RADIATION SAFETY TRAINING MANUAL

1st Edition

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1.0 Introduction

Here at Southern Illinois University – Carbondale (SIU), you may in the course of your education or employment work with radioactive isotopes or radiation producing machines. We use radioactivity in experimental and diagnostic situations at SIU because there is no better way to obtain the information we seek. However, working with radioactivity has unavoidable risks. Compared with other environmental hazards in the laboratory, we know a great deal about these risks and, unlike other hazardous material, radiation is relatively easy to measure and protect ourselves against.

One of the means by which the safe use and handling of radioactive isotopes or radiation producing machines may be accomplished is for you to become familiar with some of the technical and practical aspects associated with the safe use of the more common sources of radiation found at SIU.

The goal of this manual is to provide sufficient information so that you will be able to identify and deal effectively with the radiation hazards in the immediate work area, thus providing for your own safety, the safety of those around you, and the protection of the environment. State and University requirements will also be outlined.

SIU is licensed to possess various amounts of radioactive material and radiation producing machines that may be used in a variety of procedures. A broad scope license confers authority upon the University to approve, manage, and control the receipt, use, and disposal of radioactive materials and radiation producing machines. In fact, the University must act to "police" itself under the authority given in its broad scope license. As you review this guide, please keep in mind that each worker at SIU must be responsible for his or her own safety. Knowledge of the following guidelines and procedures will help to ensure that you can continue to conduct your research safely and without incident. Here at SIU, as at other educational institutions, working with radioactive material is a privilege, not a right. A serious violation or accident could result in the cancellation of the State Radioactive Materials License for the whole University. Therefore, the Radiological Control Committee (RCC) and the Office of Radiological Control (ORC) safety department take violations of SIU policies regarding radiation safety very seriously.

The Radiation Safety Officer is available for your consultation on the safe use of radioactive materials and radiation producing machines. Please call 536-2015 with any questions.

2.0 Objectives

This manual is a companion to the Handbook of Radiological Operations (HRO). The HRO manual describes the radiation protection program at SIU. The policies and procedures contained in the HRO have been approved by the RCC, and are submitted to the Illinois Division of Nuclear Safety (IDNS) as part of our radioactive materials license.

2.1 Radiation Safety Fundamentals

This *Radiation Safety Training Manual* presents the information necessary for users of radioactive materials and radiation producing machines to properly understand and follow the procedures in the HRO.

After studying this manual you will need to pass a written examination administered by the Radiation Safety Officer (RSO). To use radioactive material at SIU, you must first obtain authorization from the ORC Safety Department. A Certificate of Achievement will be presented to those who have successfully completed the safety course.

All new radiation users will need to complete the following:

A. Read this Radiation Safety Training Manual. You will be responsible for knowing all the information in this document. A closed book test will be administered and must be passed before radiation work begins. The questions will be similar to those included in this workbook.

B. In order to become an approved radiation user you will be required to have several important documents on file with the ORC. You will need to complete a **Training and Experience Form** (RCC-2) to provide information about you and your radiation use experience. Your Principal Investigator (PI) must sign this form to add your name to their permit, indicating that they will be responsible for your supervision. You will need to complete a **Radiation Exposure History Form** (RCC-4). If you are a female worker, read through the Regulatory Guide 8.13: Instructions Concerning Prenatal Radiation Exposure. After review, sign and return the **Acknowledgment of Instruction Form** (RCC-5) indicating that you have received information on the SIU prenatal radiation exposure policy. If you are now pregnant or attempting to become pregnant and *want* to declare yourself pregnant, complete the **Declared Pregnant Worker/Student Form** (RCC-5A).

C. Call the ORC (536-2015) to schedule a time to take the written exam. This may be scheduled at your convenience (Monday through Friday, 8 a.m.– 4 p.m.). Please bring the documents described above when you come in to take your test.

D. If you successfully pass the exam you will be issued authorization (and dosimetry if required) to begin working with radiation under **direct supervision** of your assigned Radiological Laboratory Supervisor (RLS) in the lab.

2.2 On-the-Job Training

This written guide does not replace the requirement that a laboratory supervisor provide practical, hands-on training in the correct storage, use, disposal, and transportation of radioactive materials.

After receiving authorization by the ORC you may begin using radioisotopes under the **direct supervision** of the RLS. Hands-on training for each user is also provided in the laboratory by the RLS.

Topics covered during this training include, as appropriate:

- Safe use of laboratory equipment and materials, including protective clothing.
- Experiment procedures and protocols, including operating procedures for radiation producing machines.
- Safe handling, storage, and disposal of radioactive materials.
- Methods to control and measure radiation levels and contamination.
- Proper maintenance of required records.
- Emergency procedures

2.3 Annual Refresher Training

You will also be required to complete annual refresher training to keep you up-to-date with the latest regulations and university policies. The ORC safety department will assist you in meeting this requirement.

3.0 Ionizing Radiation

To understand radiation safety procedures, some knowledge of the physical properties of ionizing radiation is required. A basic understanding of chemistry and physics is assumed.

3.1 Atomic Structure

The basic unit of matter is the atom. The basic atomic model, as described by Ernest Rutherford and Neils Bohr in 1911, consists of a positively charged core surrounded by negatively-charge shells. The central core, called the nucleus, contains protons and neutrons. Nuclear forces hold the nucleus together. The shells are formed by electrons, which exist in structured orbits around the nucleus.

Protons

Protons (p^+) are positively charged and located in the nucleus of the atom. The number of protons determines the element.

Neutrons

Neutrons (n) are uncharged and located in the nucleus of the atom. Atoms of the same element have the same number of protons, but can have a different number of neutrons.

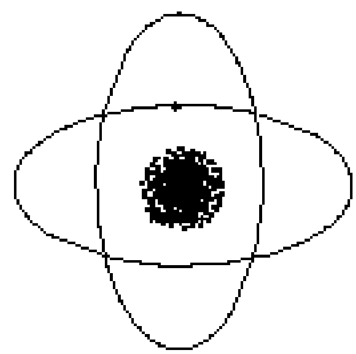


Figure 1 Atomic Model

Atoms that have the same number of protons but different numbers of neutrons are called isotopes. Isotopes have the same chemical properties; however, the nuclear properties can be quite different.

Electrons

Electrons (e^-) are negatively charged and travel in specific orbits or energy levels about the nucleus. Each electron has energy, which enables it to resist the positive charge of the nucleus. An atom is electrically neutral if the total electron charge equals the total proton charge. Electrons are bound to the positively charged nucleus by electrostatic attraction.

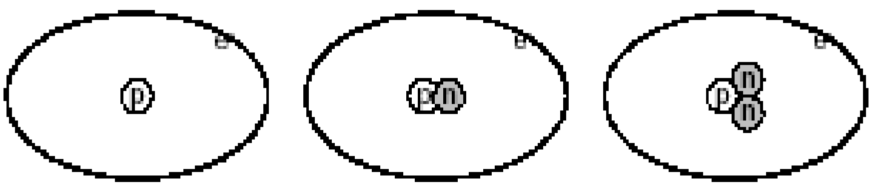
The number of electrons and protons determines the overall electrical charge of the atom. The term ion is used to define atoms or groups of atoms that have a net positive or negative electrical charge.

The energy of ionizing radiation is usually given in electron volts (eV). The electron volt is defined as the energy of an electron that has been accelerated through an electron potential of one volt. The eV is a very small amount of energy and therefore keV (thousand electron volts) and MeV (million electron volts) are used as the units of measurement for the energies associated with the emission for radioactive materials or machines. The energy of visible light is about two or three eV.

3.2 Atomic Number

The number of protons in the nucleus of an element is called the atomic number (Z). Atomic numbers are all integers. For example a hydrogen atom has one proton in the nucleus. Therefore, the atomic number of hydrogen is 1. A helium atom has two protons in the nucleus, which means the atomic number is 2. Uranium has ninety-two protons in the nucleus and, therefore, has an atomic number of 92. Elements with atomic numbers greater than 92 can be produced in the laboratory. The organization of elements into groups with similar chemical properties in the periodic table is based on atomic numbers.

The mass number is the sum of the protons and neutrons in an atom. Although all atoms of an element have the same number of protons, they may have a different number of neutrons. Atoms that have the same number of protons but different numbers of neutrons are called isotopes. For example, deuterium (^{2}H) and tritium (^{3}H) are isotopes of hydrogen with mass numbers of two and three respectively.



^{1}H	^{2}H	^{3}H
hydrogen (protium)	**deuterium**	**tritium**
Stable	**Stable**	**Radioactive**

Figure 2 Isotopes of Hydrogen

Note: *Nuclide notation*

The mass number can be used with the name of the element to identify which isotope of an element we are referring to. If we are referring to the isotope of phosphorous that has a mass number of 32, we can write it as phosporous-32. If we are referring to the isotope of mass number 33, we write it as phosporous-33.

Often, this expression is shortened by using the chemical symbol instead of the full name of the element, as in P-32 or P-33. Alternatively, the nuclide can be specified by using the chemical symbol, with the mass number written as a superscript at the upper left of the symbol:

$$^{A}X$$

Where: X = *Symbol for element*
A = *Mass number (number of protons (Z) plus the*

number of neutrons (N))
For example, the notation for uranium-238 would be ^{238}U.

3.3 Radioactivity

Only certain combinations of neutrons and protons result in stable atoms. If there are too many or too few neutrons for a given number of protons, the resulting nucleus will have excess energy. The unstable atom will become stable by releasing excess energy in the form of particles or energy (quanta). This emission of particles or energy from the nucleus is called radiation. These unstable atoms are also known as radioactive material.

The property of certain nuclides to spontaneously emit radiation is called radioactivity. (The term radionuclide has been coined to refer to these radioactive nuclides.) There are on the order of 200 stable nuclides and over 1100 unstable (radioactive) nuclides.

The emission of a particle or energy (electromagnetic radiation) in order to reach a more stable configuration usually results in the formation of a new element. Following this transmutation the nucleus is usually more stable. As the energy of the nucleus is reduced, the nucleus is said to disintegrate. The process by which a nucleus spontaneously disintegrates (or is transformed) is called radioactive decay.

3.4 Ionizing and Non-ionizing Radiation

Radiation commonly encountered in campus laboratories falls into two broad categories depending on its ability to form charged species (ions) during interactions with matter. Radiation that has single particles or quanta with enough energy to eject electrons from atoms is known as ionizing radiation. From the standpoint of human health and safety, ionizing radiation is of greater concern since it can create many energetic ionized atoms, which in living cells engage in chemical reactions that interfere with the normal processes of cells.

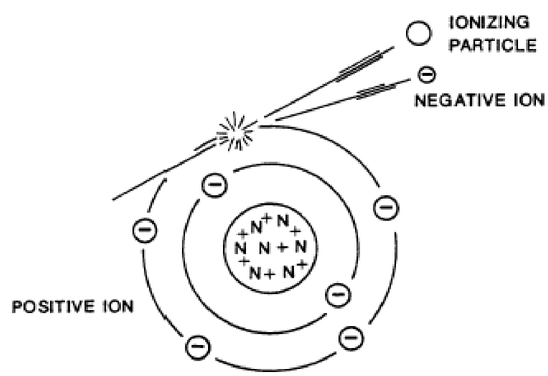


Figure 3 Ionization

Energy (particles or rays) emitted from radioactive atoms can cause ionization. Ionizing radiation includes alpha particles, beta particles, gamma or x-rays, and neutron particles.

Non-ionizing radiation does not have enough energy to eject electrons from electrically neutral atoms. Examples of non-ionizing radiation are ultraviolet (could ionize), visible light, infrared, microwaves, radio waves, and heat.

Study Questions:

1. The three components of the atom are _______________, _______________, and _________________.

2. _______________ have equal numbers of protons, but different numbers of neutrons in the nucleus.

3. The process of ______________ orbital electrons from neutral atoms is called ________________.

4. Radioactive material contains _______________ atoms.

5. The structural difference between various nucleus of an element are due to different numbers of:

   A) electrons
   B) protons
   C) neutrons
   D) neutrinos

6. _______________ radiation doesn't have enough energy to _______________ an atom.

4.0 Units of Measurement

In measurements of ionizing radiation, different units are used to quantify:

- The activity of radioisotopes in disintegrations per unit time;
- Exposure (roentgen);
- Absorbed dose (rad); and
- Absorbed dose of various types of radiation relative to x-rays (rem).

These units are commonly used in SIU laboratories. For example, the contents of radioactive vials are described in microcuries (μCi), exposure meters that measure radioactive exposure read in milliroentgens/hour (mR/hr), and the results of personal monitoring devices (badges) are recorded in millirems (mrem).

4.1 Activity

The quantity of activity of a radioisotope is expressed in terms of the number of disintegrations the nucleus undergoes per unit time. Since the fundamental unit of time is the second, the quantity of activity is measured in disintegration per second (dps). Because the second is a very short time period in which to make a measurement, activity is usually measured in units of disintegrations per minutes (dpm).

Figure 4 The curie is named after Pierre Curie photographed above with his wife Marie Curie.

The historical unit of activity is the curie. The curie is a very large unit of activity and is defined as 3.7×10^{10} disintegrations per second. Most radioactive samples at SIU contain amounts of activity which are more approximately measured in *millicuries* (mCi or 1×10^{-3} curies) or *microcuries* (μCi or 1×10^{-6} curies).

The SI unit of activity is the Becquerel (bq). The becquerel is a very small unit of activity and is defined as 1 disintegration per second. More appropriate units for expressing the activity of a sample in becquerels are *megabecquerels* (MBq or 1×10^{6} becquerels) and *gigabecquerels* (GBq or 1×10^{9} becquerels).

4.2 Exposure

Exposure is a measure of the ability of photons (x and gamma) to produce ionization in air. Traditionally, the unit of exposure is the roentgen (R).

The unit is defined as the sum of charge per unit mass of air that is:

$$1 \text{ Roentgen} = 2.58 \times 10^{-4} \text{ coulombs/kg of air}$$

There is no SI unit defined for exposure. This was done to discourage further use of the quantity.

