters, kilogram, second) system. Thus, the unit of (radio)activity was changed from the curie which is $3.7x10^{10}$ nuclear disintegrations per second (dps) to the Becquerel (Bq) which is 1 dps. The traditional unit of absorbed dose, the rad, was replaced by a new unit of absorbed dose, the gray (Gy), which is defined as 1 Joule per kilogram, and is equal to 100 rad. Similarly, the unit of dose equivalent was replaced by the Sievert (Sv) which is equal to 100 rem. Table 3 shows the relationship between the traditional and SI units.

Table 3. Radiation Quantities and Units

Traditional		SI		Conversion Factor
Unit	**Quantity**	**Unit**	**Quantity**	
curie	$3.7x\ 10^{10}$ dps	**becquerel**	1 dps	1 Bq=$2.7x10^{-11}$ Ci
rad	100 erg/gm	**gray**	1 J/kg	1 Gy=100 rad
rem	rad x Q	**sievert**	Gy x Q	1 Sv=100 rem

Table 4. Metric Prefixes

Prefix	**Quantity**		**Prefix**	**Quantity**	
deka (da)	10^1	10	deci (d)	10^{-1}	0.1
hecto (h)	10^2	100	centi (c)	10^{-2}	0.01
kilo (k)	10^3	1,000	milli (m)	10^{-3}	0.001
mega (M)	10^6	1,000,000	micro (µ)	10^{-6}	0.000 001
giga (G)	10^9	1,000,000,000	nano (n)	10^{-9}	0.000 000 001
tera (T)	10^{12}	1,000,000,000,000	pico (p)	10^{-12}	0.000 000 000 001
peta (P)	10^{15}	1,000,000,000,000,000	femto (f)	10^{-15}	0.000 000 000 000 001

Characteristics of Commonly Used Radionuclides

Radioisotope use at the University typically consist of small quantities of liquid materials, but some users have laboratories where relatively large quantities of radioactive material are used. To ensure worker safety and to prevent accidental exposure, all labs where radioactive materials may be used or stored are conspicuously posted with “Caution – Radioactive Materials” signs. To reduce radiation exposure, workers in these posted areas must understand the characteristics of the radioisotopes. Characteristics of commonly used radioisotopes are listed in Table 5. This table includes: isotope and chemical symbol; half-life; and, most importantly, energy of the major radiations emitted. Because ß particles are emitted in a wide spectrum of energies, the energy listed is the maximum energy that the emitted beta particle can possess.

Table 5. Characteristics of Common Radioisotopes

Isotope	Symbol	Half-life	Radiation	Energy, MeV
Tritium	^{3}H	12.3 years	ß	0.0186
Carbon-14	^{14}C	5730 years	ß	0.157
Sodium-22	^{22}Na	2.6 years	ß γ	0.546 1.274
Phosphorus-32	^{32}P	14.3 days	ß	1.709
Phosphorus-33	^{33}P	25.3 days	ß	0.249
Sulfur-35	^{35}S	88 days	ß	0.167
Calcium-45	^{45}Ca	163 days	ß	0.258
Chromium-51	^{51}Cr	28 days	γ	0.320
Cobalt-57	^{57}Co	272 days	γ	0.122
Nickel-63	^{63}Ni	92 years	ß	0.067
Iodine-125	^{125}I	60 days	γ	0.035
Iodine-131	^{131}I	8.0 days	ß γ	0.606 0.364
Cesium-137	^{137}Cs	30 years	ß γ	0.514 0.662

Chapter 1 – Self-Test

Fill in the correct response.

1. The three components of every atom are ____________, ____________, and ____________.
2. An atom of Carbon-14 (^{14}C) has how many of each of the following: _____ protons, ______ neutrons, and ______ electrons.
3. ___________ have equal numbers of protons but different numbers of neutrons in the nucleus.
4. ___________ is the process by which unstable isotopes disintegrate and emit energy.
5. “To activate” materials means to make them _____________.
6. The ______________ is the amount of time required for a quantity of radioisotope to decrease to one-half of its original amount.
7. One curie (Ci) of activity represents _________________ disintegrations per second.
8. The amount of X- or gamma rays present is measured in _______________.
9. One becquerel (1 Bq) is equivalent to ______________ disintegrations per second (dps).
10. The amount of energy absorbed from a radioactive source is measured in ___________.
11. One rem is equal to _____________ millirem.
12. The most penetrating forms of ionizing radiation are _____________.

Chapter 2

Radiation Detectors

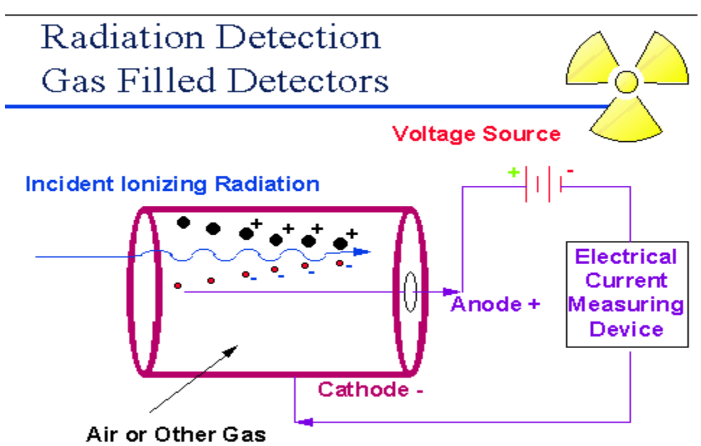
Because human beings cannot see or feel radiation it is necessary to rely on monitoring and detecting equipment to measure the amount of radioactivity present. A variety of instrumentation is available for that purpose.

Radiation is detected using special detectors which measure the amount or number of ionizations or excitation events that occur within the device. The radiation detection system can be either active or passive, depending upon the device and the mechanism used to determine the number of ionizations. Active devices provide an immediate indication of the amount of radiation or radioactivity present. Passive devices are usually processed at a special processing facility before the amount of radiation exposure can be reported. Portable radiation survey meters and laboratory counting equipment are active devices, while radiation dosimeters used in determining individual exposure to radiation and radon detectors are passive devices. At the end of this chapter, Table 6, lists expected efficiencies for commonly used radioisotopes using different types of survey equipment.

Survey Meters

Figure 7 illustrates the basic principle used by portable instruments in the detection and measurement of ionizing radiation. The detector tube (i.e. Geiger counter) is simply a gas filled, cylindrical tube with a long central wire that has a 900-volt positive charge applied to it and is then connected, through a meter, to the walls of the tube. Radiation enters the tube and produces ion pairs in the gas. The electron part of the ion pair is attracted to the positively charged central wire where it enters the electric circuit. The meter then shows this flow of electrons (i.e. the number of ionizing events) in counts per minute (cpm).

Figure 7. Radiation Detection



The only prerequisite for the detection of radiation with a survey meter is that the radiation must have sufficient energy to penetrate the walls of the detector tube and create ionizations in the gas. Particulate (alpha and beta) radiations have a limited range in solid materials so, radiation detectors designed for these radiations must be constructed of thin walls that allow the radiation to penetrate. The most common types of portable radiation survey meters used in research labs are the thin window Geiger-Mueller (GM), Low energy Gamma (LEG), and Ion Chamber survey meters.

Geiger-Mueller (GM) Survey Meters

GM survey meters are radiation detection devices used to detect radiation or to monitor for radioactive contamination. GM detectors usually have a “window” either at the end or on the side of the detector to allow alpha or beta particles to enter the detector. These detectors may have a variety of window thicknesses but, if the radiation cannot penetrate the “window” it cannot be detected. Depending upon the “window” thickness, GM systems can detect x-ray, gamma, alpha, and or beta radiation. Common radioactive materials that emit these types of radiation (e.g. ^{22}Na, ^{32}P, ^{35}S, ^{51}Cr, ^{137}Cs) can usually be detected using GM survey meters. Because GM detectors are more sensitive to x-rays, gamma rays, and high energy beta particles and less sensitive to low energy beta and alpha particles, they are usually not used to detect alpha radiation or very low energy beta radiation. Thus, GM survey meters are usually not useful for monitoring ^{3}H or ^{63}Ni, nor are they sensitive enough to detect small amounts (<1 µCi) of radionuclides that emit low energy beta or gamma radiation such as ^{14}C or ^{125}I. GM meter readings are usually expressed in counts per minute (cpm) for particle radiation or milliroentgen per hour (mR/hr) for X- or gamma rays.

Low Energy Gamma (LEG) or Scintillation Survey Meters

LEG survey meters are radiation detection systems used to monitor radionuclides that emit low energy gamma radiation (e.g., ^{51}Cr, ^{125}I). They cannot detect alpha particles nor low energy beta particles but they can detect radionuclides that emit high energy gamma (^{22}Na) and/or high energy beta (^{32}P) radiation. The meter is usually read in counts per minute. When measuring ^{125}I with a LEG survey meter, a reading of approximately 1,000,000 cpm corresponds to a gamma exposure rate of about 1 mR/hr.

Ion Chamber Survey Meters

Ion chamber survey meters are radiation detection devices designed to collect all of the ion pairs produced in the detector tube and then measure the current flow. These meters are primarily used to measure X- and γ-ray exposure in air and the readings are usually expressed as milliroentgen per hour (mR/hr) or roentgen per hour. Ion chambers are most often used for measuring high levels of X- or gamma radiation exposure and are not often used in research labs.

Liquid Scintillation Counters

A scintillation is a material which gives off a photon (flash) of light when struck by radiation. Liquid scintillation counting is a method of assaying a radioactive sample by dissolving it in a mixture of chemicals called scintillation fluid or cocktail. When the radioactive decay energy is absorbed by the solution, the cocktail emits light. The light flashes are converted to electrical signals by a detector called a photomultiplier tube (PMT). These electrical signals are directly related to the absorbed energy allowing the sample to be quantified. Liquid scintillation counters (LSC) are usually used to quantify radioactivity and to measure removable radioactive contamination. They are ideal for counting radionuclides that decay by alpha and beta particle emission (^{3}H, ^{14}C, ^{32}P, ^{35}S) and are also used to measure some low energy gamma emitters (^{125}I) which emit auger electrons as part of their decay.

Radiation Dosimeters

Because it would be quite impractical to follow each worker around with a survey meter to try to keep track of the radiation exposure fields they enter, Radiation Safety monitors a worker's external radiation exposure with a personal dosimeter or radiation badge. These devices essentially store-up the radiation energy over the period it is used and is then sent to a vendor to read the exposure and report the results. There are several types of radiation dosimeters commonly used, although the most common are film badges, thermoluminescent dosimeters and optically stimulated luminescent dosimeters.

Film Badges

Film is the oldest personal monitoring device and, world-wide is the most common type of personal dosimeter primarily because of its simplicity and ease of use. X-rays and gamma rays, along with beta particles, can darken photographic film just as visible light does. This property is the basis for the common film badge. Several different designs are available, but they all have essentially the same components. A piece of film wrapped in paper is inserted into a plastic holder. An "open window" in the plastic allows the passage of low-energy betas which would not penetrate the plastic holder. (Note: tritium betas are so weak they cannot penetrate the paper wrapper of the film, so exposure to tritium cannot be detected on a film badge). Small pieces of aluminum, cadmium or copper, and lead are molded into the plastic holder to act as filters to help differentiate and quantify the energies of radiation the film was exposed to. For example, some gamma rays that penetrate the aluminum may be stopped by the copper, cadmium, or lead. When the film is developed, different areas of blackness appear under the different metals. The film badge vendor can analyze the darkness patterns on the film to determine both the type and amount of radiation which the badge has been exposed to.

Thermoluminescent Dosimeter (TLD)

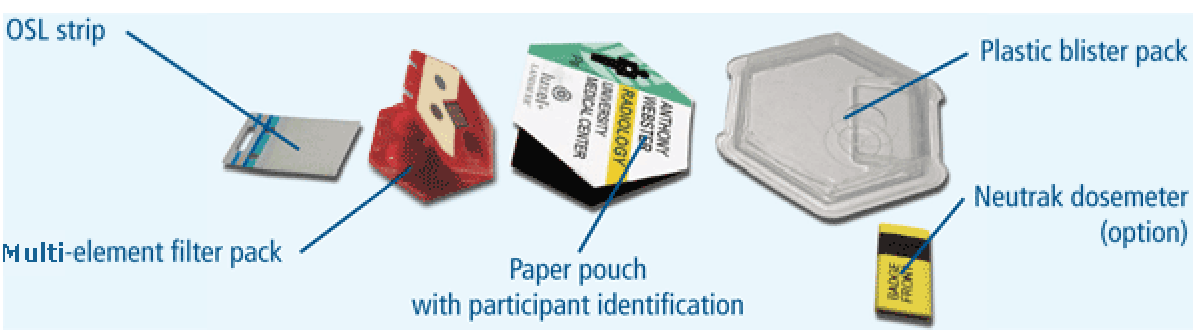
In 1953 it was proposed that thermoluminescence be used as a radiation detector. The TLD contains several mineral crystals or "chips" coated with a radiation-sensitive material. There are several different TLD crystals in use depending upon the application, but one commonly used thermoluminescent material is lithium fluoride activated with magnesium and titanium. The chips are enclosed in a plastic case that has an open window area to admit x, beta particles and three filtered areas to measure the penetration of any gamma doses. When exposed to radiation the TLD absorbs energy from the source which raises the molecular energy of the detector material to a metastable state. The molecules remain in these excited states until, through processing by the vendor, they are heated to a temperature high enough to cause the material to return to its normal state. When this occurs, light is emitted. The amount of light emitted is proportional to the dose received by the TLD. The emitted light is measured with a photomultiplier tube and the dose reading is derived.