4.3 Absorbed Dose

Units of dose quantify the amount of energy absorbed or deposited per unit mass. The old (CGS) unit of absorbed dose is the rad, which is an acronym for **R**adiation **A**bsorbed **D**ose. The unit rad can be applied to all types of radiation and is defined as the deposition by any radiation of 100 ergs of energy in one gram of any material.

Note: *For simplicity purposes, 1 rad of photons is usually considered to be equivalent to 1 R. The actual physical relationship is such that an exposure to 1 R would produce an absorbed dose of 0.87 rads in air.*

The SI unit of absorbed dose is the gray (Gy), equivalent to the deposition of one joule of energy per kilogram (1 J/kg). 1 Gy = 100 rad.

Although the rad and gray are measures of ionization produced, they do not give any information about the biological effects of the radiation that is absorbed.

4.4 Quality Factor

A quality factor (QF) is used to relate the absorbed dose of various kinds of radiation to the biological damage caused to the exposed tissue. A quality factor is necessary to relate the effects of radiation because the same amounts absorbed (energy per kilogram of tissue) of different kinds of radiation cause different degrees of damage. The quality factor converts the absorbed dose to a unit of dose equivalence that can be added with and compared to damage caused by any kind of radiation.

There is a quality factor associated with each specific type and energy of radiation (see Table 1). A high quality factor indicates that type of radiation has a greater biological risk or greater effect than radiation with a lower quality factor for the same absorbed dose.

Table 1 Quality Factors

Radiation Type	QF
X-ray	1
Gamma rays	1
Beta particles	1
Neutrons	3-10
Alpha particles	20

4.5 Dose Equivalent

A measurement of the dose equivalent is calculated as the absorbed dose multiplied by the quality factor, which relates the relative risk from the type of radiation absorbed to the risk from the same dose of x or gamma radiation.

The traditional unit of dose equivalent is the rem, which is an acronym for **R**oentgen **E**quivalent **M**an. The rem was the quantity of ionizing radiation whose biological effect (in man) is equal to that produced by one roentgen of x-rays or gamma radiation. The dose equivalent in rem is numerically equal to the absorbed dose in rad multiplied by the quality factor:

$$rem = rad \times QF$$

The SI Derived unit of dose equivalence is the sievert (Sv). The dose equivalent in sieverts is equal to the absorbed dose in grays multiplied by the quality factor:

$$Sievert = gray \times QF$$

Since, one gray is equal to 100 rad, it follows that:

$$1\ Sv = 100\ rem$$

For all practical purposes the amount of rads is equal to the amount of rems for beta, gamma, and x-ray radiation.

Table 2 Summary of Radiation Units

Term		Unit	Abbr.	Value(s)
Exposure:		Roentgen	R	87 erg/g
Ionization per unit mass of air due to X or gamma radiation		none	X	2.58×10^{-4} C/kg
Absorbed Dose (D):	CGS	Radiation Absorbed Dose	Rad	100 erg/s 0.01 Gy
Energy deposited in a unit mass by any radiation	SI	Gray	Gy	1 J/kg 100 rad
Dose Equivalent (H):		Roentgen Equivalent Man	Rem	Equivalent 1R 0.01 Sv
Measure of radiation damage in living tissue	SI	Sievert	Sv	100 rem

Table 2 Summary of Radiation Units (continued)

Term		Unit	Abbr.	Value(s)
Activity (A):	Historical	Curie	Ci	3.7×10^{10} dps
Amount of radioactive material yielding a specific rate of decay	SI	Becquerel	Bq	1 dps

Study Questions:

7. Complete the following tables:

Table 3 Curie Subunits

Unit	Abbr.	dps	dpm
curie	Ci	3.7×10^{10}	2.2×10^{12}
millicurie	mCi		2.22×10^{9}
microcurie	μCi	3.7×10^{4}	
nanocurie	nCi		2.22×10^{3}
picocurie	pCi	3.7×10^{-2}	

Table 4 Becquerel Subunits

Unit	Abbr.	dps	dpm
becquerel	Bq	1	60
kilobecquerel	kBq		6×10^{4}
megabecquerel	MBq	1×10^{6}	

8. The unit used to measure radiation exposure is the _______________.

9. The units used to measure absorbed dose are the _______________, or the _______________.

10. Calculate the number of disintegrations per minute for one μCi.

A) 2.22×10^{6}
B) 3.7×10^{10}
C) 6.25×10^{7}
D) 2.22×10^{4}

5.0 Radioactive Decay

There are several modes by which an unstable atom can decay to a more stable configuration. A brief review of the common forms of ionizing radiation and their characteristics is essential to an understanding of the reasons for specific radiation protection procedures. Although there are general precautions to be taken when using any source of ionizing radiation, the specifics of experimental design depend on a number of factors, one of the most important being the type of ionizing radiation in use.

5.1 The Nature of Radioactivity

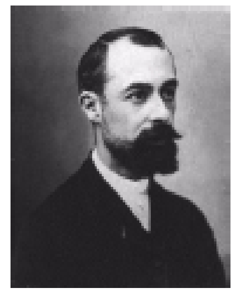


Figure 5
Henri Becquerel

Henri Becquerel first reported evidence of natural radioactivity in 1896. Becquerel demonstrated that uranium ore would darken a photographic plate shielded with opaque paper in much the same manner as X-rays. He postulated that the uranium emitted very penetrating rays, similar to X-rays. The phenomenon was ultimately called radioactivity.

After a long and complicated series of investigations, to which many outstanding physicists contributed, a better understanding of natural radioactivity was available. Finally, in 1903, Ernest Rutherford clearly showed that there were three kinds of radioactive emissions that he named alpha, beta, and gamma after the first three letters of the Greek Alphabet. Initially, all three types of radiation were commonly referred to as rays. With time, the characteristics of each type of radiation were determined. It was found that alpha and beta are actually forms of particulate radiation not rays. Since then other types of radiation have been discovered through numerous experiments and tests.

When a radioactive nuclide decays, a transmutation occurs. The decay product, or daughter has become an atom of a new element with chemical properties different than original parent atom. With each transmutation an emission from the nucleus occurs. There are several modes of decay associated with each emission.

5.2 Alpha Particles

Alpha particles (α) are essentially a doubly charged helium nucleus (He^{++}), consisting of two protons and two neutrons, which is emitted from the nucleus of an atom. With few exceptions only relatively heavy radioactive nuclides, like *radium, uranium, thorium,* and *plutonium,* decay by alpha emission. For example, Radium-226 decays by alpha emission to produce Radon-222.

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

Alpha decay is *monoenergetic*, meaning that all alpha particles emitted by a particular isotope undergoing a particular nuclear transition have the same energy.

The alpha particle's positive charge (α^{++}) strips electrons (e^-) from nearby atoms as it passes through the material, thus ionizing these atoms. Alpha particles interact very strongly with any material and deposit large amounts of energy in a short distance. One alpha particle will cause tens of thousands of ionizations per centimeter in air. This large energy deposit limits the penetrating ability of the alpha particle to a very short distance. This range in air is about one to two inches.

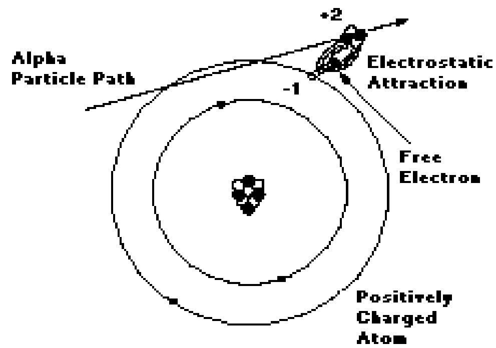


Figure 6 Ionization by an Alpha Particle

From a radiation safety standpoint, a thin absorber such as a sheet of paper or the dead layer of skin easily stops alpha particles. External exposure of the body to such alpha sources does not present a great hazard. Inside the body, however, alpha emitters are highly significant. Because the alpha particle undergoes many interactions with surrounding atoms, it deposits all its energy in a very small volume (3×10^{-9} cm^3 in muscle). An energy deposit of this magnitude within a cell nucleus will virtually guarantee cell destruction. For this reason, *extreme* precautions must be taken to prevent sources of alpha radiation from entering the body by inhalation, ingestion, or puncture.

5.3 Beta Particles

<u>Beta particles</u> (β) are high-speed electrons emitted from the nucleus of an atom. In beta decay, a neutron is converted to a proton and an electron, and the electron (or beta particle) is promptly ejected from the nucleus forming a new element with an atomic number increased by 1. For example carbon-14 (^{14}C), which has eight neutrons and six protons decays by beta decay. After the emission of the beta particle, the nucleus contains seven protons, and seven neutrons. Its mass number remains the same, but its atomic number increases by one. The new element with atomic number 7 is nitrogen.

$$^{14}_{7}C \rightarrow \;^{14}_{6}N + \beta^-$$

The most commonly used beta emitting radionuclides at SIUSOM are ^3H, ^{14}C, ^{32}P, ^{33}P, and ^{35}S.

Beta particles are emitted with a continuous spectrum of kinetic energies ranging from zero to the maximum value of the decay energy, E_{max}. However most beta particles are ejected with energies lower than this maximum energy. The mean energy of beta particles (E_{mean}) is about 1/3 E_{max}. The shape of the beta energy spectrum for various radioisotopes and values for E_{max} is characteristic for a particular isotope. Unless otherwise stated, the energy of a beta emitter given in reference literature is E_{max}.

Beta radiation causes ionization by displacing electrons from their orbits. Ionization occurs due to the repulsive force between the beta particle (β^-) and the electron (e^-), which both have a charge of minus one.

Beta particles have a finite range, in the air and in other materials, which is linearly related to their energy. In general, the range of beta particles in the air is about 12 feet per MeV. For example, ^{32}P has an E_{max} of 1.7 MeV or a maximum range in air of 12 x 1.7 or approximately 20 feet. The average range in air (E_{mean} = 0.69 MeV) would be approximately 7 feet. Plastic, glass, aluminum foil, or safety glasses can shield most beta particles.

Bremsstrahlung

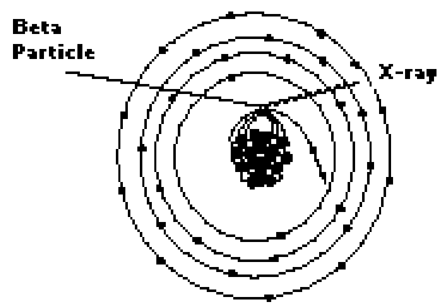


Figure 7 Bremsstrahlung Radiation

Charged particles, including beta particles, lose energy in an absorbing material by excitation, ionization, and radiation. Radiation energy losses of charged particles are very important and are termed bremsstrahlung, which in German means "braking radiation." This process occurs when the charged particle decelerates in an absorber with an attendant creation of a x-ray (or bremsstrahlung) radiation. This radiation is more penetrating than the original beta particle. The fraction of beta energy that contributes to the production of bremsstrahlung is directly proportional to both the atomic number of the absorber and the energy of the beta radiation.

To prevent the creation of bremsstrahlung radiation, high-energy beta emitters must be shielded with material having a low atomic number (e.g. Plexiglas or plastic, about 1 cm thick for P-32). Bremsstrahlung radiation is characterized in Table 5.

Table 5 P-32 Bremsstrahlung Production

Absorber	Fraction Energy Converted into Bremsstrahlung	Average Energy Bremsstrahlung Radiation
Plexiglas	0.36 %	~ 200 keV
Lead	5.0 %	~ 200 keV

Beta radiation penetrates matter to varying distances. The higher the energy of the beta particle, the deeper the penetration into matter. Depending on the maximum beta energy, the penetration depth may be an external radiation hazard, specifically to the skin and eyes. The degree of hazard depends on the beta energy of the isotope and should be evaluated in every case. Generally, beta emitters whose energies are less than 0.2 MeV, such as tritium (^3H), ^{35}S and ^{14}C, are easily absorbed in the outer (dead) layer of skin and are not considered to be external radiation hazards. An exception is in the case of skin contamination, where the dose rate to the basal cells of the skin can range from 1.4 to 9.3 rad/hr for 1.0 $\mu Ci/cm^2$ of skin contamination with isotopes other than tritium.

If ingested or inhaled, the source of the beta radiation is in close contact with body tissue and can deposit energy in a small volume of body tissue. Externally, beta particles are potentially hazardous to the skin and eyes. As with alpha radiation, sources inside the body within cells or incorporated into biologically active molecules may give significant doses that disable and kill cells.

Note: *Beta particles can be either positively or negatively charged. Positive beta particles or positrons are a form of anti-matter and are not commonly used in laboratories at SIUSOM. For the purpose of this training manual, all discussions of beta particles will refer to negatively charged beta particles.*

5.4 Gamma Rays / X-rays

<u>Gamma rays</u> (γ) and <u>X-rays</u> are electromagnetic radiation and have no electrical charge. X-rays originate in the electron cloud surrounding the nucleus as a consequence of the movement of charge from higher to lower energy levels. Gamma rays result from the rearrangement of protons and neutrons that make up the nucleus. Since nuclear reactions are the most energetic changes that occur in the atom, gamma rays may have more energy than other forms of electromagnetic radiation. Gamma and x-rays are both emitted in discrete, packets of energy known as *photons* and travel at the speed of light. The nature of these photons is determined by their *wavelength* or *frequency*.

Gamma radiation may accompany any of the other decay modes. Nuclear decay reactions resulting in a transmutation generally leave the resultant nucleus in an excited state. Nuclei, in this excited state, may reach an unexcited or *ground state* by the emission of a gamma ray. Unlike alpha and beta radiation, no new elements are formed as a result of gamma radiation.

For example, metastable barium-133 (^{133}mBa) decays to a stable form of barium by gamma emission.

$$^{133\,m}Ba \rightarrow {}^{133}Ba + \gamma$$

Orbital Electron Capture

For radionuclides having a low neutron to proton ratio, another mode of decay can occur known as <u>orbital electron capture</u> (EC). In this radioactive decay process the nucleus captures an electron from the orbital shell of the atom, usually the K shell, since the electrons in that shell are closest to the nucleus. An example of orbital electron capture is I-125.

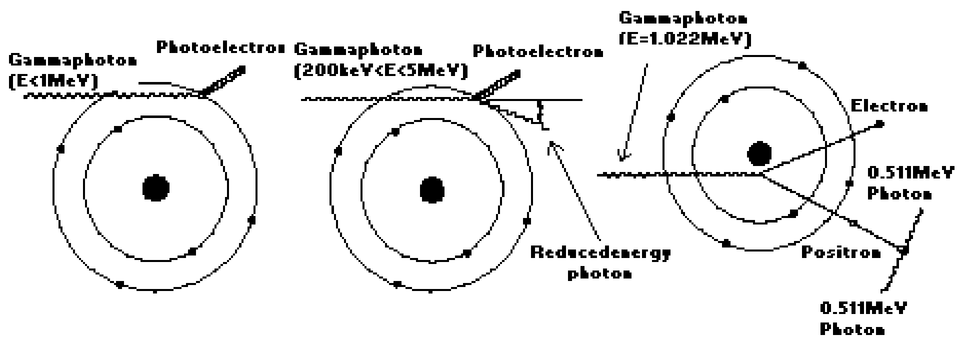
$$^{125}I + e^{-} \rightarrow {}^{125}Te + v + \text{x-rays}$$

.

The electron (e^{-}) combines with a proton to form a neutron followed by the emission of a neutrino (v). Electrons from higher energy levels immediately move in to fill the vacancies left in the inner lower-energy shells. The excess energy in these moves results in a cascade of characteristic x-ray photons.

Photons interact with matter by three primary processes: Photoelectric Effect, Compton Scattering, and Pair Production. A lengthy explanation of these processes is not required, but note that all three eventually produce energetic electrons that ionize or excite the atoms in the absorber. These interactions permit the detection of gamma rays or x-rays, and determine the thickness of shielding materials necessary to reduce exposure rates from gamma or x-ray sources.

Figure 8 Photoelectric Effect, Compton Scattering and Pair Production



The rate at which intensity (number of photons) decreases also depends on the density of the absorber. Very dense materials, such as concrete, lead or steel shield gamma and x-ray radiation best.

Because gamma/x-ray radiation has no charge and no mass, it has a very high penetrating ability. Attenuation refers to the reduction in intensity of gamma and x-ray radiation. The higher the energy of the photon, the more material will be needed to attenuate a particular photon intensity. For example, if a certain thickness of an absorber reduces the intensity to one half (50%), twice that thickness reduces it to one quarter (25%), three times to one eighth (12.5%), and so on. The thickness of the absorber that reduces intensity by 50% is called the half-value layer (HVL).

Of particular note with regard to radiation safety is that shielding reduces the intensity of electromagnetic radiation, but statistically it never reaches zero. This is in contrast to alpha and beta particles, which, because of their finite path length, can be completely shielded.

The skin of the body attenuates most photons with energy less than about

0.01 MeV. These photons may be an *external* radiation hazard to the *skin*. Higher energy photons penetrate considerable distances into and through the human body. Photons of this energy are considered an *external* radiation hazard to the *whole body*. The external hazard of gamma and x-ray emitters can be eliminated with lead foil for low energy gamma radiation or lead bricks for high energy gamma radiation. Gamma and x-ray emitters are also an *internal hazard* and precautions must be taken to prevent internal uptakes of either of these.

5.5 Neutron Particles

Of the four major types of ionizing radiation, neutron radiation is least commonly encountered in SIU research laboratories.

Neutron radiation (n) consists of neutrons that are ejected from the nucleus. A neutron has no electrical charge. Because of the lack of a charge, neutrons have a relatively high penetrating ability. Like gamma rays, they can easily travel several hundred feet in air. Their absorption properties are complex functions of the absorber's atomic weight, neutron to proton ratio, and interaction probabilities with various nuclei.

A direct interaction occurs as the result of a collision between a neutron and a nucleus. A charged particle or other ionizing radiation may be emitted during this direct interaction. The emitted radiation can cause ionization in human cells. This is called "indirect ionization."

Neutron radiation is shielded by materials with a high hydrogen content, such as water, concrete, or plastic. Because neutrons have the ability to penetrate through the body, they are considered a whole body hazard. Exposure to neutron radiation is of considerable concern as biological damage from sources external to or within the body is considerably greater than for equivalent amounts of β or γ radiation.

Table 6 provides a summary of the characteristics of the various types of radioactive emissions that have been discussed. Table 7 lists the characteristics of radionuclides that are frequently used in SIU labs.

Table 6 Radioactive Decay Characteristics

Radiation	Symbol	Form	Origin	Essential Parts	Mass (amu)	Charge	Energy Spectrum	Misc. Info.
Alpha	α	Charged	Nucleus	2p,2n	4	+2	MeV	Mono-energetic; particle from heavy radio-nuclides
Beta	β	Charged particle	Nucleus	$1e^-$	<<1	-1	0 to E_{max}	
Gamma	γ	Electro-magnetic radiation	Nucleus	Photon	None	None	MeV	Usually follows particle emission
X-ray	X	Electro-magnetic radiation	Electron orbitals	Photon	None	None	keV	Cascade following EC
Neutron	n	Uncharged particle	Nucleus	1n	1	0	eV to MeV	

Table 7 Characteristics of Radionuclides Used at SIU

Radionuclides	Emission	Energy (Mev)	Half-life
Carbon (^{14}C)	Beta (β)	0.156	5,730 yrs
Tritium (^{3}H)	Beta (β)	0.018	12.3 yrs
Iodine (^{125}I)	Gamma (γ)	0.035	60 days
Phosphorous (^{32}P)	Beta (β)	1.71	14.3 days
Sulfur (^{35}S)	Beta (β)	0.167	87 days
Chromium (^{51}Cr)	Gamma (γ)	0.32	27.8 days
Cesium (^{137}Cs)	Beta / Gamma	5.18 / 6.62	30.4 yrs

Note: *It is important that you know the characteristics for the radionuclides assigned for use in your laboratory.*

5.6 Radioactive Half-life

The activity of a radioactive isotope decreases predictably with time. The period required for the activity of a sample to decay to one half of the initial value is called the half-live of the isotope. For example, starting with an initial sample of one billion atoms of P-32, only 500 million atoms will remain as P-32 after one half-life (14.3 days). The other 500 million atoms will decay to sulfur-32, which is stable. Further, after two half-lives (28.6 days) only 250 million atoms of P-32 will remain. This process continues until all the P-32 is transformed to stable sulfur. If a graph is constructed of the number of atoms remaining versus time one obtains a curve described as an exponential decay curve. The mathematical description of the decay curve of a radioactive isotope is given as follows:

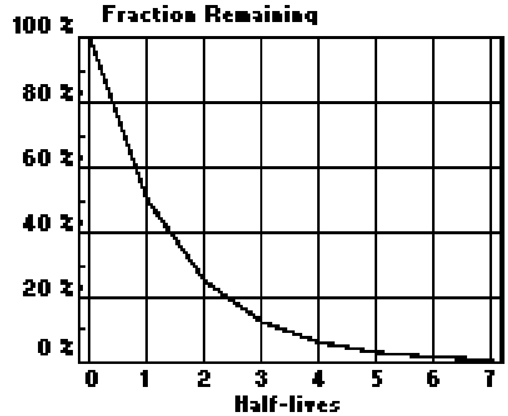


Figure 9
Radioactive Decay (Linear Scale)

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

Where:

A =	activity remaining
A_o =	the initial activity of the isotope
λ =	the radioactive decay constant = $0.693/T_{1/2}$
$T_{1/2}$ =	the half-life of the isotope
t =	elapsed time
e =	2.7183 (base of natural logarithm)

When using this formula it is important to express t and $T_{1/2}$ in the same units (i.e. second, days, years, etc.).

Example: *What activity will remain in a 5.0 mCi sample of radioactive iodine I-131 after 24 days? When $T_{1/2}$ = 8 days.*

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

A = 5.0 mCi, t = 24 days, $\lambda = 0.693/T_{1/2}$

$A = 5.0 \text{ mCi } e^{-(0.693 / 8 \text{ days})(24 \text{ days})}$

A = 5.0 mCi (0.125) = 0.625 mCi

5.7 Radioactive Material Inventory

You will be asked to fill out an inventory Form RCC-7, as part of the written evaluation of this module. The following example of has been properly recorded on a Form RCC-7 (page 26).

You receive a shipment of 1.0 mCi ^{32}P on May 1st. On this same day an experiment is performed using 200 μCi. You estimate that 25% of the activity goes to solid waste and 75% to liquid waste. On May 15th another experiment is performed leaving all 200 μCi to liquid waste. On May 29th the ORC is contacted to remove liquid and solid waste from the laboratory. The completed RCC-7 reflects your inventory after the ORC staff has removed the waste from your laboratory.

1. This first entry shows that on 5/1/06, 1000 μCi (1.0 mCi) of ^{32}P was received, as noted in "Activity Inventory μCi", column (2).

2. The second entry denotes the first use of the radioisotope in the laboratory. In column (3) of "Activity Withdrawn for Experiment/Stock μCi", 200 μCi was withdrawn for first experiment.

3. Column (4) of "Initials of User" indicates the authorized individual using the material.

4. Column (5) notes that after the experiment the amount "To Solid Waste μCi" was 50 μCi and Column (6) shows that "To Liquid Waste" was 150 μCi.

5. Moving directly across to Column (9), "Total Activity in Lab μCi" is 1000 μCi.

6. On 5/15/06, the radioisotope was used again for the second time in the laboratory. The "Activity Inventory μCi" must be determined before the experiment can begin. This value may be calculated as follows.

   We can calculate that "Activity Inventory μCi"

   $$A = A_o e^{-\lambda t}$$
   $$A = 800\ e^{-}(.693 / 14\ day)\ (14\ day)$$
   $$A = 400$$

   Therefore, 400 μCi of stock was remaining on 5/15/04.

7. The "Activity Withdrawn for Experiment / Stock μCi" on 5/15/06 was 200 μCi. Moving directly across, the initials of the user are placed in Column (4). After the experiment, all 200 μCi goes to liquid waste. Column (9) indicates that 500 μCi is the "Total Activity in Lab μCi."

8. On 5/29/06, the ORC is scheduled to remove the waste from your laboratory. The "Activity Inventory μCi" must first be determined before the waste can be calculated.

We can calculate that "Activity Inventory μCi"

$$A = A_o e^{-\lambda t}$$
$$A = 200\ e^{-}(.693 / 14\ day)\ (14\ day)$$
$$A = 100$$

Therefore, 100 μCi of stock was remaining on 5/29/06.

9. We must now make the decay calculations for the liquid and solid wastes. The 200 μCi of waste from 5/1/06 has decayed two half-lives and is now 50 μCi, as indicated in "Decay to Date of Waste Pickup μCi", Column (7). The 200 μCi of liquid waste from 5/15/06 has decayed to 100 μCi. The "Total Activity Waste Pickup μCi", in Column (8) is 150 μCi. In Column (9), the "Total Activity in Lab μCi" is now 100 μCi.

Southern Illinois University - School of Medicine
Radioisotope Inventory System

Radioactive Material Inventory Form *Inventory Number: EXAMPLE*

P.O. #: 4375 Date Received: Supplier: Dupont NEN Chemical Form: Adenosine Triphosphate
RLS: Dept: ORC Lab: Isotope: P-32 Authorized Activity:

Date	Activity Inventory μCi	Activity Withdrawn for Experiment/ Stock μCi	Initials of User	To Solid Waste μCi	To Liquid Waste μCi	Decay to Date of Waste Pickup μCi	Total Activity Waste Pickup μCi	Total Activity in Lab μCi
05/01/06	1000	200	SIU	50	150	50		1000
05/15/06	400	200	SIU		200	100		500
05/29/06	100						150	100
Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9

Study Questions:

11. The four basic types of ionizing radiation are _________ particles, ______________ particles, and ___________ or ____________ rays, and _______________ particles.

12. The decay constant, λ, is equal to:

A) $0.693/T_{1/2}$
B) 0.693/t
C) $e^{-\lambda t}$
D) A/A_o

13. Complete the following:

Type of Radiation	Alpha	Beta	Gamma / X-ray	Neutron
Mass				
Charge				
Range				
Shielding				
Hazard				

14. Both Gamma-rays and x-rays are electromagnetic radiation. How do they differ?

15. The half-life of tritium (^3H) is 12.3 years. What is the decay constant for tritium?

16. The stated activity of a ^3H sample is 1 millicurie as of 1/1/04, what is the activity of this same sample on 1/1/06?

17. The half-life of ^{51}Cr is 27.8 days. What will the activity of a ^{51}Cr sample of 5,000 dpm be 7 days later?

6.0 Sources of Radiation

We live in a radioactive world and always have. In fact, the majority of us will be exposed to more ionizing radiation from natural background radiation than from our jobs.

6.1 Natural Sources

As human beings, we have evolved in the presence of ionizing radiation from naturally occurring sources. The radiation emitted from these sources is identical to the radiation that results from man-made sources. Natural sources of radiation are often referred to as background radiation. The four major sources are:

Cosmic Radiation

Cosmic radiation comes from the sun and outer space. It consists of positively charged particles, as well as gamma radiation. At sea level, the average annual cosmic radiation dose is about 26 mrem. At higher elevations, the amount of atmospheric shielding decreases and thus the dose increases. The total average annual dose to the general population from cosmic radiation is about 27 mrem.

Terrestrial Radiation

There are natural sources of radiation in the ground (i.e., rocks, building materials and drinking water supplies). Some of the contributors to terrestrial sources are the natural radioactive elements radium, uranium and thorium. Many areas have elevated levels of terrestrial radiation due to increased concentrations of uranium or thorium in the soil. The total average annual dose to the general population from terrestrial radiation is 28 mrem.