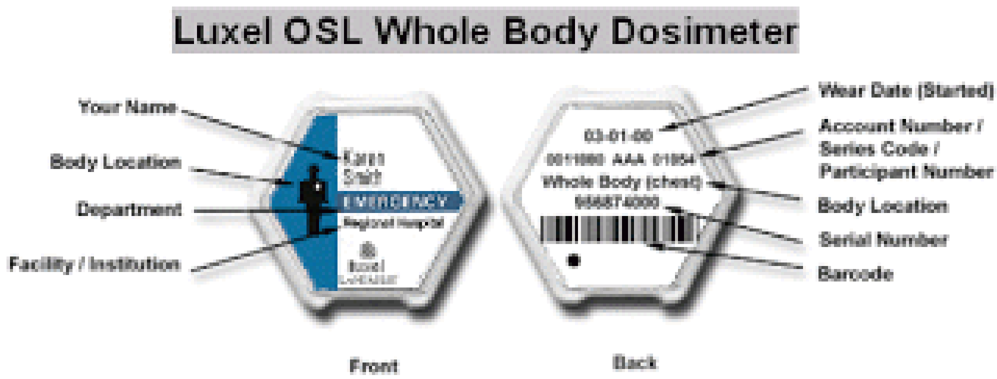
Optically Stimulated Luminescence Dosimeters (OSL)

A dosimetry product currently in use at the University is the optically stimulated luminescence (OSL) dosimeter. This dosimeter measures radiation through a thin layer of aluminum oxide. In the OSL dosimeter an aluminum oxide strip is enclosed in a blister pack that has an open window area to admit beta particles and three filtered areas to measure the penetration of any gamma doses. During analysis, the aluminum oxide is stimulated with selected frequencies of laser light, which cause it to become luminescent in proportion to the amount of radiation exposure. The luminescence is measured and a report of exposure results is generated.

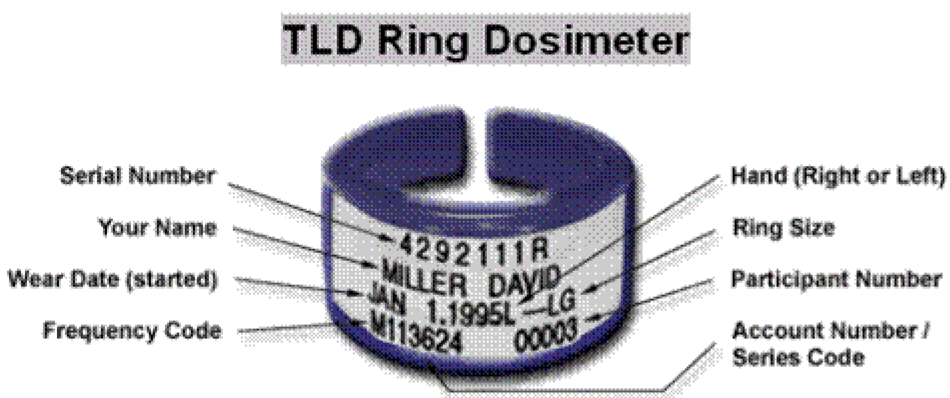
Figure 8. Personnel Dosimeters

OSL Body Badge (Optically Simulated Luminescent Dosimetry)





TLD Ring Badge (Thermoluminescent Dosimetry)



Personal Dosimetry Program

Unlike active detectors, the TLD has no readout or display. Radiation workers wear the dosimeter for a given period of time (monthly or quarterly) and return the dosimeter so it can be processed by a vendor. Thus, the worker learns of his/her radiation exposure several weeks after it has occurred.

"Radiation badges" (dosimeters) are generally used to monitor personnel and areas where radiation sources are used. The Nuclear Regulatory Commission (NRC) requires that personnel monitoring be performed if a worker is "likely to receive, in 1 year…doses in excess of 10 percent of the applicable limits." University policy requires personnel to wear radiation badges when using more than 1 mCi of radioactive material which decays by gamma or beta emission with E_{max} ≥200 keV. These dosimeters are used to monitor not just whole body exposure, but also exposure to a worker's hands. Extremity monitors are ring badges with a single chip. Persons working with small amounts or radioactivity or low energy emitters such as ^{14}C, ^{3}H or ^{63}Ni do not need to wear a dosimeter.

If you have been issued a dosimeter to monitor your radiation exposure, you should follow a few simple rules to insure that the dosimeter accurately records your radiation exposure.

- Wear only your assigned dosimeter; never wear another worker's badge.
- Wear your whole body badge between your collar and waist. Wear your ring badge beneath your gloves with the label on the palm side of the hand with the greatest potential for exposure, usually the hand that handles the radiation source.
- Do not store your badge near radiation sources or heat sources.
- If you suspect contamination on your badge, return it immediately to Radiation Safety; you will be given a new, uncontaminated badge.
- Never intentionally expose your badge to any radiation.
- Do not wear your badge when receiving medical radiation exposure (e.g., x-rays, tests, nuclear medicine procedures, mammograms, etc.)
- Return your badge(s) to Radiation Safety at the end of the monitoring period. Snap the "body badge" out of the holder and retain the holder for your replacement dosimeter. Return the complete TLD ring.

The vendor sends all dosimetry reports to the Radiation Safety Program. You will be notified immediately of any overexposure or of levels that warrant investigation. Permanent records of actual doses recorded by the dosimeters assigned to individuals during their affiliation with the University are maintained by this office. You can request your exposure history at any time by contacting 414-430-7507.

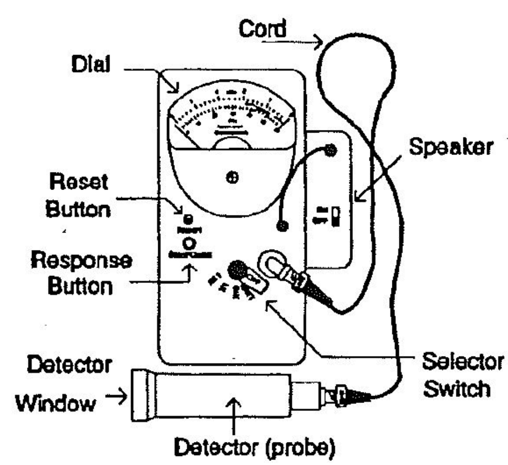
Radiation Detection and Measurement Techniques

Because radioactive material may pose a potential risk to users, all personnel who work with radioactive materials must understand how to use the various types of radiation detection systems to verify that their work place continues to be contamination free. To measure radiation, a worker must first understand how a detector works and then how to use it.

Survey Meters

All survey meters have certain controls in common.
Figure 9 shows the basic components of a survey meter.

Figure 9. Portable Radiation Survey Meter



The **detector** or **probe** is the device which produces electrical signals when exposed to radiation. It usually has a window through which beta radiation can penetrate its cavity.

The **dial** or **readout** is the gauge which indicates the amount of radiation exposure present. It often has two scales, mR/hr and/or CPM.

The **selector switch** is a switch to turn the meter on-off, check the meter batteries, or select a scale multiplier. The scale multiplier is a number (i.e., 0.1, 1.0, 10, etc.) by which the meter readings must be multiplied to calculate radiation exposure or the number of counts per minute.

The **reset button** allows the meter reading to be zeroed. When the level of radiation or the number of counts exceeds the highest reading at a particular scale multiplier, switch the scale multiplier to a higher range and push the reset button. This causes the readout needle to reset to zero so the user can accurately determine the count rate.

The **response button** adjusts the response time of the meter. When this switch is fully clockwise the meter will have a faster response but, the meter readings will be less stable. For response times in the microseconds range, this switch should be turned fully counterclockwise. For routine work, set the response button to the slow mode.

The **speaker** is an audible device connected to the radiation monitor. It may be located outside or inside the meter and may have its own battery. The speaker is in-line with the detector so each count produces an audible click on the speaker.

Operating Procedures for Radiation Survey Meters

- Read the instrument's operating manual to gain familiarity with the controls and operating characteristics.
- Check the meter for any physical damage. Look at the calibration certificate and check the date the meter was last calibrated. **Note that meters are required to be calibrated at least once a year.**
- Check the batteries. Turn the selector switch to **BATT** position. The needle must be within **BATT OK** range. If not, the batteries are weak and must be replaced. Remember to turn off the instrument when not in use. When storing the meter for extended periods of time remember to remove the batteries and have the instrument recalibrated before resuming use.
- Check the operability of the detector. Radiation Safety places a check source on all meters and records the meter's response with the detector on the source on the calibration sticker. With the meter and speaker turned on, position the selector switch to the appropriate scale, place the detector window over the check source affixed to the side of the meter, and measure the radiation of the source. Compare the response with that recorded on the calibration sticker. This response should be within ± 20% of the indicated response.

- Determine the operating background. With the meter turned on and the selector switch on its lowest scale, point the detector away and/or move away from any radiation fields and measure the background radiation. Note that the meter reading must be multiplied by the selector switch scale (i.e., x1, x10, x100, etc.). The result is the background reading. Normal background readings are about 0.02 mR/hr or 20 to 40 cpm for GM meters, and about 150-200 CPM for LEG meters.
- With the speaker on, point the probe window at the area or equipment you wish to monitor for radiation exposure or radioactive contamination. Unless contamination is expected, place the selector switch on the lowest scale. When surveying or entering contaminated areas with unknown radiation levels, turn the meter on outside the area, place the selector switch on the highest range setting and adjust the switch downward to the appropriate scale. Multiply the meter reading by the selector switch scale - if the needle is on 2 mR/hr, and the selector switch is on the x10 scale, the radiation exposure is 20 mR/hr.

Liquid Scintillation Counters

LSC's come in a variety of shapes and types and manufacturers may use different terminologies, but an overview of terms basic to scintillation counting follows.

Cocktail	The scintillation fluid. A mixture of chemicals which emits light flashes when it absorbs the energy of radioactive decay.
CPM	Counts per minute. This is the number of light flashes or counts the LSC registered per minute. The number of decays produced by the radioactivity is usually more than the number of counts registered.
Discriminator	A circuit which distinguishes signal pulses according to their pulse height. It is used to exclude noise or background radiation counts.
DPM	Disintegration per minute. This is the number of decays per minute.
Efficiency	The ratio, CPM/DPM, of measured counts to the number of decays which occurred during a measurement time.
Emulsifier	A chemical component of the liquid scintillation cocktail that absorbs the UV light emitted by the solvent and emits a flash of blue light.
Fluors	Chemicals present in the liquid scintillation cocktail that convert the energy of the beta decay to flashes of light.
PMT	The Photo-Multiplier Tube is the device that detects and measures the blue light flashes from the fluor and converts it into an electrical pulse.
Pulse	Electrical signal of the PMT; its size is proportional to the radiation energy absorbed by the cocktail.

Quenching Anything which interferes with the conversion of decay energy emitted from the sample vial into blue light photons. This usually results in reduction in counting efficiency.

QIP The Quenching Index Parameter is a value that indicates the sample's level of quenching. Another parameter that describes the amount of quenching present is the transformed Spectral Index of External Standard (tSIE) of "H" number.

Solvent A chemical component of the liquid scintillation cocktail that dissolves the sample, absorbs excitation energy and emits UV light which is absorbed by the fluors.

Basic Operating Procedures for LSC's

- Read the instrument operating manual to gain familiarity with the controls and operating characteristics.
- Place your sample into a liquid scintillation vial and add the appropriate amount of liquid scintillation cocktail.
- Prepare at least one background vial. This vial ideally contains a non-radioactive sample similar to your radioactive samples mixed with scintillation cocktail.
- Place your sample vials along with the background vial into an LSC tray and place the tray into the LSC.
- Review the instrument settings and/or counting program to ensure they are appropriate for the type of radiation you are counting.
- Begin instrument counting cycle.

Table 6. Detector Efficiencies for Common Radioisotopes

Isotope	Radiation[1]	Energy (MeV)	Counting Method[2]	Typical Efficiency[3]
Hydrogen-3	β^-	0.01	LSC	40%
Carbon-14	β^-	0.15	LSC GM	85% 10%
Sodium-22	β^+	0.54	LSC GM	95% 20%
	γ	1.27	LEG	5%
Phosphorus-32	β^-	1.71	LSC GM	95% 45%
Phosphorus-33	β^-	0.24	LSC GM	85% 20%
Sulfur-35	β^-	0.16	LSC GM	85% 10%
Calcium-45	β^-	0.25	LSC GM	90% 20%
Chromium-51	γ e^-	0.320 0.0043	LEG LSC	10% 20%
Cobalt-57	γ e^-	0.122 0.0056	LEG LSC	40% 30%
Nickel-63	β^-	0.06	LSC	60%
Zinc-65	γ e^-	1.115 0.007	LEG LSC	5% 15%
Iodine-125	γ e^-	0.035 0.032	LEG LSC	90% 20%
Cesium-137	β^-	0.51	LSC GM	95% 25%
	γ	0.66	LEG	7%

[1] Electrons are either Auger or conversion electrons, the efficiency given accounts for abundance
[2]GM – GM thin end-window probe; pancake has slightly higher efficiency
LEG – Low Energy Gamma Probe
LSC – Liquid Scintillation Counter
[3]LSC efficiency will depend on the amount of quenching present in the sample. Values listed are based on 50% quench. GM efficiency is based on the probe's end-cap being "off", efficiency with the cap on is ½ these values. GM efficiency is percent of 2π emission rate.

Chapter 2 – Self-Test

Fill in the correct response.