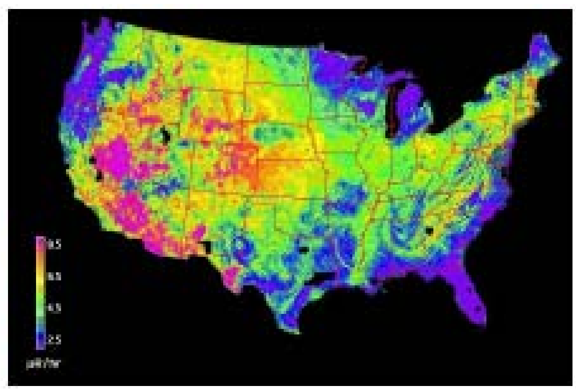


Figure 10 Terrestrial gamma-ray exposure at 1m above ground.

Internal

The food we eat and the water we drink contains trace amounts of natural radioactive materials. These naturally occurring radioactive materials deposit in our bodies and, as a result, cause an internal exposure to radiation. Some naturally occurring radioactive isotopes include sodium-24, carbon-14, argon-41 and potassium-40. Most of our internal exposure comes from potassium-40.

Combined exposure from internal sources of natural background radiation account for a radiation dose of 39 mrem per year.

Radon

Radon comes from the radioactive decay of radium, which is naturally present in the soil. Because radon is a gas, it can travel through the soil and collect in basements or other areas of a home. Radon emits alpha radiation. Even though alpha radiation cannot penetrate the dead layer of skin on your body, it presents a hazard when taken into the body. Radon and its decay products are present in the air, and when inhaled can cause a dose to the lungs. The average annual dose equivalent from radon gas is approximately 200 mrem.

6.2 Human-made Sources

The difference between human-made sources of radiation and naturally occurring sources is the place from which the radiation originates. The four major sources of human-made radiation exposures are:

Medical Radiation Sources

A typical radiation dose from a chest x-ray is about 10 mrem. The total average annual dose to the general population from medical x-rays is 39 mrem.

In addition to x-rays, radioactive sources are used in medicine for diagnosis and therapy. The total average annual dose to the general population from these sources is 14 mrem.

Atmospheric Testing of Nuclear Weapons

Another human-made source of radiation includes residual fallout from atmospheric nuclear weapons testing in the 1950's and early 1960's. Atmospheric testing is now banned by most nations. The average annual dose from residual fallout is less than one mrem.

Consumer Products

Examples include TVs, older luminous dial watches, and some smoke detectors, airport luggage inspection systems and building materials. The estimated annual average whole body dose equivalent to the U.S. population from consumer products is approximately 10 mrem. The major portion of this exposure (approximately 70%) is due to radioactivity in building materials.

Nuclear Facilities

By 1988, 90 nuclear power plants had been licensed in the U.S. In addition, over 300 other reactors, classed as non-power reactors, are being operated. Current estimates of the yearly average dose equivalent in the U.S. from environmental releases are less than one mrem.

6.3 Comparison of Radiation Doses

The average annual radiation dose equivalent to a given member of the general population, a combination of both natural background and human-made sources of radiation, is about 360 mrem. The amount of radiation dose received from natural background and human-made sources of radiation vary from location to location.

Note: *Smoking is not included in the comparison of radiation doses. Polonium and lead isotopes have been found in tobacco products. The average radiation dose from smoking is estimated to be approximately 1,300 mrem / yr.*

Study Questions:

18. Consumer products are a man made source of environmental radiation exposure. Building materials constitute approximately ___________ to this source.

19. What are the four sources of natural background radiation?
_________________ _________________ _________________ ________________

20. Complete the following:

	Source	**Annual dose (mrem / year)**
Natural Background	Terrestrial	
	Cosmic	
	Internal Emitters	
	Inhaled (Radon)	
Man-made Background	Nuclear Fallout	
	Medical Exposures	
	Consumer Products	
	Nuclear Facilities	
	Estimated Total	

7.0 Biological Effects

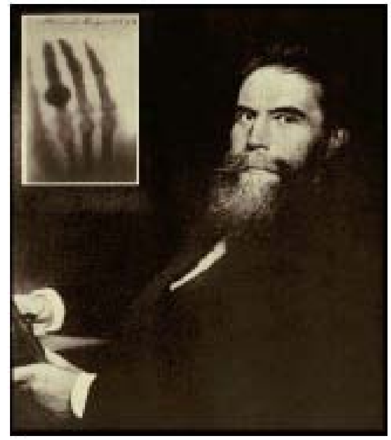


Figure 11 Wilhelm Roentgen. The insert above is a photograph of the first x-ray taken (Roentgen's wife's hand).

The fact that ionizing radiation produces biological damage has been known for many years. The first case of human injury was reported in the literature just a few months following Roentgen's original paper in 1895 announcing the discovery of X-rays. The first case of radiation-induced cancer was reported seven years later. Early human evidence of the harmful effects of ionizing radiation, as a result of high exposures, became available in the 1920's and 30's through the experience of radiologists, miners exposed to airborne activity, and workers in the radium industry. However, the long-term biological significance of smaller, repeated doses of radiation was not widely appreciated until later.
The biological effects and risks associated with exposure to radioactive materials have been studied more thoroughly than any other hazardous agent in the laboratory. We have a large body of information available regarding exposures to humans.

There are four major groups of people that have been exposed to significant levels of radiation.

- The first was early workers, such as radiologists, who received large doses of radiation before the biological effects were recognized. Since that time, standards have been developed to protect workers.
- The second group was the more than 100,000 survivors of the atomic bombs dropped at Hiroshima and Nagasaki. These survivors received estimated doses in excess of 50,000 mrem.
- The third group is individuals who have been involved in radiation accidents, the most notable being the Chernobyl accident.
- The fourth and largest group is patients who have undergone radiation therapy for cancer.

7.1 Effects of Radiation on Cells

The human body is made up of many organs, and each organ of the body is made up of specialized cells. Ionizing radiation can potentially affect the normal operation of these cells.

Biological effects begin with the ionization of atoms.

Radiation causes damage to human cells by ionization of atoms in the cells. Atoms are bound together as molecules that make up cells that make up the tissues of the body. These tissues make up the organs of our body. Any potential radiation damage to our body begins with damage to atoms.

A cell is made up of two principal parts, the body of the cell and the nucleus. Ionizing radiation may strike a vital part of the cell like the nucleus or a less vital part of the cell, like the cytoplasm.

Cell sensitivity

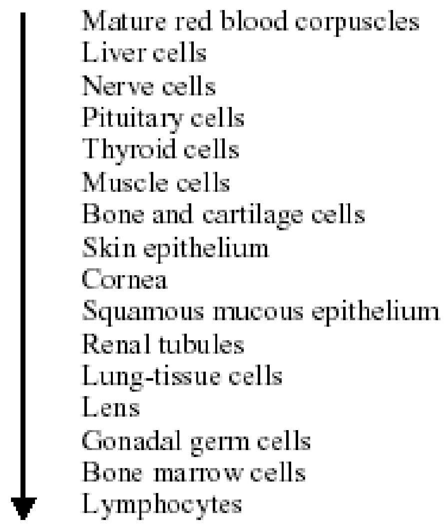
Some cells are more sensitive than others to environmental factors such as viruses, toxins and ionizing radiation. Damage to cells may depend on how sensitive the cells are to radiation.

As early as 1906 an attempt was made to correlate the differences in sensitivity of various cells with differences in cellular physiology. The Law of Bergonie and Tribondeau states:

"The radiosensitivity of a tissue is directly proportional to its reproductive capacity and inversely proportional to its degree of differentiation."

In other words, cells most active in reproducing themselves and cells not fully mature will be most harmed by radiation. This law is considered to be a rule-of-thumb, some cells and tissues showing exceptions.

Least Radiosensitive:



Most Radiosensitive:

Figure 12 Radiosensitive Tissues

Cells that are rapidly dividing include blood forming cells, the cells that line our intestinal tract, hair follicles, and cells that form sperm. Cells which divide at a slower pace or are more specialized (such as brain cells or muscle cells) are not as sensitive to damage by ionizing radiation.

Possible Effects of Radiation on Cells

When a cell is exposed to ionizing radiation, several things can happen. The following are possible effects of radiation on cells.

1. **There is no damage**

2. **Cells repair the damage and operate normally.**

   The body of most cells is made up primarily of water. When ionizing radiation hits a cell, it is most likely to interact with the water in the cell. Often the cell can repair this type of damage. Ionizing radiation can also hit the nucleus of the cell. The nucleus contains the vital parts of the cell such as chromosomes that determine the cell's function. When chromosomes duplicate themselves, they transfer their information to new cells. Damage to chromosomes, although often more difficult, can also be repaired. In fact, the average person repairs 100,000 breaks per day.

3. Cells are damaged and operate abnormally

Cell damage may not be repaired or may be incompletely repaired. In that case, the cell may not be able to do its function or it may die. It is possible that a chromosome in the cell nucleus could be damaged but not be repaired correctly. This is called a mutation or genetic effect. We will discuss genetic effects when we consider chronic radiation doses.

4. Cells die as a result of the damage

At any given moment thousands of our cells are dying and being replaced by normal cells nearby. It is only when the dose of radiation is very high or is delivered very rapidly that the cell may not be able to repair itself or be replaced.

7.2 Acute and Chronic Radiation Dose

Potential biological effects depend on how much and how fast a radiation dose is received. Radiation exposure can be grouped into two categories, acute and chronic exposure. Also, as discussed earlier, exposures can be either external or internal.

- An acute exposure is generally accepted to be an exposure to a large amount of radiation in a short period of time.
- Long term, low level exposure is called chronic exposure such as that exposure received from background radiation during the course of our lifetime.

A prompt effect manifests itself shortly after exposure. The symptoms exhibited during the early stages of the Chernobyl accident were prompt somatic effects (nausea, vomiting, reduced blood counts, etc). We know that radiation therapy patients receive high doses of radiation in a short period of time but generally only to a small portion of the body (not a whole body dose). Ionizing radiation is used to treat cancer in these patients because cancer cells are rapidly dividing and therefore sensitive to ionizing radiation. Some of the side effects for people undergoing radiation therapy are hair loss, nausea and fatigue.

Table 8 Factors affecting biological damage due to exposure to radiation

Total Dose	In general, the greater the dose, the greater the potential of biological effects.
Dose rate (how fast)	The faster the dose is delivered, the less time the cell has to repair itself.
Type of radiation	Alpha radiation is more damaging than beta or gamma radiation for the same energy deposited.
Area of the body receiving the dose	In general, the larger the area of the body that is exposed, the greater the biological effect. Extremities are less sensitive than internal organs. That is why the annual dose limit for the extremities is higher than for the whole body exposure that irradiates the internal organs.
Cell sensitivity	The most sensitive cells are those that are rapidly dividing.
Individual sensitivity	Some individuals are more sensitive to environmental factors such as ionizing radiation. The developing embryo/fetus is the most sensitive, and children are more sensitive than adults. In general, the human body becomes relatively less sensitive to ionizing radiation with increasing age. The exception is that elderly people are more sensitive than middle aged adults due to the inability to repair damage as quickly (less efficient cell repair mechanisms).

Acute radiation doses

An acute effect is a physical reaction due to massive cell damage. This damage is caused by a *large* radiation dose received in a *short* period of time. The body can't repair or replace cells fast enough from an acute dose and physical effects such as reduced blood count and hair loss may occur. Slight blood changes may be seen at acute doses of 10,000-25,000 mrem but an individual would not otherwise be affected.

Radiation sickness

At acute doses greater than 100,000 mrem, about half of the people would experience nausea (due to damage of the intestinal lining). Radiation therapy patients often receive whole body equivalent doses in this range and above, although doses to the region of a tumor can be many times higher.

If the acute dose to the whole body is very large (on the order of 500,000 mrem or larger) it may cause so much damage that the body cannot recover. An example is the 30 firefighters at Chernobyl who received acute doses in excess of 800,000 mrem. These individuals succumbed to the effects of the burns they received compounded by their radiation dose.

After an acute dose, damaged cells will be replaced by new cells and the body will repair itself, although this may take a number of months. Only in those extreme cases, such as the Chernobyl firefighters, would the dose be so high as to make recovery unlikely.

Acute doses to only part of the body

It is possible that radiation exposure may be limited to a part of the body such as the hands. There have been accidents, particularly with x-ray machines, in which individuals have exposed their fingers to part of the intense radiation beam. In some of these cases individuals have received doses of *millions* of mrem resulting in finger loss. It is important for individuals who work with x-ray or similar equipment to be trained in the safe use of this equipment.

Probability of an acute dose

What is important to understand is that it takes a large acute dose of radiation before any physical effect is seen. These acute doses have only occurred in Hiroshima/Nagasaki, a few radiation accidents, and Chernobyl. The possibility of a radiological worker receiving an acute dose of ionizing radiation on the job is extremely low. In many areas where radioactive materials are handled, the quantities handled are small enough that they do not produce a large amount of radiation. Where there is a potential for larger exposures, many safety features are in place.

Chronic radiation doses

A <u>chronic radiation dose</u> is typically a small amount of radiation received over a long period of time. An example of a chronic dose is the dose we receive from natural background every day of our lives or the dose we receive from occupational exposure.

Chronic dose versus acute dose

The body is better equipped to handle a chronic dose than an acute dose. The body has time to repair damage because a smaller percentage of the cells need repair at any given time. The body has time to replace dead or non-functioning cells with new healthy cells. It is only when the dose of radiation is high and is received very rapidly that the cellular repair mechanisms are overwhelmed and the cell dies before repair can occur. A chronic dose of radiation does not result in detectable physical changes to the body such as is seen with acute doses. Because of cell repair, even sophisticated analyses of the blood do not reveal any biological effects. The biological effects of concern from a chronic dose are changes in the chromosomes of a cell and direct irradiation of the DNA of a fetus.