1. Radiation is detected by measuring the amount of ________________ in the device.
2. GM meters can be used to _____________________ radiation or ___________________ contamination.
3. LEG meters are used to monitor low energy _______________________ emitting radionuclides.
4. Liquid scintillation counters are ideal for counting ________________ emitting radionuclides and can also measure low energy gamma emitters.
5. A portable survey meter's dial often has scales with units of ___________ and ____________.
6. The ratio of measured counts to the number of decays which occur in a measured time (CPM/DPM) will determine the ______________________ of a liquid scintillation counter.
7. Beta particles absorbed by LSC cocktail produce _____________________ flashes.
8. Persons working with tritium do not need to wear a _____________ _______________.
9. Ring badges should be worn on the hand with the greatest _________ _____ _______________.
10. _______________ _________________ are received and maintained by the Radiation Safety Program. You can request your ______________ _______________ at any time by contacting this office.

Chapter 3

Biological Effects of Radiation

Hazard Classification

In radiation safety, the major goal is to insure that most of the ionizations which occur as a result of a radiation's energy deposition do not occur in either radiation workers or in the general public. Radiation which can deposit energy within healthy tissue may carry some risk. In assessing the radiation work area it is important to distinguish between the two types of radiation hazards, external and internal.

An **external** radiation hazard is a type of radiation which has sufficient energy that, from outside the body, it is capable of penetrating through the protective layer of the skin and deposit its energy deep (>0.07 cm) inside the body. External hazards are type and energy dependent. There are three major types of external hazards: (1) X- and γ-rays, (2) neutrons and (3) higher energy (>200keV) β particles. Each of these types of radiation is considered penetrating. While the high energy β particles are capable of penetrating the skin, the uncharged particles and rays can also interact with tissues deep in the body.

An **internal** radiation hazard arises from radioactive material being taken into the body either by inhalation, ingestion, or absorption through the skin, then metabolized and stored in body compartments which utilize the particular chemical or elemental form. For example, radioiodine in the form of NaI, is capable of volatilizing. If inhaled, approximately 20-30% will be metabolized and stored in the thyroid gland. Radioactive material stored in the body is capable of irradiating surrounding healthy tissues. While all radiations pose a potential hazard, it has been found that the types of radiations which are not penetrating (e.g., α- and low energy β- particles) have the greatest potential to damage those tissues if ingested, inhaled or absorbed.

External Radiation Exposure

As we have seen, the principle difference between nuclear radiation and other types of radiation such as heat or light is that nuclear radiation deposits its energy which produces ion pairs (ionizations) as it passes through matter. The ionization of living cells can lead to molecular changes which damage the cell's chromosomes. Radiation can cause several different types of damage to cells such as small physical displacement of molecules or the production of ion pairs. If the energy deposited is high enough, biological damage can occur (e.g., chemical bonds can be broken and cells can be damaged or killed). There are several possible results from cellular radiation interaction:

- The damaged cells can repair themselves so no damage is caused. This is the normal outcome for low doses of radiation commonly encountered in the workplace.

- The cells can die, like millions of normal cells, and be replaced through the normal biological process.
- A change may occur in the cell's reproductive structure in which the cell may mutate and subsequently be repaired with no effect, or they can form precancerous cells, which may then become cancerous.

Generally, the most radiosensitive cells are those that are rapidly dividing and undifferentiated. Examples include immature blood cells, intestinal crypt cells, etc. Damage to these cells is manifested by clinical symptoms such as decreased blood counts, radiation sickness, cataracts or, in the long term, cancer.

Biological Effects

The effects on the human body as the result of damage to individual cells are divided into two classes, **somatic** and **genetic**. **Somatic effects** are dose dependent, arising from damage to the body's cells and are only seen in the irradiated person. **Genetic effects** result from damage to reproductive cells where it is possible to pass on the damage to the irradiated person's children and to later generations.

Immediate Somatic Effects/Acute Radiation Syndrome

As previously, mentioned, somatic effects are entirely dose dependent. To date, detrimental effects have only been seen for acute exposures, large doses of radiation received in a short period of time. Acute whole body exposures in excess of 100 rem (i.e., much higher that is allowed for workers to receive in a lifetime of radiation work) may damage a sufficient number of radiosensitive cells to produce symptoms of radiation sickness within a short period of time, perhaps a few hours to a few weeks. These symptoms my include blood changes, nausea, vomiting, hair loss, diarrhea, dizziness, nervous disorders, hemorrhage, and maybe death. Without medical care, half of the people exposed to a whole body acute exposure of 400 rem may die within 60 days ($LD_{50/60}$). Regardless of care, persons exposed to a whole body acute exposure exceeding 700 rem are not likely to survive (LD_{100}). Exposed individuals who survive acute whole body exposure may develop other delayed somatic effects such as cataracts and/or cancers.

Table 7. Radiation Injury vs. Whole Body Acute Exposure

Dose (rem)	Result
0-25	No clinically detectable effects
50	Slight blood changes
100	Blood changes
200	Blood changes, plus nausea, vomiting, fatigue
400	Above, plus anorexia, diarrhea, some deaths in 2-6 weeks
700	Probable death for 100% of those exposed within 2 months

Delayed Somatic Effects

Radiation damage to somatic cells may result in cell mutations and the manifestation of cancer. However, these delayed effects cannot be measured at low radiation doses received by radiation workers. In fact, radiation worker populations exposed to currently allowed standards (see Chapter 4) have not been shown to have increased cancer rates when compared to the rest of the population. The estimate of any (statistically) small increased cancer risk is complicated by the facts that:

- There is a long, variable latent period (about 5 to 30 years or more) between radiation exposure and cancer manifestation
- A radiation-induced cancer is indistinguishable from spontaneous cancers
- The effects vary from person to person
- The normal incidence of cancer is relatively high (i.e., the fatal cancer risk from all causes in the U.S. is about 20% or one person in five)

Most regulators take a conservative approach to radiation-induced cancer risk, assuming the risk from radiation is linearly related to the radiation exposure and that there is no threshold for effects. For that reason, workers should aim to keep their exposure **ALARA** (**As Low As Reasonable Achievable**). As an estimate, a single exposure of 1 rem carries with it an increased chance of eventually producing cancer in 2-4 of 10,000 exposed persons. Lengthening the time for the same exposure should lower the expected number of cancers because of cellular repair (a factor not considered in the establishing the dose limits). To compare radiation risks to other risks, refer to Chapter 3, Radiation Exposure Risks.

Genetic Effects

Genetic effects from radiation exposure could result from damage of chromosomes in the exposed person's reproductive cells. These effects may then show up as genetic mutations, birth defects or other conditions in the future children of the exposed individual and succeeding generations. Again, as with cancer induction, radiation-induced mutations are indistinguishable from naturally occurring mutations. Chromosome damage is continually occurring throughout a worker's lifetime from natural causes and mutagenic agents such as chemicals, pollutants, etc. There is a normal incidence of birth defects in approximately 5-10% of all live births. Excess genetic effects clearly caused by radiation have not been observed in human populations exposed to radiation. However, because ionizing radiation has the potential to increase this mutation rate (e.g., an exposure of 1 rem carries with it an increased chance for genetic effects of 5-75 per 1,000,000 exposed persons), it is essential to control the use of radioactive materials, prevent the spread of radiation from the work place, and ensure that exposure of all workers is maintained ALARA.

Mutations become genetic effects as they are carried through to succeeding generation by genes. Exposure to radiation of a person beyond child bearing age will have no genetic effect on future populations because they cannot pass on damaged chromosomes to their offspring.

Internal Radiation Exposure

As previously discussed, not all radiation is equally penetrating. When exposed to external sources of ionizing radiation, only high-energy beta particles and gamma/X-rays are potentially hazardous. Table 8 lists some commonly encountered, low-energy beta emitting radioisotopes which are not external hazards. Generally, beta emitters which have maximum beta energies of less than 200 keV are not external radiation hazards.

Table 8. Common Low Energy Beta Emitters

Isotope	Symbol	Half-Life	Decay Product	Energy (keV)
Tritium	^{3}H	12.3 years	β	18.6
Carbon-14	^{14}C	5730 years	β	157
Sulfur-35	^{35}S	88 days	β	167
Nickel-63	^{63}Ni	92 years	β	67

However, once inside the body, radioisotopes emitting particulate radiations are extremely hazardous. Radioisotopes can enter the body by workers eating or drinking in an area where radioactive materials are used, by breathing in vapors or aerosols from volatile radioactive compounds, or absorption into the body through cuts or wounds in the skin. The body treats these radioisotopes as it does similar, non-radioactive elements. Some is excreted through normal body processes, but some may be metabolized and incorporated in organs which have an affinity for that element.

The hazard an internal radionuclide poses is directly related to the length of time it spends in the body. Radioactive material not incorporated in an organ is rapidly excreted, thus the hazard is less than if it remains inside the body for a long time as part of the body tissue. Radioisotopes incorporated in organs are more slowly excreted. Different organs have different affinities for certain radionuclides, so the excretion rate depends on the organ involved. This natural elimination rate, the **biological half-life**, is the time required for the body to naturally reduce the amount of a chemical or elemental substance in the body to one-half of its original amount. However, all the time the radioisotope is in the body it is also decaying so, even if none of the isotope is excreted the amount in the body is still continually decreasing. Specific organs may have different biological half-lives, and the biological half-life and the physical half-live is called the **effective half-life**. Table 9 give the physical, biological and effective half-lives of some common radioisotopes. The value listed as the biological half-life is the whole body half-life, not organ specific.

Table 9. Half-Lives of Common Radioisotopes

Isotope	Physical Half-Life	Biological Half-Life	Effective Half-Life
Tritium	12.3 years	12 days	12 days
Carbon-14	5730 years	10 days	10 days
Sodium-22	2.6 years	11 days	11 days
Phosphorus-32	14.3 days	257 days	13.5 days
Phosphorus-33	25.3 days	257 days	23.0 days
Sulfur-35	88 days	90 days	44.3 days
Chromium-51	27.7 days	616 days	26.6 days
Cobalt-57	271.8 days	9.5 days	9.2 days
Nickel-63	92 years	667 days	655 days
Iodine-125	60 days	138 days	42 days
Iodine-131	8 days	138 days	7.6 days
Cesium-137	30.2 years	70 days	69.5 days

Radiation Exposure during Pregnancy

The embryo/fetus is especially sensitive to radiation during the first three months of pregnancy when there is rapid cell division and organ development taking place. Radiation damage at this time could produce abnormalities that would result in birth defects or fetal death.

Most of the research on fetal radiation effects has been performed on laboratory animals exposed to very high radiation levels. Some studies of children who were exposed to low levels of radiation (during medical procedures or tests) as fetuses have suggested that even at the levels allowed for radiation workers (5 rem TEDE/year) there may be an increased risk for fetal damage. Therefore, Federal regulatory agencies require that the radiation dose to the embryo/fetus as a result of the occupational exposure to the expectant mother should not exceed 0.5 rem TEDE (10% of the normal limit) during the duration of the pregnancy. Workers who are pregnant or are trying to become pregnant can inform the Radiation Safety Officer. Once a worker has declared her pregnancy in writing, Radiation Safety Program staff will provide additional information on actions to take to ensure that the "declared" pregnant worker maintains her radiation exposure ALARA, and within the 500 mrem limit. Additional information on the various risks to the fetus from radiation and other information on the University's "Declared Pregnant Worker Policy" can be found in Appendix B-1. This information is extracted from several of the Nuclear Regulatory Commission's pregnancy guides, including Regulatory Guide 8.13, "Instruction Concerning Prenatal Radiation Exposure".

Biological Hazards from Radioactive Compounds

Much of the research conducted at the University uses compounds which have radioactive elements as components (i.e., ^{3}H steroids, ^{32}P nucleic acids) of the compound. This type of material is specially synthesized to provide information about metabolism or other cell processes. If taken into the body these compounds, unlike “pure” radioactive elements, will then be processed by the body differently and perhaps will be stored for even longer periods of time. For example, it is estimated that ^{3}H ingested in the form of thymidine is 9 times more hazardous than ^{3}H ingested in the form of water. Thus, those radionuclides which are incorporated into nucleic acids are of particular concern in radiation safety.

Damage to a cell’s genetic material, particularly to the DNA, is the major harmful effect of radiation and can lead to cell death, mutations, and other detrimental effects. Compounds which contain radiolabeled nucleic acids have the potential, if ingested by a worker or entering the body through cuts, needle sticks, or breaks in the skin, of exposing the worker’s DNA to radiation that may affect cell replication or cause a change in genetic function. The nucleic acids which use ^{3}H, ^{14}C, ^{32}P, ^{35}S, and ^{125}I are of concern not only because the radioactive material can be incorporated into a cell’s nucleus, but also because the radiation emitted will be absorbed primarily within the cell, increasing the possibility that harmful effects will occur.

Therefore, individuals who work with these radioactive compounds must take great caution to ensure the material remains outside the body where they pose only a minor hazard. Good housekeeping and cleanliness is crucial. Wear gloves and never mouth pipette any solutions, radioactive or otherwise. Additionally, at the completion of work with a radioactive compound, wash your hands and forearms thoroughly and use appropriate radiation survey instruments to check your hands, feet, clothing, and work area for radioactive contamination before leaving the lab.

Chapter 3 – Self-Test

Fill in or select the correct response.

1. ________________ effects result from damage to a person's cells and only effect the irradiated person.

2. ________________ effects can be passed onto future generations.

3. Inside the body, radioisotopes emitting ___________________ radiations are the most harmful.

4. Biological half-life measure how long it takes for _______________ the original amount of isotope to be ______________ from the body.

5. The unborn child is (more/less) sensitive to radiation than the mother.

6. The embryo/fetus should be exposed to no more than ____________ mR during the entire pregnancy.

7. Unlike "pure" radionuclides, radioactive compounds used to provide information about cell processes are (more/less) of an internal hazard.

8. Among general safety rules, good housekeeping and cleanliness is important. Additionally, wear gloves and _____________ mount pipette any solution.

9. Acute radiation effects (are/are not) likely at the University.

10. Beta emitters with maximum energies less than ___________ keV are not external radiation hazards.

Chapter 4

Current Standards and Dose Limits

Background Radiation

The radiation exposure that we receive in any given time period does not just come from man-made sources. Besides man-made radiation we are constantly bombarded by a low level of natural background radiation. In the United States the average radiation exposure of the population to both natural and man-made sources is approximately 620 mrem per year. Half of this dose comes from natural background radiation (Cosmic, Terrestrial, Radon, and Internal). The other half (310 mrem per year) comes from man-made sources including medical, commercial and industrial sources.

- **Cosmic** radiation is high-energy particulate radiation produced in the stars and our own sun which bombards the earth and makes the atoms in the upper atmosphere radioactive. A person's exposure to cosmic radiation is dependent on how close they are to outer space.
- **Terrestrial** radiation is radiation resulting from the decay of naturally occurring radioactive material, like uranium and thorium, in the earth's crust. The exposure is greater if one lives near large sources of naturally occurring materials as in granite-type mountainous areas as opposed to calcite type (limestone) areas.
- **Radon** is a gaseous element resulting from the decay of uranium, which escapes the earth's crust through fissures and other natural breaks. As the radon is inhaled, it is deposited in the lungs where the massive energy of the alpha particles can damage the exposed lung cells.
- **Internal** radiation results from naturally occurring radionuclides, like ^{14}C, ^{3}H, and ^{40}K, that are ingested and treated by the body like their non-radioactive isotopes. They are stored in various organ systems and give a long-term, low-level radiation exposure.

History of Current Standards

Radiation safety regulations regarding the use and handling of radioactive materials have evolved significantly during the past century. Initially it was not well known what the effects of radiation were. Many early experimental procedures involved high radiation exposures and resulted in workers and patients suffering prompt, somatic effects such as skin burns and hair loss. As research continued, researchers found that exposure to radiation had the potential to cause long term genetic effects in addition to the somatic effects. Personnel exposed to high levels of radiation or radioactive materials seemed to have an increase in certain types of cancers over people not exposed to radiation. As further studies continued and more was learned about the potential effects of radiation exposure, federal regulators worked to determine what "acceptable risks" radiation workers could assume as they work with radioactive materials.

It must also be noted that society's perception of the risk from radiation is different from a scientist's perception of risk. While researchers were working with radiation and studying its effects, movie goers were watching "The Fly" and other science fiction films which portrayed radiation as universally harmful. Additionally, the generation from 1945 to 1975 saw the effects of radiation weapons on large, unprepared populations, experienced an increase in above ground nuclear testing, and lived with the threat these weapons posed to them. One effect of the above ground nuclear testing was the fear that all the nuclear fallout would have detrimental effects on the world's gene pool, potentially increasing the rate of birth defects and cancers. Thus, when determining radiation exposure levels the regulators needed to consider not just the effects on radiation workers, but society's fears and the potential effects to the entire population.

As the concept of ALARA has been incorporated into federal exposure limits, the goal has been changed from only protecting workers from their radiation work to include reducing the risk of cancers and birth defects in a population which could result from our total radiation exposure.

Current Exposure Limits

Current federal exposure limits address exposure to several groups in the population. Their goal is to weigh the radiation risk to the groups involved with the benefits derived. There is no risk-benefit question involved with exposing a person to 500 mrem that allows for a lifesaving medical diagnosis to be made. Nor is there undue concern with giving the population of the U.S. an average of 0.001 mrem/year from smoke detectors because of their early warning benefit. But, what about exposing laboratory workers to 10 mrem/year in the hope of finding the purpose of a specific DNA site?

Radiation workers do derive some benefit from their work, specifically their livelihood. However, while all jobs carry some risk (e.g., needle sticks in medical care, auto accidents in transportation, etc.) today's worker expects to survive work so they can retire. The permissible exposure limits for workers are thus set so there will be no somatic effects from their radiation exposure, even if the worker is exposed to the maximum allowed exposure year after year. Additionally, although statistics suggest that the worker population may be at an increased risk for cancer induction, at the permissible exposure level no increases in cancer have been detected in populations of "radiation workers". Table 10 outlines the permissible dose limits for workers.

Table 10. Maximum Permissible Dose Limits

Population	mrem/year
Radiation Worker – Whole Body	5,000
Radiation Worker – Lens of Eye	15,000
Radiation Worker – Skin	50,000
Radiation Worker – Extremities, Hands	50,000
Unborn Child of Radiation Worker	500 for Entire Pregnancy
Individual Members of the General Public	100

Some workers (i.e., delivery people, clerical staff, and facilities personnel) are exposed to very small levels of radiation because of incidental exposure. Because these workers do not derive some benefit from this exposure, their allowable limits are less. Exposure to individual members of the general public who do not routinely access radionuclide labs as part of their assigned duties are limited to 100 mrem/year exposure. Unborn children may be exposed when their radiation worker mother is at work. To keep the unborn child's exposure below 500 mrem for the entire gestation period, the radiation exposure of a "declared" pregnant worker is below 500 mrem during her pregnancy.

Radiation Exposure Risks

On common way to assess radiation risk is to compare it to other risks. Several studies have been done comparing the projected average loss of life expectancy from radiation exposure to other health risks. Using these studies, and individual who gets cancer loses an average of 15 years of life expectancy while his/her coworker suffers no loss. The average U.S. radiation worker exposure in 1992 was 0.3 rem and the University's radiation worker average annual exposure is below 0.02 rem. Using this data we can compare the average number of days of life expectancy lost per rem exposure to other health risks. Thus, we assume 0.3 rem radiation exposure per year from 18 to 65 results in a projected estimate of life expectancy loss of 15 days. Radiation risks are compared with other risks in Tables 11 and 12.

Table 11. Health Risks vs. Life Expectancy

Health Risk	Expected Life Expectancy Loss
Smoking 20 cigarettes a Day	6 years
Overweight (by 15%)	2 years
Alcohol Consumption (U.S. Average)	1 year
Motor Vehicle Accidents	207 days
Home Disasters	74 days
Natural Disasters (Earthquake, Flood)	7 days
0.3 rem/year from age 18 to 65	15 days
1 rem/year from age 18 to 65	51 days

Table 12. Industrial Accidents vs. Life Expectancy

Industry Type	Estimated Life Expectancy Loss
All Industries	60 days
Agriculture	320 days
Construction	227 days
Mining/Quarrying	167 days
Transportation/Public Utilities	160 days
Government	60 days
Manufacturing	40 days
Trade/Service	27 days

ALARA Program

As a safe-sided estimate, it is believed that exposure to radiation may carry some risk. Therefore, it is a goal of Radiation Safety to keep radiation exposures **ALARA (As Low As Reasonably Achievable)**. Additionally, Radiation Safety works to protect radiation workers from predicted cancers and reduce the predicted risk of cancers and birth defects in the population as a whole from radiation exposure. The University has implemented an ALARA program aimed to keep radiation exposure to workers and members of the general public ALARA by focusing on the following areas:

- **Control the use of radioactive materials**. Radioactive material use is strictly controlled. All orders for radioactive material must be approved by the Radiation Safety Officer. Each authorized user is allowed sufficient material to perform research, however there are limits established to insure new receipts of radioactive material are balanced by disposals of on-hand radioactive material.
- **Prevent the spread of contamination**. All lab workers must be sufficiently trained in both radiation safety and general laboratory procedures to work competently and insure that accidents with radioactive material are kept to a minimum. Additionally, lab personnel need to be trained in emergency response so that if an accident occurred proper action would be taken to prevent the spread of contamination off site.
- **Audits of Authorized Users**. Radiation Safety inspects each authorized user of radioactive materials to insure that the labs record keeping system meets the conditions of our DHS license. These inspections review both the ability of the lab to document their use of radioactive materials and that the adequacy of required surveys. The Radiation Safety Program also perform radiation and contamination surveys both in the laboratory and in areas outside the lab to insure that radiation exposure of non-radiation workers is kept as low as reasonable achievable.
- **Review of dosimetry records**. As part of the ALARA program established at UWM, the Radiation Safety Program is required to monitor and investigate, as necessary, worker radiation exposure. Normally, when a worker's monthly exposure (as reported by our dosimetry service) is more than 100 mrem, the Radiation Safety Program will investigate the situation to determine why the worker received such a dose and what potential actions can be taken to reduce future doses for similar work.

Internal Doses

Radiation exposure from internal doses to radioactive materials is restricted by defined **Annual Limits of Intake (ALI's)**. The ALI is a derived limit for the amount of radioactive material that, if taken into the body of an adult worker by inhalation or ingestion in one year, would expose an individual to the occupational limits. Table 13 lists the Annual Limits of Intake (ALI's) of some commonly used radionuclides.

Table 13. Annual Limits of Intake for Various Radionuclides

Radionuclide	ALI in mCi
Tritium	80.0
Carbon-14	2.0
Sodium-22	0.4
Phosphorus-32	0.6
Phosphorus-33	6.0
Sulfur-35	10.0
Calcium-45	2.0
Chromium-51	40.0
Magnesium-54	2.0
Iron-59	0.9
Nickel-63	9.0
Iodine-125	0.1
Cesium-137	0.1

DHS requires that any individual who may receive, in a year, an intake in excess of 10% of the applicable ALI must be monitored for internal exposure. To ensure regulatory limits are not exceeded, urine samples or other bioassay methods to monitor an individual's intake of beta or gamma emitters will be required when working with unsealed sources of radionuclides that exceed certain quantities. Additionally, other random bioassays may be required of individuals working with radioactive materials to ensure that the occupational limits are not being exceeded.

Chapter 4 – Self-Test

Fill in the correct response.

1. The average annual radiation exposure we receive in the U.S. due to natural background radiation sources is approximately ____________ mrem/year, which is further broken down into _________ mrem/year from natural sources and __________ mrem/year from man-made sources.

2. The annual whole body dose limit for a radiation worker is __________ mrem/year.

3. The maximum hand or extremity dose limit for a radiation worker is ___________ mrem/year.

4. The maximum dose limit for an individual member of the general public is ___________ mrem/year.

5. The maximum dose limit for the unborn child of a declared pregnant worker is _________ mrem in 9 months.

Chapter 5

Reducing Radiation Exposure

As we have previously discussed, radiation exposure of workers can be from two categories, external and internal. **External radiation exposure** comes from radioactive sources outside the body where only the emitted radiations strike the body while **internal radiation exposure** comes from radioactive sources inside the body. Both types of radiation exposure carry some risk, so when working with radiation or radioactive materials you must understand the basic radiation safety principles and follow certain basic procedures to protect yourself and others from the radiation emitted by the radioactive substance and from radioactive contamination. The basic principles used to reduce radiation exposure are **time, distance, and shielding**.

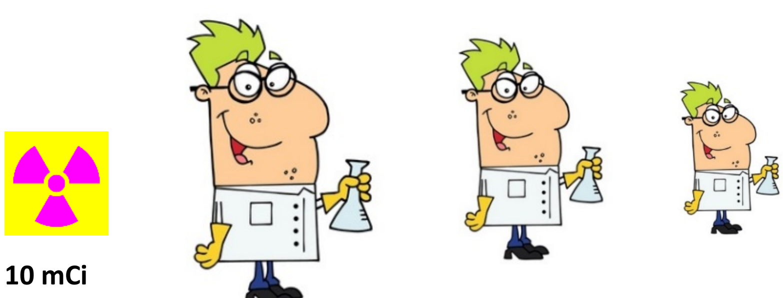
Time

The length of time that you spend near a source of radiation will determine the radiation exposure you receive. Reducing the time you spend near a radioisotope will reduce the total dose received by your body. The dose received while working in a given field is directly proportional to the time spent in the field. If the time is doubled, the dose is doubled. You can reduce your "timely" radiation exposure by first practicing new procedures with simulated radiation sources. Once you become proficient using non-radioactive sources, you can work more rapidly with the real source and thus receive a lower exposure than if you had increased your proficiency using "real" radiation. Additionally, one should not stand or sit near unshielded radiation sources unless you are actually working with them.

Distance

A second method of reducing the dose rate you receive from radioactive materials is to increase your distance from the source so less radiation will "hit" you. Just as light is bright when you are close, but gets dim as you move away, so the dose rate from a radioactive source decreases as you move away.

Figure 10. Effect of Distance on Dose Rate



10 mCi Na-22

50 cm 50 mR/hr

100 cm 12.5 mR/hr

200 cm 3.1 mR/hr

Figure 10 shows how the dose rate decreases as the distance from the source increases. Radiation follows the "Inverse Square Law" which specifies that if you double the distance from a source of radiation, the radiation intensity will decrease by a factor of 4. For example, if the unshielded radiation intensity at 50 cm from a 10 mCi vial of ^{22}Na is 50 mR/hr, then at 100 cm from the source, the radiation intensity will decrease to 12.5 mR/hr, and at 200 cm (i.e., twice 100 cm, 4 times 50 cm) the intensity will only be 3.1 mR/hr.

Increasing the distance from a source of radiation is often the most effective way of decreasing exposure. Do not stand or sit near unshielded radiation sources unless actually working with the radiation. When it is necessary for you to handle radioactive materials, stand at least 2 feet from the source. If you must do work with high activity sources, work at arm's length and use tongs or long-handled tools to increase the distance to your hands and whole body from the source.