7.3 DNA Effects

The most important target for radiation in the cell is DNA in the nucleus. Genetic effects result when DNA damage is not repaired or is improperly repaired. Genetic effects can be somatic (cancer) or heritable (affecting future generations).

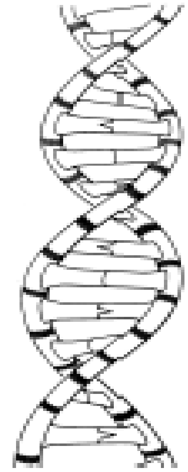


Figure 13 DNA Double Helix

Somatic effects

Somatic effects are those effects experienced only by the irradiated individual. The abnormality may be a delayed effect manifested only after many generations of cell replication. The delayed somatic effects of ionizing radiation include an increase in the probability of the development of various types of cancers. The probability of this is very low at occupational doses.

Heritable effects

A heritable effect is a genetic effect that is inherited or passed on to an offspring. In the case of heritable effects, the individual has experienced damage to some genetic material in the reproductive cells. Heritable effects from radiation have never been observed in humans but are considered possible and have been observed in studies of plants and animals. This includes the 77,000 Japanese children born to the survivors of Hiroshima and Nagasaki. (These are children who were conceived *after* the atom bomb). Studies have followed these children, their children and their grandchildren.

7.4 Prenatal Radiation Exposure

While the risks of cancer or genetic damage are barely significant for a prudent worker, the unborn embryo or fetus is at significantly higher risk. It is important for women who are pregnant or who are considering pregnancy to be aware of the special needs of their situation. The embryo is particularly radiosensitive during the first three months after conception, when a woman may not be aware she is pregnant.

Women who work with radioactivity and are considering pregnancy should request specific information from the Radiation Safety Officer. Federal and state laws require that women who are pregnant or are considering pregnancy be fully familiar with what the dangers are and how they may be avoided. Since the health of the unborn can be influenced by the behavior of the mother's co-workers and supervisors, it is essential that every radiation user, not just the mother, be familiar with the section of this manual pertaining to pregnancy.

All female radiation users are required to sign a statement that they have read and understand SIU's Prenatal Radiation Exposure Policy.

Sensitivity of the Unborn

The Law of Bergonie and Tribondeau indicates that the radiosensitivity of tissue is directly proportional to its reproductive capacity and inversely proportional to the degree of differentiation. It follows that children could be expected to be more radiosensitive than adults, fetuses more radiosensitive than children, and embryos even more radiosensitive.

Potential Effects Associated with Prenatal Exposures

Many chemical and physical (environmental) factors are suspected of causing or known to cause damage to an unborn child, especially early in the pregnancy. Alcohol consumption, exposures to lead, and heat from hot tubs are only a few that have been publicized lately.

Both experimental and clinical findings have shown that the human embryo is subject to severe radiation injury. A few of the types of human abnormalities reported in the literature are blindness, cataracts, mental deficiency, coordination defects, deformed arms and legs, and general mental and physical abnormality. Although no effects were seen in Japanese children conceived after the atomic bomb there were effects seen in some children who were in the womb when exposed to the atomic bomb radiation at Hiroshima and Nagasaki. Some children who were exposed while in the womb to the radiation from the atomic bomb were born with a small head size and mental retardation. It has been suggested but is not proven that dose to the unborn may also increase the chance of childhood cancer. Only when the dose exceeds 15,000 mrem is there a significant increase in risk.

The degree and kind of radiation damage is dependent on the state of development of the embryo. Most of the major organs in humans are developed during the period from the second to the sixth week post conception. The majority of the gross abnormalities that are produced by irradiation of the embryo occur during this critical period.

Experimentally, doses as low as 20,000 mrem have been shown to produce developmental changes if applied during this time. Irradiation of the embryo after the period of major organ development produces delayed and less obvious undesirable effects, such as changes in mental abilities, sterility, etc.

Limits are established to protect the embryo/fetus from any potential effects that may occur from a significant radiation dose. This may be the result of dose from external sources of radiation or internal sources of radioactive material. At present occupational dose limits, the actual risk to the embryo/fetus is negligible when compared to the normal risks of pregnancy.

7.5 Dose Response Curves

The effects of high doses of radiation delivered acutely are well established and characterized. The challenge is in determining the effects of low-level doses over extended periods of time.

Dose response curves are graphical plots of the number of biological effects versus dose. Dose response curves can then be used to *estimate* the number of biological effects attributable to a particular radiation dose and thereby estimate the risk associated with a particular dose.

The extent to which low doses of ionizing radiation contribute to cancer risks is not known. This is because the data from human and experimental studies are insufficient to resolve with certainty whether the dose response curve for ionizing radiation is linear or non-linear and whether or not it has a threshold.

Radiation is like most substances that cause cancer in that the effects can be clearly seen at high doses. Our best *estimates* of the risks of cancer at *low levels* of exposure, such as you may be exposed to at SIUSOM, are derived from data available at high dose levels and high dose rates. Generally, for radiation protection purposes these estimates are made using a *linear no-threshold* model (curve 1 in Figure 14). We have data on known health effects at high doses as shown by the solid line in Figure 14.

Below about 50,000 mrems (50 rems) studies have not been able to accurately measure the risk, primarily because of the small numbers of exposed people and because the effect is small compared to the differences in the normal incidence of cancer from year to year and place to place. In order to obtain accurate estimates of the risk for low-level radiation exposure, very large groups of people (many millions) would be needed for scientific study.

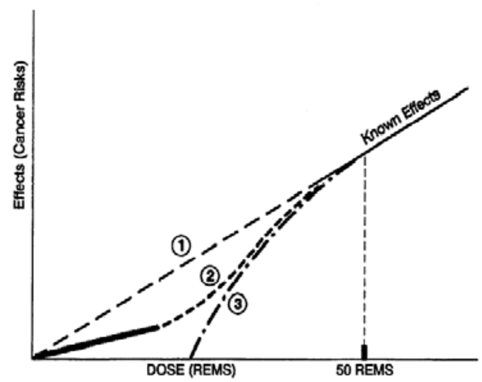


Figure 14 Dose Response Curves

Most scientists believe that there is some degree of risk no matter how small the dose (curves 1 and 2). Some scientists believe that the risk drops off to zero at some low dose (curve 3), the threshold effect. A few believe that risk levels off so that even very small doses imply a significant risk, while others believe that small amounts of exposure are actually beneficial (curves not shown).

The majority of scientists today endorse either the *linear no-threshold* model (curve 1) or the linear-quadratic model (curve 2). For radiation protection purposes, the IDNS employs the more conservative linear model (curve 1), which shows the number of effects decreasing as the dose decreases. Estimated risks using the linear model are discussed in the next section. It is a generally accepted practice to limit radiation exposure to reasonable levels and take a conservative approach.

Study Questions:

21. ____________ of atoms in the cells of the body cause radiation damage by causing bonds to break, molecules to rearrange etc..

22. The law of Bergonie and Tribondeau explains the radiosensitivity of tissues is:

    A) Directly proportional to the growth rate and inversely proportional to the degree of specialization.
    B) Directly proportional to the degree of specialization and inversely proportional to the growth rate.
    C) Directly proportional to the growth rate and directly proportional to the degree of specialization.

23. What are the possible effects of radiation on cells?

    a. ____
    b. ____
    c. ____
    d. ____

24. Exposure from natural background is considered to be what type of an exposure? __________________

25. A dose received from an accident such as Chernobyl, would be what type of a dose? __________________

26. If you as a radiological worker showed an effect from exposure to radiation, what type of an effect would this be? ________________

27. If the offspring of a radiological worker showed an effect from a radiation dose that the worker received prior to conception, what type of effect would this be? _____________

28. How much radiation can a fetus maximally be exposed to during gestation? __________

29. Who is required to know the special risks associated with radiation exposure of the unborn?

    A) Male radiation users
    B) Female radiation users
    C) Supervisors of radiation users
    D) All of the above

30. Late (delayed) effects (5-20 years) of a large exposure to ionizing radiation may result in:

    A) Nausea, vomiting
    B) Carcinogenesis
    C) A change in skin pigmentation
    D) Significant blood changes

8.0 Occupational Radiation Exposure Risks

For investigators working with radioactive materials in SIU laboratories, the risk, if any, from the low levels of radiation exposure is small. Nevertheless, the potential for harm is real. It can be minimized if the policies and procedures of the University, along with the regulations of the State and Federal government, are carefully followed.

Because ionizing radiation can damage the cell's nucleus, it is possible that through incomplete repair a cell could become a cancer cell.

8.1 Risk from Exposures to Ionizing Radiation

While the relationship between acute effects and radiation levels is well known, the relationship to late effects, both *somatic* and *genetic*, is more obscure. No increases in cancer have been observed in individuals exposed to ionizing radiation at occupational levels. The possibility of cancer induction cannot be dismissed even though an increase in cancers has not been observed. The risks *calculated* based on the linear no-threshold model (curve 1 in Figure 14) are listed in Table 9 below:

Table 9 Comparison of Risks from 1 rem whole body irradiation

Biological Effects	Natural Occurrence	Radiation Related
Cancer Cases	2,500 in 10,000	3 in 10,000
Cancer Fatalities	2,000 in 10,000	5 in 10,000
Genetic Effects	1,000 in 10,000	10 in 10,000
Fetal Effects	700 in 10,000	10 in 10,000

Explanations of the risks are as follows:

Cancer Cases: Of 10,000 people, 2,500 may exhibit some form of cancer during their lifetime. If 10,000 people are each irradiated with 1 rem of whole body radiation, it is *estimated* that the radiation may cause three additional cases of cancer in the group.

Cancer Fatalities: Of 10,000 people, 2,000 may succumb to some form of cancer. If 10,000 people are each irradiated with 1 rem of whole body radiation, it is *estimated* that the radiation may cause 5 additional cancer death in the group.

Genetic Effects: The current incidence of all types of genetic disorders and traits that cause some kind of serious handicap at some time during an individual’s lifetime is about 1,000 incidents per 10,000 live births.

Fetal effects: The current incidence of all types of fetal effects is about 700 incidents per 10,000 live births. This includes effects due to measles, alcohol, drugs, etc. If each child were to receive 1 rem of whole body irradiation before birth, it is estimated that the radiation may cause 10 additional effects in the group.

The difficulty arises in part because the effects are so small. Since so many of the population (16-25%) die of cancer, small effects due to low levels of chronic radiation exposure are impossible to measure. Risk estimates have been extrapolated derived from studies of individuals who have been exposed to high levels of radiation, such as the victims of nuclear weapons, accidents, or experimental medical procedures. An additional problem in making an accurate assessment is the factor of age at the time of exposure (latent period).

8.2 Comparison of Occupational Radiation Exposure Risk and Other Risks

Acceptance of a risk is a highly personal matter and requires a good deal of informed judgment. The risks associated with occupational radiation doses are considered acceptable as compared to other occupational risks by virtually all scientific groups who have studied them.

The following information is intended to put the potential risk of radiation into perspective when compared to other occupations and daily activities.

Table 10 compares the estimated days of life expectancy lost as a result of exposure to radiation and other health risks. These estimates indicate that the health risks from occupational radiation dose are smaller than the risks associated with normal day-to-day activities that we have grown to accept.

Table 10 Average estimated days lost due to daily activities

Occupation	Days of Life Lost
Being an unmarried male	3,500
Smoking (1 pack/day)	2,250
Being and unmarried female	1,600
Being a coal miner	1,100
Being 25% overweight	777
Drinking alcohol (US average)	365
Being a construction worker	227
Driving a motor vehicle	207
All industry	60
Being exposed to 100 mrem/yr of radiation for 70 years	10
Drinking coffee	6

The risks associated with occupational radiation exposures at SIU are very small when compared to the risks associated with radiation exposures for other occupations. The average annual radiation doses associated with various occupations, including working at SIU, are compared in Table 11.

Table 11 Average Annual Radiation Dose for Various Occupations

Occupation	Dose (mrem/yr)
Airline flight crew member	About 1,000
Nuclear power plant worker	700
Grand Central Station worker	120
Medical personnel	70
SIUSOM radiation worker	<10

In Table 12 the risk of working with or around sources of ionizing radiation is compared with other risks encountered in everyday life.

Table 12 Activities with One-in-a-Million Chance of Causing Death

Receiving 10 mrem of radiation (cancer)
Smoking 1.4 cigarettes (lung cancer)
Eating 40 tablespoons of peanut butter (liver cancer)
Eating 100 charcoal broiled steaks (cancer)
Spending 2 days in New York City (air pollution)
Driving 40 miles in a car (accident)
Flying 2,500 miles in a jet (accident)
Canoeing for 6 minutes (accident)

8.3 Benefit versus Risk

Accepting the potential risks of working with ionizing radiation is a personal matter. Each individual must weigh the benefits against the potential risks. Upon accepting the risks, each individual must respect radiation, and work safely with and around it.

Study Questions:

31. The dangers due to low levels of exposure of ionizing radiation have been scientifically proven.

A) True
B) False

32. Whose responsibility is it to decide if the risks of working with radioactive material are unacceptable?

A) The Radiological Control Committee
B) The RSO
C) The PI
D) Yours - the radiation user

9.0 Dose Limits

Several scientific groups provide information and recommendations concerning radiation safety. These groups include the National Council on Radiation Protection (NCRP), the International Commission on Radiation Protection (ICRP), the International Atomic Energy Agency (IAEA), and the American National Standards Institute (ANSI). Scientists with these agencies have determined acceptable dose limits for the radiation worker. No clinical evidence of harm would be expected in an adult working within these limits for an entire lifetime. Committees of scientists in the field of radiation science and biology periodically review the literature and, if indicated, recommend changes in the dose limits. These groups provide only recommendations without the force of law and do not enforce or establish radiation safety policy.