Shielding

The third method of reducing your radiation exposure is to utilize shielding. By placing a physical barrier between yourself and a radiation source you can reduce your radiation exposure dose. Anything that you place between yourself and a source of radiation will absorb some of the radiation. Recall from Table 1 that different radionuclides emit different types and energies of radiation. The differing types and energies require different types and thicknesses of material to effectively absorb the radiation. Table 7 lists various radioisotopes, the type and thickness of shielding that will stop the beta radiation or reduce the X- or gamma ray exposure by a factor of 10 (tenth value layer, TVL).

Effective Shielding

Alpha Particles

Because of their large size and charge, alpha particles can be stopped by very thin absorbing materials. A few sheets of paper or thin aluminum foil will absorb alphas from any source. The most energetic alpha will travel only about 5 cm in air. The dead layer of skin will absorb all alpha particles with no harmful effect.

Beta Particles

Beta particles interact in ways similar to alpha particles. Compared to an alpha particle, a beta particle has a small mass and, for the same energy, will have a greater velocity. Thus, a beta particle is less densely ionizing and will penetrate farther into an absorber than an alpha particle. In order to penetrate the dead layer of skin, a beta particle must have an energy greater than 70 keV. For this reason, most beta radiation is considered a slight external hazard and is mainly a skin exposure hazard.

The shielding of beta particles is accomplished by using less dense material such as plastic, wood, lucite or aluminum. Just a few millimeters of plastic will stop even the high energy beta particles form ^{32}P. Thick dense materials like lead are **NOT** suitable for stopping higher energy (≥500 keV) beta particles because as a beta particle passes through an absorber (the shielding media), secondary photons are produced. For high atomic number absorbers, like lead, the production of the secondary photons produced by the rapid deceleration of charged particles passing through matter act like X-ray radiation and are called "**Bremsstrahlung**" or "**breaking**" radiation. This radiation presents an equal or greater hazard than the beta particle itself. Light materials do not produce bremsstrahlung radiation in stopping beta particles so lucite is the preferred shielding material for beta sources.

X-and Gamma Rays

Shielding of X- and gamma ray emitters is accomplished by using thick, dense materials such as lead or tungsten or by using greater thicknesses of less dense and less expensive materials like concrete or steel. Lead is a preferred shielding material because of its great density. Table 7 shows the thickness of lead needed to reduce a radiation exposure by a factor of 10.

Table 7. Shielding Facts

Isotope	Unshielded Dose Rate 30 cm (12 in) From 10 mCi Source (mR/hr)	Thickness (mm) of:	
		Lead to Reduce Dose Rate by 10	Lucite to Stop all Beta Particles
Sodium-22	133	34	1.6[1]
Phosphorus-32	3530[2]	--	7
Phosphorus-33	--	--	0.5
Sulfur-35	--	--	0.3
Chromium-51	1.8	5	--
Cobalt-57	1.810	0.5	--
Iodine-125	107.8	0.1	--
Iodine-131	24	7	1.2[1]
Cesium-137	37	18	1.41[1]

[1]If the gamma is attenuated by a factor of 10, the dose rate from the Bremsstrahlung X-rays should also be relatively low.
[2]Pure beta emitting radionuclides do not technically produce radiation exposure rates and should not be shielded with lead, instead stop the beta's with lucite.

Mixed Beta/Gamma Emitters

Shielding of radionuclides which emit both high energy beta and gamma radiations, such as ^{22}Na or ^{131}I, is often done by using a graded shield. Closest to the source, light material is used to stop the beta particles. Next to the light material, thick dense material is used to stop the gamma rays and any of the bremsstrahlung radiation produced in the light material. For most practical applications involving beta/gamma emitters, using enough lead to reduce the gamma exposure rate by a factor of ten is sufficient to stop the beta and attenuate the bremsstrahlung radiation produced.

Review

A good example to demonstrate the three factors of time, distance, and shielding is to think of a sunlamp as a source of radiation. The longer you lie under a sunlamp the more exposure you receive and the tanner you become. The farther away from the sunlamp, the less intense the ultraviolet radiation and your exposure is lower. Also, if while under the sunlamp you wear sunglasses or clothing, you will notice the outline where your body was shielded and the exposure reduced.

Laboratory Practices

Most research procedures at the University use unsealed sources of radioactive materials which are capable of contaminating areas that, in turn, a radiation worker could come in contact with. Internal radiation exposure results from the deposition of unsealed radioactive material within the body. As previously discussed, radioactive materials can enter the body through inhalation, ingestion, wound penetration, or skin absorption. Once in the body, the potential for damage by particulate radiation is greater than if the radiation source were outside the body. Thus, it is essential that radiation workers combine the practices of **time, distance and shielding** with good laboratory practices to keep the radionuclides outside the body. The following procedures will help to prevent internal radiation exposure:

- Procedures that may produce or release airborne gas, vapor, dust or aerosols must be performed in an approved fume hood.
- Always wear disposable gloves, lab coats or aprons, and if necessary face shields to prevent contamination of your hands, face, and clothing when working with radioactive materials.
- Do not eat, drink, smoke, mouth pipette or do other things like licking stamps, labels, or applying makeup in a radiation work area.
- Food and drink containers along with medications of any kind are not to be stored or used in the same room as radioactive materials. This specifically means that refrigerators in radionuclide laboratories, whether they contain radioactive material or not, are off limits for lunches, soda cans, and other food or beverage containers.
- If issued a radiation dosimeter(s), wear it/them when working with radiation sources.
- Radiation workers should be thoroughly familiar with the properties of the radionuclides they are using. If you are uncertain about the safety of a procedure call the Radiation Safety Program Office.
- Employ the three basic principles of **time, distance, and shielding**, whenever you work with radioactive materials.

- Assume containers labeled "**Caution – Radioactive Materials**" are also contaminated. Wear disposable gloves when handling all such containers.
- Perform a "dry-run" without radioactive materials to learn new procedures.
- Perform radiation work on a non-porous tray which is capable of containing the entire volume of liquid radioactive material in case it is spilled. Cover the work area with plastic backed absorbent material.
- Immediately after use or work with radioactive materials wash hands thoroughly.
- Monitor hands and clothing for evidence of radioactive contamination during and after work; especially before leaving the lab. Decontaminate and re-monitor if necessary.
- Monitor work area, including the floor, for contamination after working with radioactive materials.
- If you are contaminated with radioactivity, or suspect contamination, wash the contaminated area and notify Radiation Safety.
- Monitor laboratories where radioactivity is used or stored. Pay special attention to all areas which may come in contact with potentially contaminated hands like door knobs, phones, and refrigerator handles.

Chapter 5 – Self-Test

Fill in or select the correct response.

1. The three factors which influence radiation exposure are _____________ , ______________ , and ________________ .
2. Shield gamma emitters with _________________ materials.
3. Lucite is the best material to shield high energy _________________ emitters.
4. Procedures that may produce radioactive vapors, aerosols, or dusts must be done in a ___________ ___________ .
5. Moving twice as far away from a source of radiation reduces the dose by a factor of ____________ .
6. **Do/Do not** store food or drink containers in refrigerators within radionuclide laboratories.
7. **Do/Do not** eat, drink, smoke, or mouth pipette in a radiation work area.
8. Always perform radiation work on a _________________ which is capable of containing the entire volume of a liquid radioactive spill.
9. **Do/Do not** work with radioactive materials if you have an open cut.
10. If you are contaminated with radioactivity, ____________________ the contaminated area then contact Radiation Safety.

Chapter 6

Current Regulations and Radiation Safety Procedures

The University of Wisconsin-Milwaukee is licensed by the Department of Health Services (DHS) to use reactor produced radionuclides and to use accelerator produced radiation and X-ray producing equipment. DHS requires that the use of radiation and the radiation producing equipment be strictly controlled to ensure that both the people using the materials and members of the general public receive as little radiation exposure as possible.

Within the University's license are many pages of conditions that define the campus radiation safety program and the management of radioactive materials on campus. DHS inspects the campus on a periodic basis to verify compliance with those license conditions. Items of non-compliance damage the good standing of the University's license and could subject us to fines and other penalties.

Area Monitoring

Area monitoring surveys can detect areas of contamination, pinpoint projects that need improved laboratory procedures, and locate areas that need additional shielding. Area monitoring surveys should be conducted with equipment appropriate for the type and energy of radioactive materials used, with either a portable survey meter and/or wipe testing of selected surfaces.

Areas in which gamma or high-energy beta emitters have been used can easily be surveyed using portable instruments. A survey meter probe (see Chapter 2) is moved slowly around the area of interest and the meter readings at selected locations are recorded on a room diagram. Be careful when extending the detector's cord as it may generate electrical noise and register as radiation counts. Make sure you do not contaminate the probe. For surveying ^{32}P you may cover the probe with a thin sheet of plastic wrap; for ^{35}S do not cover the detector and take special care to prevent contamination. Any areas in which levels of **five times background** are detected are considered **contaminated** and remedial actions must be taken.

Wipe tests are the most effective way of routinely monitoring for contamination from low-energy beta emitters such as tritium or carbon-14. Areas to be wiped should include lab tables, hoods, and other areas of use or probable contamination. Using a piece of filter paper or any of the commercially available "swipe" filters, wipe an area 100 cm^2 (approximately 4"x 4") at each identified area on the lab diagram. The filter papers can then be placed into scintillation vials, the proper amount scintillation cocktail added, and the wipes counted as normal scintillation samples. Any sample which gives off counts over **five times background** levels or with activity greater than **200 dpm** indicates an area of local contamination and remedial action must be taken.

One stated condition of our license requires that each laboratory be responsible for ensuring that adequate area monitoring surveys for radioactive contamination are performed at the end of each day of work with unsealed sources of radioactive materials. All survey data must be adequately documented and a copy of the current month's survey sheet must be posted in each laboratory.

As previously discussed, any area which has a detected count or exposure level in excess of five times (5x) the background rate is considered contaminated and corrective actions or decontamination methods need to be performed. After decontamination is completed, the area must be re-surveyed to verify the count or exposure levels are below 5x background and documentation of this result must be provided on the survey sheet.

Radiation Safety will conduct routine area monitoring surveys in all labs on a monthly basis as a spot check of the laboratories monitoring program.

Radioactive Material Ordering

All orders of radioactive material must be approved by Radiation Safety before the order is placed. This allows us to check the requisition for conformance with DHS license conditions and to record necessary inventory information. Researchers must also notify Radiation Safety when orders are placed on blanket accounts with radionuclide vendors to ensure that the order can be properly received and checked-in, and that the amount requested is within the user's order and possession limits.

Orders for radioactive material can only be released to persons who have proper training and experience recorded on file with the Radiation Safety Program. These records need to be in place before the material is received. Additionally, any lab personnel who will be ordering and using high level beta or gamma emitting radionuclides in quantities greater that 1.0 mCi must have a dosimetry badge. Dosimeters are provided free of charge by our office to all University personnel requiring them. See Chapter 2 for additional information on obtaining a dosimeter.

Failure to follow the above procedures constitutes a violation of UWM's DHS license conditions and may result in delay or cancellation of your order.

Record Keeping

DHS requires authorized users to maintain up-to-date records of radionuclide receipt, use and disposal. Copies of these radioactive material records, disposals, and transfer forms must be kept on file by the lab for at least **3 years** so they are available for review by DHS Inspectors. Each person independently using radioactive material in a lab must have access to the permanent book or system which records radioactive receipt, use and disposal. The information recorded must be such that the authorized user can calculate the total activity of each radionuclide on hand at any time.

Radiation Safety also maintains an inventory of each radionuclide a user possesses. This information is based on receipt, transfer and disposal data for each user. At least once a year, the radiation safety balance will be compared to that of the authorized user and checked for agreement. Maintaining a good inventory system helps in correcting discrepancies between the two balances.

With each radioactive material order, Radiation Safety provides a Radionuclide Inventory Form. This form (or a compatible method) should be used to keep a record of use and disposal of material for that order. To complete the form:

- Initially verify order is correct and complete.
- Use only one Radionuclide Inventory Form for each order. Keep inventory forms in a binder or posted in a central location such as a refrigerator door so they are available to all users.
- Record use and disposal as they occur.
- Total activity dispensed should equal the total used, minus any activity remaining in stocks, samples, etc.
- If unsure how to track your inventory, check with the authorized user or call the Radiation Safety Program Office.

Waste Disposal

After using unsealed radioisotopes in a laboratory procedure, the radioactive residue and other waste material must be properly disposed of to protect workers, staff and the environment from unnecessary radiation exposure or contamination. The disposal of radioisotopes is very strictly regulated by federal and state laws and currently, the three approved methods for disposing of radioactive waste materials are:

1. Collection by the Radiation Safety Program
2. Radioactive Decay
3. Release to the Sanitary Sewer or Atmosphere

Collection by the Radiation Safety Program

The most common and convenient way to dispose of radioactive waste is to contact the Radiation Safety Program to arrange for a pick-up of the materials. All waste materials picked up by Radiation Safety must be packaged to meet the following requirements:

1. Solid and liquid wastes are handled differently at disposal time, therefore they must be packaged differently. All vials, test tubes, etc., packaged as solid waste **MUST NOT** contain **ANY** liquid.
2. Solid wastes should be packaged in the plastic bags provided by the Radiation Safety Program. The attached radioactive waste label must be filled out completely. All labels and radioactive material markings on solid waste material inside the bag **MUST** be removed or defaced.
3. All needles, syringes, sharps, blades, etc., MUST be placed in a sharps container. Once the container is filled, it should be sealed and disposed of as solid low-level radioactive waste.

4. Liquid wastes should be contained in plastic carboys or plastic containers furnished by the Radiation Safety Program. A complete radioactive waste label and a liquid waste tag MUST be attached to each jug. Do no fill containers above the “Full Line”; allow room for thermal expansion.
5. Aqueous wastes MUST be kept separate from organic solvent wastes. Neutralize all aqueous liquids: $5.5 \leq pH \leq 8.5$.
6. Liquid scintillation wastes MUST be kept separate from other wastes. Additionally, LSC wastes must be segregated by cocktail type, i.e., sewer disposable or organic hydrocarbon.
7. The Radiation Safety Program will NOT accept improperly packaged or labeled waste.

Radioactive Decay

Because of radioactive decay, the amount of radioactive material on hand continually decreases. If the isotope half-life is less than 30 days (e.g., ^{32}P), it may be convenient to wait until the natural decay process removes most of the radioactivity. After the material has gone through ten (10) half-lives, only 0.1% of the original amount will remain. This may be low enough for disposal, however, a 1.0 mCi solution of radioactive material will still have 1 µCi of material remaining after 10 half-lives.

For disposal by natural decay, the following procedures should be followed:

1. Hold the material for **AT LEAST 10 half-lives**
2. Survey for detectable radiation/radioactivity before disposal to the normal trash
3. The survey must show less than **50 cpm or 0.03 mR/hr** (essentially background) with a thin window GM survey meter in contact with the trash
4. Deface or remove all radiation symbols before disposal to the normal trash
5. Report the disposal to the Radiation Safety Program on the bottom section of the Radioactive Waste Disposal Form

Disposal to the Sanitary Sewer or Atmosphere

Disposal of radionuclide wastes into the municipal sewerage system is highly regulated and poses a potential hazard to Facilities Service personnel who service the plumbing in laboratories where radioactive materials are used. In general, the only wastes allowed to “go down the drain” would be those small amounts associated with washing glassware or animal blood and urine wastes. Release of additional wastes down the drain must be approved by the Radiation Safety Officer and appropriate arrangements must be made to insure that any personnel servicing the drain pipes will not be exposed to significant radioactivity. In any event, an accurate inventory of all radioactive materials released to the sewerage system must be maintained and all such disposals reported to Radiation Safety **MONTHLY** on the bottom section of the Radioactive Waste Disposal Form.

Releases of radioactivity to the atmosphere are permitted only in cases where it would be extremely difficult to contain the activity otherwise. Releases to the atmosphere, which are regulated by the U.S. Environmental Protection Agency (EPA) as well as DHS, should occur only in approved fume hoods, must remain with legal effluent concentration limits, and should be accurately inventoried and reported to the Radiation Safety Program. All such disposals must be reported to Radiation Safety **MONTHLY** on the bottom section of the Radioactive Waste Disposal Form.

Iodine-125

The use of Iodine-125 (NaI) in radioiodination procedures requires special approval and procedures. In areas where iodinations are carried out, solutions of sodium iodine in mCi amounts are handled, usually in high radioactive concentration. This may present significant concerns regarding both radiation exposure rates and potential contamination. The critical organ for iodine is the thyroid, which may accumulate up to 30% or more of the total iodine ingested.

Work with volatile iodine solutions must be done in a fume hood approved by Radiation Safety. Air concentration monitoring is required for all uses of radioiodine involving 0.1 mCi or greater of volatile radioiodine or 1.0 mCi or greater of nonvolatile radioiodine. An activated charcoal filter will be supplied with each order to monitor the concentration of iodine **outside** the fume hood during the iodination procedure. Radiation Safety conducts continuous monitoring of radionuclide releases from approved iodine fume hoods at the point of exhaust to the atmosphere.

The following is a summary of practical hints for use during radioiodination reactions:

- A Low-Energy Gamma survey meter must be on hand and switched on throughout the operation.
- Clothing, especially sleeves, cuffs, and gloves, should be monitored frequently. Wear two pairs of gloves and replace them should they become contaminated.
- A “recipe” or protocol should be posted in the fume hood for easy reference.
- Do several practice runs following the protocol but without radioactive materials until you are comfortable with the procedures. These “dummy” runs will also increase speed and identify potential problems.
- An assistant who is familiar with the process should be available to help if anything unforeseen occurs.
- Solutions of sodium thiosulfate and carrier iodine for use in dealing with a spill or other unplanned release should be available. Other materials to have available include:
    - A good supply of disposable gloves
    - A good supply of tissues or absorbent paper

- A container with a lid for highly contaminated solid waste, contaminated gloves, tissues, etc.
    - Local shielding, if appropriate
    - A large tray which could contain at least ten times the volume of any leakage
    - A small tray for iodination pipettes, etc., which must be reserved for iodinations and not taken from the hood
- Ventilation conditions of the hood should be periodically checked to ensure that they remain satisfactory.
- Minimize the items in your work area when you do iodinations. Any materials you handle during the procedure – pens, papers, keyboards, phones – should be treated in the following ways:
    - Keep the items clean by handling them only after removing your outer gloves
    - Bag items before moving them out of the area where iodinations are done. Leave them in the bag until they are returned to the iodination hood/area.
    - Consider all items handled/used during the iodination to be contaminated. Handle them only while wearing gloves until an appropriate survey indicates they are not contaminated.
    - Places where these items are stored (drawers, pipette racks, pencil cups) should be included in your area surveys.
    - Items that can be reserved for use only during iodinations should be labeled as such. Prevent their removal by tethering with string or wire.

Animals

The use of radioactive material in animals requires the coordination of Radiation Safety, the University Animal Care and Use Committee (ACUC), and the Animal Resource Center (ARC). Before an investigator can begin research using radioactive materials in animals they must have an approved **Animal Use of Radionuclides** form on file with Radiation Safety in addition to the protocol approved by the ACUC.

The basic principles of time, distance and shielding are still applicable, however, the type of animal, the characteristics of the radionuclide, and the physical form (sealed vs. unsealed) of the radioactive material must be considered before the project will be approved.

For research involving the use of radioactive materials in unsealed sources in animals, the authorized user must insure that contamination is controlled and not spread outside of the animal room. After administering high energy β or γ emitters, a meter survey must be performed to assure that the radiation exposure in all adjacent, uncontrolled areas (e.g., rooms, hallways, storage areas, etc.) do not exceed 2mR/hr and a cumulative exposure of 100 mrem/year. Areas must also be monitored after the administration of high energy β or γ emitters to determine the appropriate labeling for the room, e.g., **Radiation Area** signs if the exposure rate is greater than 5 mR/hr or **High Radiation Area** signs if the exposure rate is greater than 100 mR/hr. All animal waste, urine, feces, and/or blood contaminated dressings should be treated and handled as contaminated until surveys show otherwise.

Each cage in which radioactive animals are housed must be labeled as follows:

- "Caution – Radioactive Materials" label
- Radionuclide and amount administered
- Date administered
- Name and Phone Number of Authorized User

Whenever possible, use lab personnel to take care of the animals. All individuals caring for animals in which radioactive materials are used must be both trained radiation workers and ACUC certified animal users. Animal caretakers should report to Radiation Safety and the authorized user if the animal is bleeding or if the urine or feces of the animal is no longer confined. All animals should be marked so that they will be disposed of through the radiation Safety Program upon death or sacrifice.

Emergency Procedures

In the event of a spill or an emergency involving radioactive material, the immediate objectives are to:

1. Render first aid, if necessary.
2. Prevent or reduce the chance of personal contamination.
3. Prevent dispersal of the contaminant.
4. Begin personnel decontamination, if necessary.
5. Decontaminate the area under the supervision of the Radiation Safety Officer.

All individuals working with radioactive materials should be familiar with these procedures.

Minor Spill or Emergencies

Minor spills and emergencies are those spills of a few microcuries of activity where the radionuclide does not become airborne and emergencies where there is no personal injury. Most minor spills can be handled by lab personnel utilizing the spill kit provided to each laboratory by the Radiation Safety Program. Detailed procedures to follow are:

1. Notify all individuals in the room at once.
2. Limit access to the area to those persons necessary to deal with the spill. Do not let other persons into the area until the spill is decontaminated.
3. Open the lab spill kit and obtain necessary supplies.
4. Confine the spill immediately.

Liquid spills:

Put on protective gloves and clothing.

Drop absorbent paper or vermiculite on the spill.

Dry Spills:

Put on protective gloves and clothing.
Dampen thoroughly, taking care not to spread the contamination. Generally, water may be used, except where a chemical reaction with the water could generate an air contaminate of a chemical or physical hazard. Mineral oil or another predetermined organic solvent should then be used.

5. Notify Radiation Safety of the spill at the first opportunity. If after hours, notify campus police who can contact members of University Safety and Assurances.
6. Survey personnel involved with the spill before they disperse; decontaminate or change clothes as necessary.
7. Complete systematic decontamination based on a pre-established plan of action.
8. Submit a written report of the accident to the Radiation Safety Officer. Include a complete history of the accident and subsequent corrective measures which were taken, and signatures of all individuals involved.

Major Spill and Emergencies

Major spills and emergencies are those spills involving millicurie or greater activity, where airborne contamination occurs, or personal injury or fire are involved. These situations require additional assistance and these procedures should be followed:

1. During working hours, notify the Radiation Safety Officer (**414-430-7507 or 414-229-6339**) at once. During holiday, evenings, and weekends, call the UWM Campus Police (**9-911** from campus phones, or **414-229-9911**). Campus police will contact members of University Safety and Assurances. Consult the emergency phone list posted on the laboratory door for additional numbers.
2. Remove personnel from the area of the spill and hold them nearby until they can be checked for contamination by Radiation Safety.
3. If an individual is injured, apply immediate first aid as necessary. Do not let the possibility of radioactive contamination hinder first aid efforts. Decontamination of wounds, etc. can always be done after the victim's medical condition has been stabilized.
4. If the spill is liquid and the hands are protected, right the container by hand; otherwise, use tongs, a stick, or similar lever.
5. If the spill is on the skin, flush thoroughly with water and wash gently with soap or detergent.
6. If the spill is on clothing, remove the article at once and discard it in a plastic bag.
7. If the spill is airborne, evacuate the area at once. Switch off ventilation and fans. Facilities Services should be contacted (**414-22-4742**) during business hours or **414-229-4652** after hours.

8. Vacate and seal the room and go to a safe area, avoiding additional contamination of personnel. As practical, take precautions to limit the spread of contamination to other areas.
9. Shield the source spill if possible, but only if it can be accomplished without further contamination or without significantly increasing your radiation exposure.
10. Take immediate steps to decontaminate personnel involved.
11. Decontaminate the area following a pre-established plan. Radiation Safety will direct the decontamination procedure.
12. Monitor all personnel involved in a spill and cleanup.
13. Submit a written report of the accident to the Radiation Safety Officer. Include a complete history of the accident, as well as corrective measures taken, and signatures of all individuals involved.

Chapter 6 – Self-Test

Fill in or select the correct response.

1. Laboratories in which radioactive materials are used must be surveyed every ______________ in which radioactive materials are used.

2. ______________ ________________ which are counted in a liquid scintillation counter is the most effective method of surveying for tritium or ^{14}C contamination.

3. After administering high level beta or gamma emitters to an animal, a meter survey of adjacent uncontrolled areas should be performed to ensure exposure level do not exceed ______________ and cumulatively _______________.

4. Radiation Safety (**should/should not**) be notified when ordering material from a vendor on a blanket account or running order.

5. Three ways to dispose of radioactive wastes are: ______________________________, ___________________________________, ___________________________________ .

6. The Radiation Safety Program will not accept waste that is improperly ______________ or _________________________.

7. Short-lived (half-lives less than 30 days) radioisotopes may be held for radioactive decay. After _______________ half-lives, only 0.1% of the original activity will remain.

8. In the event of a spill of less than 1 mCi of radioisotope, you should attempt to ______________________ the spread of radioactive materials.

9. Persons working nearby should be ___________________________ of a radioactive spill.

10. Clean up of a spill is complete when the survey meter or wipe tests show that radiation levels are less than ________________________ times background levels and/or ___________________ disintegrations per minute (dpm).

Self-Test Answers

Chapter 1

1. Proton, Neutron, Electron
2. 6, 8, 6
3. Isotopes
4. Radioactivity or Decay
5. Radioactive
6. Half-life (physical)
7. 37,000,000,000
8. Roentgen
9. 1
10. rad
11. 1000
12. X- or Gamma Rays

Chapter 2

1. Ionization
2. Monitor
3. Gamma
4. Beta
5. mR/hr, cpm
6. efficiency
7. light
8. dosimeter or badge
9. potential for exposure
10. dosimetry reports, exposure history

Chapter 3

1. somatic
2. genetic
3. particulate
4. half, excreted
5. more
6. 500
7. More
8. Never
9. Are not
10. 200

Chapter 4

1. 620, 310, 310
2. 5000
3. 50,000
4. 100
5. 500

Chapter 5

1. Time, distance, shielding
2. Dense
3. Beta
4. Fume hood
5. 4
6. Do not
7. Do not
8. Tray
9. Do not
10. Wash

Chapter 6

1. Day
2. Wipe tests
3. 2 mR/hr, 100 mrem/year
4. Should
5. Disposal to radiation safety, natural decay, disposal to sewer or atmosphere
6. Packaged, labeled
7. 10
8. Contain
9. Notified
10. 5, 200

RS FORM 350 **APPENDIX A**

TRAINING AND INSTRUCTION CHECKLIST

The following is a checklist of the subject areas that must be covered as part of required instruction and training. This training must be completed PRIOR to the individual using radioactive materials. Upon completion, forward the original of this form to the Radiation Safety Program.

All Radiation Workers must complete parts 1, 2, & 3.
All Lab Workers must complete parts 2 & 3.