The Nuclear Regulatory Commission (NRC) sets federal radiation dose limits for occupational workers. The Illinois Division of Nuclear Safety (IDNS) is responsible for the development and enforcement of radiation policy. These agencies often adopt the recommendations from the NCRP and the ICRP. Dose limits are based on the sum of both internal and external dose. Internal dose results from radioactive material being inhaled, ingested, or absorbed through the skin or a wound.

SIU's administrative control levels for radiological workers are lower than the State limits and are set to ensure the State limits and administrative control level are not exceeded. They also help reduce individual and total worker population (collective dose) radiation dose.

9.1 Dose Philosophy

In order to minimize the biological effects associated with radiation, dose limits and administrative control levels have been established. As a general approach, three principles designed to control radiation exposure are:

1. *The justification principle* states that occupational exposure should only take place when the benefit to society warrants the risk. There is little doubt that University research falls into this category.

2. *The optimization principle* requires that exposure to workers should be **A**s **L**ow **A**s **R**easonably **A**chievable (ALARA). The goal of ALARA is to ensure that no exposure is unjustified, and that there are no other available alternatives. ALARA will be discussed in detail in the next section.

3. *The dose-limitation* principle limits exposure of individuals to radiation. A "maximum allowable individual dose" must be established to set an upper limit on the risk to individual workers.

9.2 Radiation Worker Dose Limits

Whole Body

The "whole body" extends from the top of the head down to just below the elbow and just below the knee. This is the location of most of the blood producing and vital organs.

The State radiation dose limit during routine conditions is 5,000 mrem /year. Since SIU's objective is to maintain personnel radiation doses well below the regulatory limits, a SIUSOM administrative control level has been established. The SIUSOM administrative control is 500 mrem /year.

Extremities

Extremities include the hands and arms below the elbow and the feet and legs below the knees. Extremities can withstand a much larger dose than the whole body since there are no major blood-producing organs located there. The State radiation dose limit for extremities is 50,000 mrem/year and the SIU administrative control level is 5,000 mrem/year.

Skin and other organs

The State radiation dose limit for skin and any individual organ is 50,000 mrem/year and the SIU administrative control level is 5,000 mrem/year.

Lens of the eye

The State radiation dose limit for lens of the eye during routine conditions is 15,000 mrem/year and the SIU administrative control level is 1,500 mrem/year.

Minors

State dose limits to minors (under 18 years of age) are set at 10% of the above limits. Additionally parental consent is required prior to giving authorization for radiation use.

9.3 Declared Pregnant Worker (Embryo/Fetus) Dose Limits

A female worker is encouraged to voluntarily notify the RSO, in writing, when she is pregnant. This can be accomplished by completing the **Declared Pregnant Worker/Student Form** (RCC-5A). It is important to do this *promptly* as the unborn child is most sensitive to radiation during the first 3 months of pregnancy. The declared pregnant worker may withdraw her declaration, in writing, at any time.

For a declared pregnant worker who continues working as a radiological worker, the dose limit for the embryo/fetus (during the entire gestation period) is 500 mrem. Efforts should be made to keep the radiation exposure of an embryo or fetus at the very lowest practical level during the entire period of pregnancy and to avoid exceeding 50 mrem/month to the pregnant worker. If the dose to the embryo/fetus is determined to have already exceeded 500 mrem, the worker shall be assigned to tasks where additional occupational radiation exposure is not likely during the remainder of the pregnancy.

The University is required to take all practicable steps within reason to reduce the radiation exposure of a potential mother and to ensure that dose rates are kept low in work areas. The advice of the Radiation Safety Officer should be obtained to determine whether radiation levels in your working areas are high enough that an unborn child could receive 500 mrem or more before birth. However, it is *your responsibility* to decide whether the exposure you are receiving is sufficiently low to protect your unborn child.

Note: *There is no need to be concerned about a loss of your ability to bear children. The radiation required to produce such effects is more than 100 times larger than the State dose limit for adults.*

If you are pregnant now or are considering becoming pregnant, refer to the NRC Regulatory Guide Concerning Prenatal Radiation Exposure. Contact the Radiation Safety Officer for more information pertaining to prenatal radiation risks.

9.4 General Public Dose Limits

For a variety of reasons, dose limits for the general population are set lower than those for radiation workers. Justifications for this approach include the following:

- The public includes children who might represent a group at increased risk and who may be exposed for their whole lifetime.
- It is not the decision or choice of the public that they be exposed.
- The public is exposed for their entire lifetime; workers are exposed only during their working lifetime and presumably only while on the job.
- The public may receive no direct benefit from the exposure.
- The public is already being exposed to risks in their own occupations.
- The public is not subject to the selection, supervision, and monitoring afforded radiation workers.

The State radiation dose limit for visitors and the public is <u>100 mrem/year and 2 mrem in any one hour</u>. Under the law, these lower limits apply to visitors to radiation laboratory lab workers who are not trained in radiation safety, custodial staff, students, any other non-radiation workers, and all members of the general public.

Table 13 Dose Limits

	Radiation Worker		Declared	General
	State Limit[1]	**SIU Limit**	**Pregnant Worker**	**Public**
Whole Body	5,000 mrem/yr	**500** mrem/yr		**100** mrem/yr[2]
Extremities	50,000 mrem/yr	**5,000** mrem/yr		
Skin/Organ	50,000 mrem/yr	**5,000** mrem/yr		
Lens (Eye)	15,000 mrem/yr	**1,500** mrem/yr		
Embryo/Fetus			**500** mrem/gestation	

[1] Occupational dose limits for minors are 10% of the adult limit.
[2] Exposure rates must also not exceed 2 mrem in any one hour.

Study Questions:

33. What is the purpose of SIU administrative control levels?

____

____

34. Occupational radiation dose limit for a minor is ________ percent of the exposure limit set for an adult.

35. What is SIU's policy for prenatal radiation exposure?

____

____

10.0 As Low as Reasonably Achievable (ALARA)

ALARA is an acronym for *As Low As Reasonably Achievable*. This term is based on the belief that exposure to certain agents could cause undesirable effects. The concept also implies that there is a relationship between the amount of exposure and the possibility of an effect; there is a risk involved in receiving the exposure. The basis for the ALARA philosophy is quite simple; if you reduce your exposure to certain agents, you reduce the potential risk of an unwanted effect. This basic philosophy is used for a number of agents. Radiation is only one of these agents.

10.1 Why ALARA?

The ALARA philosophy is based on the assumption that exposure to radiation poses a risk. The *cautious* assumption that a proportional relationship exists between dose and effect *for all doses* (non-threshold concept) is the basis for ALARA. There may be some risk associated with any dose. This is also called the linear model of exposure.

SIU is firmly committed to having a Radiation Safety Program of the highest quality. Therefore, maintaining occupational exposures to radiation and radioactive material as low as reasonably achievable is an integral part of all SIU activities.

ALARA is achieved through both administrative and practical controls. SIU is fully committed to the principle of ALARA. Appendix VI of the Handbook of Radiological Operations spells out the commitment and the ALARA program for the campus. All users should familiarize themselves with this material.

10.2 Responsibilities for the ALARA Program

Office of Radiological Control (ORC)

The ORC is responsible for implementing the ALARA program at SIU. They provide a point of contact for the worker to obtain the most current radiological assessment of an experiment. The ORC provides assistance when trying to interpret protective requirements or radiological information concerning an experiment or work assignment and they address radiological questions or concerns.

The ORC measures radioactivity, designates radiological areas, and ensures that SIU complies with rules and requirements for radiological safety.

SIU's commitment to ALARA has resulted in the administrative imposition of even lower limits than those required by regulation. In essence, the goal at SIU is to keep the radiation doses to occupationally exposed workers at levels 10% or less than the State limits. Based on years of monitoring the exposures of SIU laboratory workers, radiation exposures rarely exceed the detectable limits of the dosimeter (approximately 10 millirem/month).

10.3 Personnel Responsibilities for the ALARA Program

Radiological workers

Individual radiation workers are ultimately responsible for maintaining their radiation dose ALARA. Each person involved in radiological work is expected to demonstrate responsibility and accountability through an informed, disciplined and cautious attitude toward radiation and radioactivity. The annual whole body exposure that you are most likely to receive while working at SIU is only a small percentage of the dose limits listed in Table 13. It is prudent and your responsibility to do what you can to keep your annual dose limits as low as reasonably possible.

In support of the ALARA principle, radiological controls are in place to protect personnel from exposure to radiation and radioactive material. These controls include a radiological identification system used to designate radiological areas and radioactive materials. The SIU Handbook of Radiological Operations contains complete descriptions of the rules and requirements for radiological controls at SIU.

All personnel, not just radiological workers, are responsible for maintaining exposures to radiation and radioactive material as low as reasonably achievable.

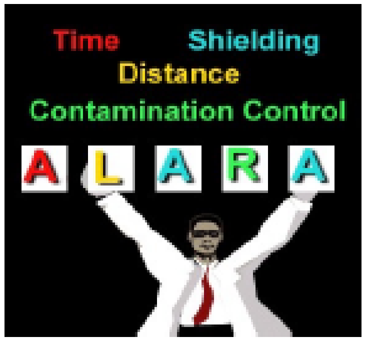
Personnel at SIU facilities must:

- Obey all radiological postings.
- Comply with all radiological and safety rules.
- Stay out of radiological controlled areas unless escorted or specially trained.
- Report unusual radiological situations. Unusual radiological situations may include, for example, finding radioactive material outside a radiation use area.
- Know how to contact Radiation Safety personnel in the ORC.
- Comply with all emergency procedures.
- Keep exposures to radiation and radioactive material as low as reasonably achievable.

10.4 Principles of Radiation Protections

There are four basic principles for maintaining exposures to radiation and radioactive material as low as reasonably achievable. These will be discussed in detail in the next two sections.

- **Contamination Control** – Prevent the spread of contamination.
- **Time –** Reduce the amount of time spent near a source of radiation.
- **Distance –** Stay as far away from the source as possible. Radiation exposure decreases rapidly as you move away from the source.
- **Shielding –** Surround the source with shielding. Appropriate shielding reduces radiation exposure.



Study Questions:

36. SIU ALARA policy applies to (check all that apply):

☐ Radiation exposures
☐ Contamination exposures
☐ Cosmic radiation exposures
☐ Medical x-rays

37. SIU's Radiation Safety policy is designed to keep radiation doses well below regulatory limits and ensure that there is no occupational radiation dose without ___________________.

38. Who provides a point of contact for the workers to obtain radiological safety information?

____

39. The basic protective measures for ALARA are:

☐ Maximizing time in an area
☐ Minimizing time in an area
☐ Maximizing distance in an area
☐ Minimizing distance in an area
☐ Maximizing shielding in an area
☐ Minimizing shielding in an area
☐ Maximizing contamination in an area
☐ Minimizing contamination in an area

11.0 Internal Radiation Protection

A major hazard when working with low energy radionuclides comes from inhalation, absorption, and ingestion. An internal radionuclide is inherently more hazardous than an externally located one because most or all of the radioactive emissions are captured by the body. Its removal rate depends on the rate at which the body metabolizes the compound. Safety requires that personnel know how to avoid inhaling, absorbing, or ingesting radionuclides.

Internal dose is a result of radioactive material being taken into the body. Radioactive material can enter the body through one or more of the following pathways:

- Inhalation
- Ingestion
- Absorption through the skin
- Injection through cuts and wounds

11.1 Contamination Control

Contamination control is one of the most important aspects of radiological protection. Using proper contamination control practices will help ensure a safe working environment. It is important for all employees to recognize potential sources of contamination as well as to use appropriate contamination prevention methods.

Figure 15 Visualization of Radioactive Contamination

A common misconception is that individuals exposed to radiation will become contaminated. Exposure to radiation (a type of energy) does not result in contamination. Radioactive contamination occurs only if individuals come in contact with radioactive material, such as radioactive liquids or dusts that adhere to them. Radioactive contamination can be fixed or removable.

Fixed contamination is contamination that cannot be readily removed from surfaces. It cannot be removed by casual contact. It may be released when the surface is disturbed (buffing, grinding, using volatile liquids for cleaning, etc.) Over time it may "weep," leach or otherwise become loose or transferable.

Removable contamination is contamination that can readily be removed from surfaces. It may be transferred by casual contact, wiping, brushing or washing. Air movement across removable contamination could cause the contamination to become airborne.

Even when this radioactive material is properly contained, it may still emit radiation and be an external dose hazard, but it will not be a contamination hazard. When this radioactive material escapes its container, it is then referred to as radioactive contamination.

Sources of radioactive contamination

Regardless of the precautions taken, radioactive material will sometimes escape and contaminate an area. The following are some sources of radioactive contamination:

- Sloppy work practices that lead to cross-contamination of tools, equipment or workers.
- Poor housekeeping in contaminated areas.
- Leaks or tears in radiological containers such as carboys, plastic bags or boxes.

Contamination control methods

Every possible effort should be made to confine the spread of radioactive materials to the smallest area possible. By controlling contamination, the potential for internal exposure and personnel contamination can be decreased. Radiation users should always ensure that the proper procedures to avoid the spread of contamination are followed.

Preventive measures

- Perform all work with volatile compounds or fine particulates in a fume hood or glove box.
- Establish adequate work controls before starting jobs.
- Discuss measures that will help reduce or prevent contamination spread. This can be done before the start of the experiment. Use "Good Housekeeping" practices. Good housekeeping is the prime factor in an effective contamination control program. It involves the interaction of all members within the lab. Each individual should be dedicated to keeping "his or her house clean" to control the spread of contamination. Wash your hands thoroughly with soap and water after working with radioisotopes and before leaving the laboratory.

Figure 16 Wash your hands

- Cover all surfaces with plastic-backed absorbent paper placed with the plastic side down.
- Label containers of radioactive material.
- Ensure that the ventilation system is properly functioning. Ventilation is designed to maintain airflow from areas of least contamination to areas of most contamination (i.e., clean from contaminated to highly contaminated areas). A slight negative pressure is maintained on labs/rooms.