Part 1) Training required for Radiation Workers

________ Authorized radioactive materials permitted in the lab, including order and possession limits.

________ Authorized laboratory procedures (including animal uses or other special protocols)

________ Authorized areas where radioactive materials are used and stored

________ Proper operation and use of survey and measurement equipment used in lab

________ Procedures for contamination control surveys appropriate to materials used within laboratory

________ Inventory and waste disposal procedures

Part 2) Training required for other Laboratory workers (including radiation workers)

________ Type of radioactive materials used and stored in lab

________ Locations where radioactive materials are used and stored

________ Review of emergency procedures

________ Instructions for contacting Radiation Safety

________ Location of "Guide to the Safe Use of Radioactive Materials" manual and other pertinent postings and notices

________ Generic safe handling procedures

Part 3) Certification

I have received and understand the radiation safety training as documented on the previous page.

____
Worker Name (print) Worker Signature

____
Authorized User or Designee (print) Authorized User or Designee Signature

____
Date of Training Department

Appendix B-1

Instruction Concerning Prenatal Radiation Exposure

Section 19.12, "Instructions to Workers," of 10 CFR Part 19, "Notices, Instructions and Reports to Workers: Inspection and Investigations," requires instruction in, among other things, the health protection problems associated with exposure to radioactive materials or radiation.

Section 20.1208 of 10 CFR Part 20, "Standards for Protection Against Radiation," requires licensees to "ensure that the dose to an embryo/fetus during the entire pregnancy, due to occupational exposure of a declared pregnant woman, does not exceed 0.5 rem (5 mSv)." The regulation also requires the licensee to make efforts to avoid substantial variation above a uniform monthly exposure rate to a declared pregnant woman is defined in 10 CFR 20.1003 as "a woman who has voluntarily informed her employer, in writing, of her pregnancy and the estimated date of conception." The embryo/fetus is defined in 10 CFR 20.1003 as "the developing human organism from conception until the time of birth." The embryo is an early stage of development before the individual limbs and organs are recognizable. In humans, this development takes about eight weeks. The organism is considered a fetus from that stage until birth.

Section 20.1502 of 10 CFR Part 20 specifies the requirements for monitoring for external and internal occupational dose to a declared pregnant woman. Licensees must monitor the external occupational dose to a declared pregnant woman, using an individual monitoring device, if it is likely that the embryo/fetus will receive, from sources external to the body of the declared pregnant woman, a dose in excess of 50 millirems (0.5 millisievert) during the pregnancy. Licensees must also monitor, but not necessarily with individual monitoring devices, the occupational intake of radioactive material by declared pregnant women likely to receive, during the pregnancy, a committed effective dose equivalent in excess of 50 millirems (0.5 millisievert). For monitored declared pregnant women, the licensee must assess the effective dose equivalent delivered to the embryo/fetus during the pregnancy. Regulatory Guide 8.36, "Radiation Dose to the Embryo/Fetus," provides guidance on calculating the radiation dose to the embryo/fetus.

Section 20.2106 of 10 CFR Part 20 requires that the licensee maintain records of dose to an embryo/fetus if monitoring was required, and it requires that the records of the dose to the embryo/fetus be kept with the records of the dose to the declared pregnant woman. Regulatory Guide 8.7, "Instructions for Recording and Reporting Occupational Radiation Exposure Data," includes recommendations concerning records of dose to the embryo/fetus. That guide recommends that "Licensees should be sensitive to the issue of personal privacy with regard to embryo/fetus dose. If requested by the monitored woman, a letter report may be provided to subsequent licensees to document prior embryo/fetus dose." The declaration of pregnancy must also be kept on file but may be maintained separately from the dose records

[10 CFR 20.2106(e)]. The licensee must retain each required form or record until the NRC terminates each pertinent license requiring the record.

Appendix B-2

Instruction Concerning Pregnant Workers

Regulations requires that licensees instruct individuals working with licensed radioactive materials in radiation protection as appropriate for the situation. This Appendix describes information that you should know about the radiation exposure of pregnant workers. In particular, radiation protection regulations allow a pregnant worker to decide whether she wants to formally declare her pregnancy to her “employer” (UWM policy defines employer as the Radiation Safety Officer for purposes of pregnancy declaration), thereby taking advantage of the special dose limits provided to protect the developing embryo/fetus. This Appendix provides information on the potential effects of declaring a pregnancy in order to help workers make informed decisions or whether or not to declare pregnancy. This information is provided in the form of answers to a worker’s questions.

Making the Decision to Declare Pregnancy

Q. If I become pregnant, am I required to inform Radiation Safety of my pregnancy?

A. No. It is your choice whether to declare your pregnancy to Radiation Safety. If you choose to declare your pregnancy, a lower radiation dose limit will apply to you. If you choose not to declare your pregnancy, you will continue to be subject to the same radiation dose limits that apply to non-pregnant workers, even if you are visibly pregnant.

Q. If I inform Radiation Safety in writing of my pregnancy, what will happen?

A. The amount of radiation that you will be allowed to receive will decrease because there is a lower dose limit for the embryo/fetus of workers who have formally declared their pregnancy in writing. Ordinarily, the radiation dose limit for a worker is 5 rems in a year. But if you declare in writing that you are pregnant, the dose to the embryo/fetus is generally limited to 0.5 rem during the 9 month pregnancy, which is one-tenth of the dose limit that an adult worker may receive in a year. In addition, licensees must make efforts to avoid substantial variation above a uniform monthly dose rate so that all the dose received does not occur during a particular time of the pregnancy. This may mean that if you declare your pregnancy, you may not be permitted to perform some of your normal job functions and you may not be able to respond to emergencies.

Q. Why do the regulations have a lower dose limit for a worker who has declared her pregnancy than a normal worker?

A. The purpose of the lower limit is to protect the unborn child. Scientific advisory groups recommend that the dose before birth be limited to about 0.5 rem rather than the 5 rem occupational annual dose limit because of the sensitivity of the embryo/fetus to radiation. Possible effects from excess radiation exposure to the embryo/fetus include deficiencies in the child's development, especially the child's neurological development, and an increase in the likelihood of childhood cancer.

Q. What effects of development can be caused by radiation exposure?

A. The effects of large doses of radiation on human development are quite evident and easily measurable, whereas at low doses the effects are not evident or measureable and therefore must be inferred. For example, studies on the effects of radiation on animals and humans demonstrate clearly and conclusively that large doses of radiation – such as 100 rems – cause serious developmental defects in many of the body's organs when the radiation is delivered during the period of rapid organ development. The developing human brain has been shown to be especially sensitive to radiation. Intellectual Disability has been observed in the survivors of atomic bombings in Japan exposed *in utero* during sensitive periods. Additionally, some other groups exposed to radiation *in utero* have shown lower than average intelligence scores and poor performance in school.

The sensitivity of the brain undoubtedly reflects its structural complexity and its long developmental period. The most sensitive period occurs during weeks 8 to 15 of gestation followed by a substantially less sensitive periods for the 2 months after the 15^{th} week. There is no known effect on the child's developing brain during the first two months of pregnancy or the last three months of pregnancy.

No developmental effects caused by radiation have been observed in human groups at doses at or below the 5 rem occupational dose limit. Scientists are uncertain whether there are developmental effects at doses below 5 rems. It may be that the effects are present but are too mild to measure because of the normal variability form one person to the next and because the tools to measure the effects are not sensitive enough. Or, it may be that there is some threshold dose below which there are not developmental effects whatsoever. In view of the possibility of developmental effects, even if very mild, at doses below 5 rems, the scientific advisory groups consider it prudent to limit the dose to the embryo/fetus to 0.5 rem.

Q. How much will the likelihood of cancer be increased?

A. Radiation exposure has been found to increase the likelihood of cancer in many studies of adult human and animal groups. At doses below the occupational dose limit, an increase in cancer incidence has not been proven, but is presumed to exist even if it is too small to be measured. The question here is whether the embryo/fetus is more sensitive to radiation than an adult. While the evidence for increased sensitivity of the embryo/fetus to cancer induction from radiation exposure is inconclusive, it is prudent to assume that there is some increased sensitivity. Scientific advisory groups assume that radiation exposure before birth may be 2 or 3 times more likely to cause cancer over a person's lifetime than the same amount of radiation received as an adult. If this is true, there would be 1 radiation-induced cancer death in 200 people exposed *in utero* at the occupational dose limit of 5 rems. Scientific advisory groups have considered this risk to be too high and have thus recommended that the radiation dose to the embryo/fetus be limited to a maximum of 0.5 rem. At that dose, there would be 1 radiation-induced cancer death per 2000 people. This would be in addition to the 400 cancer deaths from all causes that are normally expected in those 2000 people.

Q. How does this risk to the embryo/fetus from the occupational radiation exposure compare to other avoidable risks?

A. The risk to the embryo/fetus from 0.5 rem or even 5 rems of radiation exposure is relatively small compared to some other avoidable risks. Of particular concern is excessive consumption of alcohol during pregnancy. The U.S. Public Health Service has concluded that heavy alcohol consumption during pregnancy (three drinks per day and above) is the leading known cause of intellectual disability. Children whose mothers drank heavily during pregnancy may exhibit developmental problems such as hyperactivity, distractibility, short attention spans, language difficulties, and delayed maturation, even when their intelligence is normal. In studies tracking the development of children born to light or moderate drinkers, researcher have also correlated their mother's drinking pattern during pregnancy with low birth weight, decreased attention spans, delayed reaction times and lower IQ scores at age 4 years. Youngsters whose mothers averaged three drinks per day during pregnancy were likely to have IQ's 5 points lower than normal.

Cigarette smoking may also harm the unborn. There is direct correlation between the amount of smoking during pregnancy and the frequency of spontaneous abortions and fetal death. Children of mothers who smoke while pregnant are more likely to have impaired intellectual and physical growth. Maternal smoking has also been associated with such behavioral problems in offspring as lack of self-control, irritability, hyperactivity, and disinterest. Long-term studies indicate that these children perform poorer than matched youngsters of non-smokers on tests of cognitive, psychomotor, language, and general academic functioning.

Alcohol and smoking are only examples of other risks in pregnancy. Many other toxic agents and drugs also present risk. In addition, many factors that cannot be controlled present risk. There is an increased risk in pregnancy with increasing maternal age. Maternal disease may be an important factor. Malnutrition, toxemia, and congenital rubella may be associated with birth defects. Maternal diabetes and high blood pressure have been associated with problems in newborns. In addition, many birth defects and developmental problems occur without an obvious cause and without any obvious risk factors. For example, viruses that we may not even be aware of can cause defects, and defects also can arise from spontaneous random errors in cell reproduction. But these are things that we can't do anything about.

In summary, you are advised to keep radiation exposure of your unborn child below 0.5 rem, but you should also remember that alcohol consumption, cigarette smoking, and the use of other drugs can do a great deal of harm.

How to Declare your Pregnancy

Q. What information must I provide in my declaration of pregnancy?

A. You must provide your name, a declaration that you are pregnant, the estimated date of conception (month/year), and the date that you give the letter to Radiation Safety. A sample letter is included at the end of this section (APPENDIX B-3).

Q. To declare my pregnancy, do I have to have documented medical proof that I am pregnant?

A. No. No proof is necessary.

Q. Can I tell Radiation Safety orally rather than in writing that I am pregnant?

A. No. The declaration must be in writing. As far as the regulations are concerned, an oral declaration or statement is the same as **NOT** telling Radiation Safety that you are pregnant.

Q. If I have not declared my pregnancy in writing, but it is noticeable that I am pregnant, do the lower dose limits apply?

A. No. The lower dose limits for pregnant workers apply only if you have declared your pregnancy in writing. The choice of whether to declare your pregnancy and thereby work under lower dose limits is your choice. No one else can make that decision for you. No one may remove you from a specific job because you appear to be pregnant.

Q. What if I have a miscarriage or find out I am not pregnant?

A. If you have declared your pregnancy in writing, you should promptly inform Radiation Safety that you are no longer pregnant. The regulations do not require that the revocation of a declaration be in writing, but we recommend that you revoke the declaration in writing to avoid confusion. If you have not declared your pregnancy, there is no need to inform Radiation Safety of your new, non-pregnant status.

Q. If I have declared my pregnancy in writing, can I revoke my declaration of pregnancy even if I am still pregnant?

A. Yes. The choice is entirely yours. If you revoke your declaration of pregnancy, the low dose limits no longer apply.

Q. How long is the lower dose limit in effect?

A. The dose to the embryo/fetus must be limited until:

- Radiation Safety knows you have given birth, or
- You inform Radiation Safety that you are no longer pregnant, or
- You inform Radiation Safety that you no longer wish to be considered pregnant.

Steps to Lower Radiation Dose

Q. What steps can I take to lower my radiation dose?

A. The general principles of maintaining exposure to radiation exposure as low as reasonably achievable are summarized here. You should already be applying these principles to your current work, but now is a good time to review them.

External Radiation Exposure

External radiation is radiation you receive from radiation sources or radioactive materials that are outside your body. The basic principles for reducing external radiation exposure are time, distance, and shielding – decrease your time near radiation sources, increase your distance from radiation sources, and increase the shielding between yourself and the radiation source. You should work quickly and efficiently in a radiation area so that you are not exposed to the radiation any longer than necessary. As the distance is increased from the source of radiation, the dose decreases. When possible, you should be work behind shielding. The shielding will absorb some of the radiation, thus reducing the amount that reaches you.

Internal Radiation Exposure

Internal radiation exposure is radiation you receive from radioactive materials that have entered into your body, generally entering with the air you breathe, the food you eat, or the water you drink. All laboratories already have specific procedures in place to minimize internal radiation exposure. Those procedures probably incorporate the following general precautions that should be taken when you are working with radioactive materials:

- Wear lab coats or other protective clothing.
- Use gloves while handling unsealed sources of radioactive materials.
- Do not eat, drink, smoke or apply cosmetics in areas where unsealed sources of radioactive materials are used.
- Do not mouth pipette radioactive (or any other) solutions.

- Wash your hands when your work is completed.

These basic principles should be incorporated into the specific methods and procedures for doing your individual work. Your lab should have already trained you in those specific rules and procedures. If you become pregnant, it is a good time to review the training materials on the methods and procedures that you were provided in your initial training. You can also contact the Radiation Safety Office for refresher training on how to keep radiation doses as low as reasonably achievable.

Additional Information

Q. Where can I get additional information?

A. You can find additional information on the risks of radiation exposure in the NRC's Regulatory Guide 8.29, "Instruction Concerning Risks from Occupational Radiation Exposure."

You can also call the NRC Regional Offices, 630-829-9500. Legal questions should be directed to the Regional Counsel and technical questions should be directed to the Division of Radiation Safety and Safeguards.

If you believe you have been discriminated against, you can contact the U.S. Equal Employment Opportunity Commission (EEOC), 800-669-EEOC.

Appendix B-3

Sample Letter – Declaration of Pregnancy

To: Radiation Safety Officer

Please accept this letter as notice that I am formally declaring that I am pregnant. I believe I became pregnant in _______________, _______________ ***(only the month and year need to be provided)***. My anticipated due date is ___________________________.

I understand that my occupational radiation exposure during my entire pregnancy will not be allowed to exceed **0.5 rem** unless that dose has already been exceeded between the time of conception and submitting this letter.

(Optional Paragraph)

If I find out that I am not pregnant, or if my pregnancy is terminated, I will promptly inform you in writing that my pregnancy has ended.

____

(Your Signature)

____

(Your Name Printed)

____

(Date)

Appendix C

Glossary

Absorbed Dose – The basic quantity which characterizes the amount of energy imparted to matter, often expressed in units of ergs per gram or joules per kilogram.

Accelerator – A machine capable of accelerating charged particles (i.e., electrons or protons) to produce particulate or other radiation at various energies.

Activate – To bombard an element with neutrons of other high energy radiation and make the element radioactive.

Activity – A measure of the number of nuclear disintegrations per unit time, usually denoted as disintegrations per second (dps) or disintegrations per minute (dpm), occurring in a sample. Activity is measured in units of curies (Ci) or becquerels (Bq).

ALARA – An NRC mandated program to insure that personnel and environmental radiation exposures are maintained "**As Low As Reasonably Achievable**"; ALARA must be considered in the design of all procedures where radiation or radioactive materials are used.

Alpha Particle, α – An electrically charged particle consisting of 2 neutrons and 2 protons which is commonly emitted from the nucleus in the radioactive disintegration of the heaviest nuclides in the periodic table.

Alpha Emitter – A radioisotope which emits an alpha particle in the process of radioactive decay.

Annual Limit of Intake (ALI) – The derived limit for the amount of radioactive material which can be taken into a radiation worker's body by inhalation or ingestion in a year.

Atom – The smallest part of an element. Made up of a nucleus surrounded by an electron field.

Authorized User – An individual member of the teaching or research faculty or staff, who, because of extensive training and experience with radiation, has been approved by the Radiation Safety Officer and DHS to use or supervise the use of radioactive material under conditions specified in an application for authorization. All work involving radioactive materials must be conducted under the authorization of an authorized user.

Background Radiation – Radiation in the environment resulting from natural causes, such as cosmic rays or naturally occurring radioactive materials in the earth's crust.

Becquerel – The unit of activity in the International System (SI) of units, which is equal to 1 nuclear disintegration per second. 1 Bq = 1 dps.

Beta Particle, β – A fast moving electrically charged particle emitted from a nucleus which has the same mass and charge as an electron.

Beta Emitter – A radioisotope which emits a beta particle in the process of radioactive decay.

Bioassay – Monitoring and biological sampling to determine the quantity or concentration of radioactive material in an individual's body.

Biological Half-Life – The time required for the body to naturally reduce the amount of chemical or elemental substance in the body to one-half of its original amount.

Bremsstrahlung Radiation – Electromagnetic radiation, similar to X-rays, produced by the sudden deceleration or "breaking" of beta particles and electrons as they pass through the strong electric fields found near an atom's nucleus.

Cancer – The uncontrolled growth of cells in an organ.

Cell – The basic building block of biology. Made up of a nucleus inside cytoplasm.

Chromosomes – Tiny thread-like structures located in a cell's nucleus which carry genes and are instrumental in passing along genetic information.

Committed Dose Equivalent, (CDE) – The sum of all the individual doses received in a given period of time by a specified population resulting from exposure to a specified source of radiation.

Committed Effective Dose Equivalent, (CEDE) – The sum of the products of the weighing factors applicable to each of the body organs or tissues that are irradiated and the committed dose equivalent to these organs or tissues.

Contamination – Unwanted deposition of radioactive materials on a work surface or suspended in the air. A surface is contaminated when removable levels in excess of 200 dpm per 100 cm^2 or 5x background levels are detected.

Controlled Area – An area, outside of a restricted area, which access can be limited by the licensee for any reason.

Curie, Ci – The historic unit of radioactivity, originally related to the activity of 1 gram of radium, but later standardized as 3.7×10^{10} nuclear disintegrations per second (dps) or 2.22×10^{12} disintegrations per minute (dpm).

Decay – The internal rearrangement of neutrons and protons within an atomic nucleus resulting in the emission of decay products.

Decay Products – The energetic radiation, such as alpha/beta particles and gamma rays, emitted from the nucleus of an unstable atom as a result of nuclear disintegration.

Declared Pregnant Worker – A worker who has voluntarily informed her employer and/or radiation safety, in writing, of her pregnancy and the estimated date of conception.

Derived Air Concentration, (DAC) – The concentration of a specific airborne radionuclide which, if breathed for a working year of 2000 hours under conditions of light work, results in an intake of one ALI for that radioisotope.

DNA – Abbreviation for deoxyribonucleic acid. A fundamental constituent of chromosomes which are the carriers of genetic information.

Dosimeter – A passive device which records the amount of absorbed dose, usually used to monitor external radiation exposure in radiation workers.

Effective Dose Equivalent – The sum of the products (rem) to an organ or tissue and the weighing factors applicable to each of the body organs or tissues that are irradiated.

Electron – One of the three fundamental particles from which atoms are constructed, it has a negative electrical charge of the same magnitude as the proton's positive charge but has a mass approximately 2000 times smaller than a proton or neutron.

Exposure – A quantity expressing the amount of ionization caused by X- or gamma radiation in air. This special unit of exposure is the roentgen, R. Sometimes it is also used to mean the Effective Dose Equivalent of a worker.

Exposure History – A summary report of a radiation worker's radiation exposure (in rem or Sievert) for the term of employment.

External Radiation – Radiation that comes from sources outside the body.

Gamma Ray, γ – Electromagnetic radiations emitted by a radioactive nuclei as packets of energy, called photons. Gamma rays are similar to light but with more energy so they are highly penetrating.

Gamma Emitters – A radioisotope which emits a gamma ray in the process of radioactive decay.

Geiger-Mueller (GM) Counter – A gas-filled radiation detection system which is sensitive enough to detect a single ionizing event. Appropriately configured, such systems can be used to survey for and measure either particulate (alpha/beta) or electromagnetic (X-/gamma) radiations.

Gene – Consisting of DNA and protein molecules, the combination of many genes form the chromosomes.

Genetic Effects – The heredity effects that radiation exposure may have on succeeding generations, particularly concerns a potential increase in the population's mutation rate.

Gray, Gy – The unit absorbed dose in the International System (SI) of units, which is equal to 1 joule per kilogram. In terms of historic units, 1 Gy = 100 rad.

Half-Life, $T_{1/2}$ – The time required for a radioactive substance to decay to one-half of its ordinal activity.

Ion – A particle with either positive or negative electrical charge.

Ionization – The removal of an orbital electron from an atom producing an ion.

Ionizing Radiation – Energetic radiation capable of removing electrons from atoms or molecules, thereby producing ion pairs.

Ionization Chamber – A gas-filled radiation detection system in which a sufficient voltage is applied to collect all the ion pairs formed without those ions producing further ionization in the chamber. Such systems are usually used to measure electromagnetic (X-/gamma) radiation.

Internal Radiation – Radiation from sources inside the body.

Inventory – An authorized user's detailed record of radionuclide receipt, use and disposal.

Isotopes – Atoms which have the same atomic number (i.e., the same number of protons) but with different atomic weights (i.e., different numbers of neutrons). Because isotopes of an element have the same number of electrons, they have the same chemical properties.

Labeled Compound – A chemical compound containing one or more radioactive isotopes.

Leukemia – A cancer of the blood system characterized by an excess production of white blood cells.

Liquid Scintillation Counter (LSC) – A stationary (i.e., not portable) radiation counting system designed to measure the quantity of radioactivity in laboratory samples or wipes.

Maximum Permissible Dose Equivalent (MPD) – The permissible dose for an individual, accumulated over a long period of time or resulting from a single exposure, which in the light of present knowledge carries a negligible probability of severe somatic (e.g., leukemia) or genetic injuries.

Microcurie, µCi – 2.22×10^6 disintegrations per minute.

Millicurie, mCi – 2.22×10^9 disintegrations per minute.

Milliroentgen, mR – Unit of gamma ray exposure, 10^{-3} roentgen.

Monitoring – The process of measuring and recording personnel radiation exposure or the amounts of radiation or radioactive contamination present in a certain location.

Mutation – Damage to cells capable of reproduction that take the form of alterations to genetic information.

Neutron – One of the three fundamental particles from which atoms are constructed, it has no electrical charge and a mass approximately equal to the proton.

Nuclear Regulatory Commission (NRC) – The Federal agency established to regulate the use of radioactive material through its licensing, inspection, enforcement, and standard development activities.

Nucleus – The dense, central core of an atom composed of protons and neutrons (Atomic Nucleus). In a cell, the component which contains all the information which the cell needs to carry out its function and reproduce itself (Biological Nucleus).

Nuclide- Any isotope of any element.

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/or radioactive material. Occupational dose excludes background radiation and radiation from medical procedures.

Photon – Radiation which consists of packets of energy transmitted in the form of electromagnetic waves and is similar to visible light, radio waves, and X- and gamma rays.

Proton – One of the three fundamental particles from which atoms are constructed. It has a positive electrical charge equal in magnitude to the charge of the electron, but its mass is approximately 2000 times that of an electron.

Public Dose – The dose received by a member of the general public from exposure to radiation and/or radioactive material released by a licensee.

Quality Factor, Q – Assigned factor which expresses the effectiveness of an absorbed dose of a certain type of radiation to cause biological damage to man. Absorbed does in rad/gray is multiplied by the quality factor to obtain the dose equivalent in rem/sievert.

Rad – The traditional unit of absorbed dose in any matter, it is equal to 100 ergs per gram. The corresponding international unit is the gray. 1 Gy = 100 rad.

Radiation Hazard – Any condition under which persons might receive a radiation dose in excess of the maximum permissible dose equivalent.

Radioactive – Any unstable nuclide which spontaneously emits ionizing radiation.

Radioactive Decay – The spontaneous disintegration or transformation of an unstable nuclide into a generally more stable nuclide, usually accompanied by the emission of charged particles and/or gamma rays. The decay process results in a decrease in the original number of radioactive atoms in the sample.

Radioactivity – Spontaneous disintegration of unstable atomic nuclei resulting in the emission of decay products.

Radioisotope – An isotope whose nucleus is unstable and undergoes radioactive decay.

Rem – The unit for measuring the dose equivalent to body tissue from any ionizing radiation in terms of its estimated biological effect. The corresponding international unit is the Sievert.
1 Sv = 100 rem.

Restricted Area – Any area, access to which is limited by the licensee for the purpose of protecting individuals against unnecessary exposure to radiation and radioactive materials.

Roentgen, R – The quantity of X- or gamma ray exposure in air; it is a measure of the ionization produced by the passage of those rays and is defined as 2.58×10^{-4} coulombs/kg of air.

Scintillation – The emission of light from an atom or molecule.

Scintillation Counter – A radiation detection system which used molecules that scintillate as a result of radiation interactions. Appropriately configured, such systems can be used to measure either particulate (alpha/beta) or electromagnetic (X-/gamma) radiation.

Sealed Source – Radioactive material which is permanently enclosed in a capsule designed to prevent leakage or escape of the radioactive material; there is no contact between the radioactive material and the open air.

Sievert, Sv – The unit of dose equivalent in the international system of units, it has the same relationship to the gray as the rem has to the rad in the traditional system.

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.

Survey Meter – A portable radiation detector used to determine the amount and location of radioactive contamination or radiation exposure levels in an area.

Thermoluminiscent Dosimetry – A method of determining absorbed dose by using radiation sensitive “crystals” which, when heated, emit a quantity of light that is proportional to the amount of radiation the crystals were exposed to.

Total Effective Dose Equivalent (TEDE) – The sum of the deep dose equivalent from external sources and the committed effective dose equivalent form internal sources.

Tracer – A labeled compound used in chemical or biological experiments or *in vitro* procedures.

Tritium, ^{3}H – A radioactive isotope of hydrogen which contains 1 proton and 2 neutrons in the nucleus and decays by beta emission.

Unrestricted Area – Any area where access is neither limited nor controlled by the licensee for the purpose of protecting individuals against unnecessary exposure to radiation and radioactive materials.

Unsealed Sources – Radioactive material in any form other than plated or sealed sources, such that the material is accessible to manipulation by the user. Unsealed sources are capable of contaminating their surroundings.

Volatile – A substance, usually a liquid, but sometimes a solid, which is capable of evaporating at room temperature to a fume, vapor, or gas.

X-Ray – Highly penetrating electromagnetic radiations similar to gamma rays but emanating from outside the nucleus of an atom.