Contamination monitoring

Perform radiation surveys of your work area and promptly decontaminate "hot spots." Decontamination is the removal of radioactive materials from locations where it is not wanted. If the presence of removable contamination is discovered, decontamination is a valuable means of control.

Monitor your clothing and body for radioactive contamination frequently and at the end of the day. Contamination monitoring equipment is used to detect radioactive contamination on personnel and equipment.

Monitoring Procedures

Periodic radiation surveys must be conducted in all areas in which radioactive materials are used or stored. The surveys are conducted once a month by the ORC. Moreover, for prudent monitoring practices, the user of radioactive materials should perform a contamination survey after each experiment.

Depending upon the type of radioactive materials in use, contamination surveys are performed directly with portable survey instruments and indirectly by wiping surfaces (~100 cm^2) with a filter paper and assaying the removed radioactivity in a liquid scintillation-counting instrument. The criterion for "acceptable removable activity" is 200 disintegrations per minute per 100 square centimeters of surface tested (200-dpm/100 cm^2). A typical wipe test survey of a laboratory consists of about 10 – 20 wipes of areas commonly contaminated when radioactive materials are used, e.g., bench tops, floor, doorknobs, telephones, desks, the front of fume hoods, etc.

If the assay indicates removable activity in excess of the 200-dpm/100 cm^2 level, the area must be cleaned and re-tested until the removable level is acceptable. Washing with a good detergent and water is the most effective method of cleaning up contamination. After decontamination, repeat the monitoring procedure and repeat cleaning if necessary.

11.2 Personal Protective Equipment (PPE)

Personal Protective Equipment (PPE) is required when handling radioactive material to prevent contamination of skin, eyes, and clothing. As a minimum lab, coat, safety glasses and gloves are required for all handling of unsealed radioisotopes.

11.3 Food and Drink Policy

Due to the potential for IDNS violations, the SIU Radiological Control Committee has developed a policy regarding food and drink. The following policy must be adhered to by Radiological Laboratory Supervisors (RLS) and users:

There shall be no eating, drinking, smoking, taking medication or applying cosmetics in the laboratories that have radioactive materials, biohazardous materials, or hazardous chemicals present. There shall be no storage, use or disposal of any “consumable” items in laboratories (including refrigerators within laboratories). Rooms which are adjacent, but are separated by floor to ceiling walls, and do not have any chemical, radioactive, or biohazardous agents present, may be used for food consumption or preparation at the discretion of the principal investigator responsible for these areas.

In short, ***NEVER*** eat, drink or smoke in areas controlled for radiological purposes. It is important to be aware that even the presence of empty food and drink containers in the normal trash may cause a violation, since it is construed as “evidence of consumption” by regulators, and the burden of proof to the contrary lies with the licensee. Please note that gum and tobacco chewing are prohibited in laboratories.

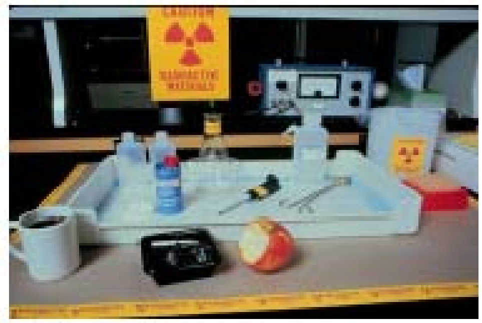


Figure 17 Some of the biggest mistakes in radiation safety

11.4 Radioactive Waste

The HRO describes the requirements and specific procedures for correctly managing and disposing of radioactive waste. All radioactive waste must be separated from non-radioactive waste. Under no circumstances is it permissible by laboratory personnel to dispose of any radioactive material into ordinary trash receptacles or into any drains. Radioactive waste must be segregated according to waste category and half-life and safely stored until removed by the RSO for disposal. The three categories of segregation are:

- Half-life < 15 days (^{32}P)
- Half-life between 15 and 90 days (^{35}S, ^{51}Cr, ^{125}I)
- Half-life > 90 days (^{3}H, ^{14}C, ^{45}Ca)

Preparation of Dry/Liquid Radioactive Waste

- Place solid waste in garbage cans or plastic containers appropriately labeled with the radiation warnings. Use only heavy-duty plastic bags to line waste containers.
- Remove all lead containers from dry waste and store separately for pickup.
- Needles and other sharp objects must be collected in puncture-resistant containers.
- No liquids may be placed in dry waste containers, with the exception of residual liquid in emptied containers and small quantities (such as milliliter or less) in micro-tubes.
- Liquid wastes are stored in glass or rigid plastic containers approved by the RSO. Milk jugs may not be used.
- Contact the ORC to request the disposal of liquid radioactive wastes into the sanitary sewer system.

- Liquid wastes must be readily dispersible in water and may not contain any hazardous material such as solvents or scintillation fluid.
- All radioactive wastes must be labeled indicating radionuclide, activity, RLS, date, lab location as well as waste type.
- The ORC picks up radioactive waste on request at 536-2015 or by e-mail at: mbarnstable@cehs.siu.edu.

11.5 Use of Radioactive Materials in Live Animals

Approval to use radioactive materials in animals requires authorization from both the Laboratory Animal Care and Use Committee (LACUC) and the Radiological Control Committee (RCC). An individual must also prove competence by examination prior to approval for use of radioactive materials in animals. Specific information required by the RCC for authorization to use radioactive materials in live animals are presented in the HRO (See Section 3.4 and 4). The following information describes some of the special problems of waste disposal.

The use of living animals as experimental tools in studying biological processes presents some special problems for the radioisotope user. This is especially true since radioactive waste from living tissues may appear as a solid, liquid, and or gas. Animal excreta should be regarded as radioactive waste unless appropriate monitoring indicates that is not. Extreme care must therefore be taken in the experimental design to ensure that contamination does not occur.

Excreta and animal carcasses must be double-bagged and labeled with the name of the RLS, the date, the isotope and quantity administered, and placed in a freezer designated by the ORC to prevent bacterial or fungal decomposition. Bedding and litter must be given the same consideration. Sharps contaminated with radioactive materials must be appropriately packaged in rigid plastic containers to avoid punctures.

Although animal carcasses containing less than 0.05µCi of ^{3}H or ^{14}C per gram of tissue may be disposed of as non-radioactive animal carcasses, the ORC must be consulted before utilizing this method of disposal.

Gaseous waste products may be a special problem in university laboratories. Proper ventilation must be maintained in the design of all buildings and facilities including hoods, glove boxes, metabolism chambers, etc. The ORC should be consulted regarding any special procedures and precautions after calculating the levels of gaseous radioactive products metabolized as $^{14}CO_2$, $^{3}H_2O$, etc. In all cases where animals are producing radioactive metabolic by-products, appropriate steps must be taken to ensure that these do not escape to the environment.

Study Questions:

40. Radioactive _______________ is radioactive material in an unwanted place.

41. Draw lines to match the term with the definition.

    Fixed: Contamination that can be transferred by casual contact.

    Removable: Contamination that cannot be readily removed from surfaces.

42. Which of the following are sources of radioactive contamination (check all that apply)?

    ☐ Poor housekeeping
    ☐ Receiving an X-ray
    ☐ Excessive movement in contamination areas
    ☐ Leaks or breaks in radioactive waste containers.
    ☐ Over exposure to sunlight

43. What is the limit for contamination during a laboratory survey?

    A) 200 dpm / 100 cm^2
    B) 2000 dpm / 100 cm^2
    C) 50 cpm / 100 cm^2

44. The three general methods to prevent internal exposure to radioactive materials are ______________________________ , ________________________, and __________________.

45. Protective clothing must be ____________________ prior to use.

46. Which of the following are pathways radioactive material may enter the body?

    ☐ Chewing gum in a contamination area.
    ☐ Entering a radiation area without proper dosimetry.
    ☐ Not covering wounds prior to handling radioactive material.
    ☐ Not using a fume hood when required by procedure.
    ☐ Receiving a medical x-ray.
    ☐ Working with radioactive materials that can be absorbed through the skin without protective equipment.

47. Proper authorization for use of radioactive materials in live animals requires approval from both what two SIU institutional committees?

48. The study of biological processes in animals using radioactive materials requires special precautions and procedures to address waste concerns, which can be in the form of either a _____________, ______________, or ______________.

11.0 External Radiation Protection

External radiation exposure is primarily a problem related to high-energy beta and gamma emitters and x-ray sources. One of the most important practices for limiting external radiation exposure is to use the least amount of radioactive material needed to perform the experiment. Normally, for health, safety, and financial reasons, we have already minimized the amounts of radioactive material involved in an experiment and have little choice about which radionuclide to use. There are three ways to reduce the exposure from external radiation sources. Some methods may be more appropriate in your particular situation than others.

12.1 Time

Reducing the time of exposure is a very practical method of radiation protection. Since the amount of exposure occurs as a function of the duration of the exposure, less time means less exposure.

Methods for minimizing time:

- Plan and discuss the experiment before performing it.
- Have all necessary equipment present before starting the experiment.
- Use practice runs until the procedure is routine.
- Never loiter in the vicinity of a radioactive source.
- Work efficiently and swiftly. However, do not work so fast that you will compromise your results or cause spills.
- Do the job right the first time.

The exposure received (X) is equal to the radiation field intensity (dose rate) times the exposure time.

$$X = RT$$

X = exposure received
R = dose rate
T = length of time exposed.

Example: *A survey meter located near a radioactive source reads 12 mR/hr. How long can a worker stay in the same area and still keep their dose below 2 mrem.*

Assume 1 mR approximately = 1 mrem

$$12\,\frac{mR}{hr} \times \frac{1\ hr}{60\ \text{min}} = 0.2\ \frac{mrem}{\text{min}}$$

So, a person may remain in the area up to 10 minutes, resulting in a 2 mrem radiation exposure.

12.2 Distance

Distance is a very effective protection measure and often the least expensive way to reduce radiation exposure. As one moves away from a point source of radiation, the amount of radiation at a given distance from the source is inversely proportional to the square of the distance (inverse square law).

Methods for maximizing distance from sources of radiation:

- The worker should stay as far away from the source of radiation as possible.
- During work delays, it is advisable to move to lower dose rate areas.
- When possible, use remote handling devices (tongs, forceps, etc.) when possible.

$$ID^2 = id^2$$

I = intensity at a distance (D) from a point source
i = intensity at a different distance (d) from the same point source

This law states that if you double the distance, the dose rate falls to 1/4 of the original dose rate. If you triple the distance, the dose rate falls to 1/9 of the original dose rate.

Example: A source reads 30 mR/hr at 8 inches. What is the dose rate at 2 inches?

$$ID^2 = id^2$$

$$30 \text{ mR / hr x } (8 \text{ in})^2 = \text{I x } (2 \text{ in})^2$$

$$i = \frac{30 \text{ mR / hr x } 64 \text{ in}^2}{4 \text{ in}^2}$$

$$\text{i} = 480 \text{ mR / hr}$$

12.3 Shielding

Shielding is also a practical means of radiation protection. For α and β radiation very little shielding is required to completely absorb the emissions. With the proper materials, γ or X-radiation can be shielded to acceptably reduced levels.

Table 14 Shielding

Radiation	Shielding
Alpha (α)	None
Low-energy beta (β) (<0.2 Mev)	None
High-energy beta (β) (>0.2 Mev)	1 cm of Plexiglas
Gamma radiation (γ)	1 TVL of high Z material (e.g., lead)
Neutron (n)	hydrogen rich material (e.g., water or paraffin)

Use shielding whenever it is necessary to reduce or eliminate exposure. By placing an appropriate shield between the radiation source and the worker, radiation is attenuated and exposure may be completely eliminated or reduced to an acceptable level. The type and amount of shielding needed to achieve a safe working level varies with the type and quantity of radioactive material used.

In general, as the density and/or thickness of a shielding material increases, the absorption of radioactive emissions by the material also increases. Usually, the higher the atomic number of the shielding material, the higher its density.

Proper uses of shielding:

Shielding reduces the amount of radiation dose to the worker. Different materials shield a worker from the different types of radiation.

Figure 18 Use of Plexiglas Shielding

- Shielding reduces the amount of radiation dose to the worker. Different materials shield a worker from the different types of radiation.
- Use the appropriate shielding for the type of radiation.
- Use shielded containments when available.
- Wear safety glasses/goggles to protect your eyes from beta radiation, when applicable.
- Persons outside the shadow cast by the shield are not necessarily protected.
- A wall or partition may not be a safe shield for people on the other side.
- Radiation can be "scattered" around corners.

Beta Shielding

Shield beta emitters with low Z materials such as plastics and glass to minimize the production of bremsstrahlung. The absorption of high-energy beta radiation (e.g. P-32 and Sr-90) in high Z materials such as lead and tungsten may result in the production of electromagnetic radiation (bremsstrahlung), which is more penetrating than the beta radiation that produced it. Low Z materials such as plastics and glass minimize the production of bremsstrahlung.

If you are using P-32 or other high-energy beta emitters, you should consider using shielding if a G-M survey meter reads about 10 times background. As previously discussed, approximately 1 cm of Plexiglas can provide adequate shielding for most high-energy beta emitters. Shielding is not required for low energy beta emitters such as P-33, S-35 or C-14 since these betas have a very limited range, even in air.

Gamma Shielding

Recall from Section 5.4 that the thickness of an absorber needed to reduce a given radiation intensity by one half is called a half-value layer (HVL). This concept applies also to an even thicker absorber that reduces the initial intensity by one tenth, and is called a tenth-value layer (TVL).

Example: *At 30 cm, a certain Co-60 gamma source produces an exposure rate of about 16 mR/hr. How much lead shielding is required to reduce this rate to 2 mR/hr. One HVL for Co-60 is 1.5 cm of lead.*

Since one HVL reduces the exposure by ½ and ½ x ½ x ½ = 1/8, then three half-value layers will reduce the intensity to 2 mR/hr. Therefore, 3 x 1.5 cm or 4.5 cm of lead shielding is required.

Study Questions

49. What are the three basic methods for reducing external exposure to radiation?
___________________, _____________________, and ______________________.

50. List three methods to reduce the amount of time spent in a radiation area.

1. ____
____

2. ____
____

3. ____
____

51. The intensity of radiation at 2 m from a point source is 1.3 mR/hr. What is the radiation field at 50 cm?

52. If the intensity of radiation from a point source of Cs-137 is 64 mR/hr, how much lead will be required to reduce the radiation to 2 mR/hr? (HVL = 0.8 cm)

12.0 Radiation Use Permits

Radioactive materials and radiation producing machines are used in a variety of laboratories at SIU. SIU is granted a broad scope license by the State of Illinois, Division of Nuclear Safety. Experienced faculty members on campus are approved for each operation involving radiation sources by the Radiation Safety Officer (RSO), acting on behalf of the SIU Radiological Control Committee, whose function it is to safeguard the radiological health of the University community. Each such faculty user or PI is granted a "Radiation Use authorization" (RUA) which specifies what radioisotopes or machines can be used, where they may be used, how much activity may be used, and what special radiation safety procedures must be followed.

12.1 Radiation Safety Office

The Radiation Safety Officer (RSO), appointed by the Dean, is responsible for managing the license and the laboratory surveillance program. The RSO communicates the requirements of the license to the principal investigator and users through the *Handbook of Radiological Operations (HRO) Manual*, each individual RUA, lab postings, training session and personal communication. The *HRO Manual* contains an in-depth presentation of the organization and requirements of the radiation safety program at SIU as well as practical information about the use of radioisotopes and radiation producing machines at the campus. You are strongly encouraged to become familiar with its contents.

The Radiation Safety staff is available for consultation and to answer questions on the safe use of radioactive materials and radiation producing machines. Radiation Safety will also keep Principal Investigators informed of changes in government regulations or university policies.

12.2 Radiation Use Authorizations (RUAs)

Radiation Use Authorizations establish radiological controls for experiments that use radiological material. They serve to inform users of any radiation safety requirements associated with an experiment, and provide a means to relate radiation doses received by users to specific work activities.

The RUA includes the following information:

- Protocols for radiation use
- Dosimetry requirements
- Protective clothing and protective equipment requirements
- Contamination reduction considerations
- Date of issue and expiration
- Authorizing signatures
- Bioassay requirements
- Contamination monitoring requirements
-

13.3 Radiological Laboratory Supervisors (RLS)

The Radiological Laboratory Supervisor (RLS) is legally responsible for the safety of all personnel under their supervision. The RLS must recognize and understand the duties and responsibilities of the position as outlined in the HRO Manual. Contingent to the RCC issuing an RUA, the PI is required to prove competence by examination on the specifics of the position addressed below.

13.4 Duties and Responsibilities of the RLS and Laboratory Personnel

The RLS must ensure that all pertinent rules and regulations contained in the HRO Manual be strictly complied with by all project personnel. It is imperative that good safety practices and techniques be utilized at all times and full cooperation is extended to the RSO. Further, the RLS <u>shall</u> have full knowledge of all laboratory operations at all times in order to assure compliance. The RLS <u>shall</u> assure that:

1. Safe storage areas, shielding (if required) and the security of radioactive materials and radiation-producing devices are maintained at all times. Radioactive materials in <u>restricted areas shall be kept under lock and key</u> at all times when not in use and authorized personnel are not present.

2. Proper warning signs, notices, emergency procedures, and cautions are posted and utilized properly.

3. Adequate monitoring devives are provided and utilized properly, e.g., personnel monitoring devices and survey instruments.

4. Accurate and current inventory and other required records are maintained (See HRO Subsection 3.8 Records).

5. Accurate, current and complete “Application for Procurement and Use of Radioisotopes” (RCC-1) and “Application: Radiation Equipment and Facilities Approval” (RCC-3) forms are on file in the ORC and have been approved by the RCC before any project work is undertaken. The RLS <u>shall</u> notify the ORC in writing and receive RCC approval before any major procedural changes are attempted.

6. All project personnel utilizing radiation under supervision by the RLS have a “Statement of Training and Agreement” (RCC-2) and an “Occupational External Radiation Exposure History” (RCC-4) form on file in the ORC before commencing work (See HRO Subsection 3.11 Use in Laboratory Class Use).

7. All project personnel are adequately trained in the safe utilization and handling techniques for radiation, and have knowledge of any particular project hazards.

8. All requisitions for radioactive materials or radiation-producing devices are approved prior to ordering. <u>All shipments of radioactive materials must be shipped to the ORC for processing.</u>

9. The RSO is immediately notified in the event of an emergency situation or suspected hazardous situation.

10. The RSO is consulted in the event that a question of a safety nature arises that is not specifically covered in the HRO Manual.

11. The RSO be notified at least two weeks in advance of termination of use of radioactive material in an approved area. This time period shall be required in order to ensure that all radioactive materials and contaminated apparatus and equipment have been properly disposed of or transferred correctly to other approved areas.

The above sections of the HRO Manual have been reproduced merely to form an outline for the RLS. This does not relieve the RLS from being familiar with the entire contents of the Handbook, as it is the basis for all procedures and operations at Southern Illinois University School of Medicine.

13.5 Your Responsibilities

The individual user is ultimately responsible for the safe use of the radiation sources to which s/he has access. Workers shall:

1. Keep their exposure as low as practical.

2. Report to the RSO if radiological controls are not adequate or are not being followed.

3. Read and comply with the RUA requirements.

4. Wear assigned personnel monitoring devices in an approved manner.

5. Comply with all sections of the HRO Manual applicable to their work.

6. Be knowledgeable of the lab's radiation sources, the extent of their potential risk and use the proper means of coping with them safely.

7. Monitor their use area frequently for contamination.

8. Clean up minor spills immediately.

9. Dispose of radioactive waste in an approved manner.

10. Properly label sources and containers of radioactive material.

11. Assist their supervisor in maintaining required records and inventories.

12. Prevent unauthorized persons from having access to radiation sources in their area.

13. Protect service personnel, allowing no maintenance or repairs of area facilities or equipment unless approved by the RLS and/or the RSO.

14. Handle accidents or injuries with common sense and in the spirit of the Emergency Procedures Section. They shall notify and seek the assistance of their immediate supervisor and the RSO as soon as possible in emergencies.

Study Questions:

53. Check the information found on an RUA (check those that apply).

☐ Work area radiological conditions
☐ Hot work permit requirements
☐ Material safety data sheets
☐ Description of protocols
☐ Dosimetry requirements
☐ Protective clothing
☐ Lock out/ tag out permit number
☐ Authorizing signatures
☐ Fire systems check out
☐ Worker's current dose

54. Identify which of the following are worker responsibilities concerning RUAs.

☐ Workers must read the RUA
☐ Workers must write the RUA
☐ Workers must comply with the RUA requirements
☐ Workers may substitute controls specified in the RUA

13.0 Radiological Identification System

Radiological signs alert personnel to the presence of radiation and radioactive materials, aid in minimizing personnel dose, and prevent the spread of contamination. All radiation use areas and radioactive material will be designated by one or more of the following signs:

- Yellow signs with the standard three bladed radiation-warning symbol (trefoil) in magenta or black.
- Yellow and magenta rope, tape, chains, or other barriers.

Figure 19 Radioactive Material Label

Examples of some of the types of radiological signs at SIU are shown in Appendix A.

Radioactive material may consist of equipment, components or materials that have been exposed to contamination or have been activated. Sealed or unsealed radioactive sources are also included. All radioactive material is identified by one or more of the following types of postings:

- Yellow tags and labels with the standard radiation symbol in magenta or black.
- Yellow plastic wrapping or labeled containers.

The posting should be placed where it is clearly visible to personnel. Indiscriminate use of warning signs and/or labeling of non-radioactive materials with “Radioactive” stickers or labels are prohibited.

13.1 Radioactive Materials Use Area

Radioactive Materials Use Area (RMA) is an area where radioactive materials are used, handled or stored.

In Radioactive Material Use Areas the potential exists for radioactive contamination due to the presence of un-encapsulated or unconfirmed radioactive material. All of the laboratories at SIU that use radioactive materials are labeled “Caution Radioactive Materials” on the entry doors and/or at entry points to a RMA located within the lab.

Posting Requirements:

"CAUTION, RADIOACTIVE MATERIAL"

Note: *In the unlikely event that you discover radioactive material that appears to be unattended (such as radioactive material that has been discarded in a trash receptacle, or is found outside or in a building corridor), you should:*

1. *Not touch or handle the material.*

2. *Warn others to stay away from the area.*

3. *Guard the area and have someone immediately notify the RSO at 536-2015. Off-hours, notify SIU Police at 453-1381.*

4. *Await the arrival of Radiation Safety personnel.*

13.2 Radiation Area

Radiation Areas means any area accessible to individuals in which radiation levels could result in an individual receiving a deep dose equivalent in excess of 5 mrem/hr but less than or equal to 100 mrem/hr. This is established based on dose rates at 30 cm from the source of radiation.

Posting Requirements

“CAUTION, RADIATION AREA"
"Personnel Dosimetry Required for Entry"

Minimum requirements for Unescorted Entry:

Radiological User Training

Requirements for working in Radiation Areas:

Don't loiter in the area
Follow proper emergency response to abnormal situations

Requirements for Exit:

Observe posted exit requirements

Table 15 Laboratory Designations

Area	Definition (Dose Rates Are:)	Area Working Requirements	Public Allowed
Radioactive Materials Area	An area where radioactive material is used, handled or stored.	1) Always practice ALARA 2) No eating, drinking, chewing or use of tobacco in the area	Yes - Only under the escort of a radiation worker
Radiation Area	An area where radiation levels are >5 mrem/hr but ≤ 100 mrem/hr	1) Don't loiter in the area 2) Follow proper emergency response in abnormal situations 3) No eating, drinking, chewing or use of tobacco in the area	No - Restricted Area

Study Questions:

55. Describe the colors and symbols used on radiological postings.

56. Match the definition to the radiological area.

____ Radiation Area
____ Radioactive Materials Area

a. Any area accessible to individuals in which radiation levels could result in an individual receiving a deep dose equivalent in excess of 5 mrem/hr but less than or equal to 100 mrem/hr. This is established based on dose rates at 30 cm from the source of radiation.

b. An area where radioactive materials are used, handled or stored. This posting will not be required when radioactive materials are inside Contamination or Airborne Radioactivity Areas.

14.0 Radiation Survey Meters

There are several types of portable radiation survey instruments in use on campus. Each type has different qualities and can therefore have very different detection capabilities.

As a user of radioactive materials or radiation producing machines, you are expected to be able to use the survey meter in your laboratory. During your initial training, you will learn how to operate the instrument(s) in your lab. You should know their capabilities and limitations and be able to interpret the meter readings.

14.1 Geiger-Mueller Detector

The Geiger-Mueller (G-M) detector is the most common radiation detection instrument on campus. Ionization in the Geiger counter detector results in a large output pulse that causes meter and audio responses. Because of the inherent characteristics of the detector, all initial ionizing events produce the same size output pulse. Therefore, the meter does not differentiate among types or energies of radiation

Figure 20 G-M Detector

A G-M detector is basically a hollow gas-filled chamber fitted with a thin mica "window" at one end. The thin window is very fragile. A constant high voltage is applied between the chamber exterior wall and an interior electrode which when radiation passes through causes the filling gas to conduct. The detector output is amplified and converted to produce a meter reading in counts per minute (cpm).

Very low energy beta emitters such as H-3 and Ni-63 are not detectable since their betas do not have enough energy to penetrate the window. They are best detected by using liquid scintillation counting techniques. C-14 and S-35 emit betas energetic enough to pass through the thin window but have very poor efficiencies.

Because of the randomness of radioactive decay, the meter reading at low count rates often fluctuates widely. For this reason, the audio speaker is sometimes a better indicator of small amounts of radioactivity than the meter reading. At higher count rates, the speaker response is often faster than the meter reading. It is better, therefore, to have the speaker on when using a G-M dectector.

14.2 Liquid Scintillation Detector

Liquid scintillation counting is the method of choice for measuring beta emitters, particularly weak beta emitters. The sample is dissolved or suspended in a solution that contains an organic chemical, which fluoresces when acted upon by ionizing radiation. The radiation is converted into pulses of light, which are detected by a photo-multiplier tube. The amount of light produced is related to the energy absorbed by the detecting medium. By employing suitable electronics, amplifier gain and window width settings on the analyzer, beta emitters having different energies can be distinguished. It is, therefore, possible to use two or more beta emitters in a single experiment if their energies of emission are sufficiently different.

15.3 NaI Scintillation Detector

Scintillation detectors that incorporate a sodium iodide (NaI) crystal are used in some laboratories for the detection of low energy gamma emitters such as I-125. Impinging gamma rays excite electrons, which produce light when they return to their ground state. The light is detected by a photomultiplier tube and analyzed similar to that used for liquid scintillation detection. The efficiency of a low energy scintillation probe for the detection of I-125 is about 5% at one inch – over a hundred times better than a G-M probe.

15.4 Ion Chamber

Ionization chambers are suitable for measuring radiation exposure rate or cumulative radiation exposure at high radiation intensities. They are not especially useful at low radiation intensities or for detecting small quantities of radioactive material.

15.5 Calibration

Radiation Safety calibrates all of the portable radiation survey instruments on campus. Survey meters are calibrated for the detection and measurement of particulate radiation. These meters are calibrated using an electronic pulse generator so that the cpm or cps scales read correctly. This type of calibration is required once a year.

15.6 Efficiency

Efficiency is a measure of how effectively the instrument detects the radiation source being monitored. The efficiency of a meter for a specific source of radiation is given by the ratio of the meter count rate to the actual disintegration rate of the source (cpm/dpm). Some examples of approximate G-M efficiencies through the end window at 1 inch from a point source are given in Table 16.

Table 16 G-M Efficiencies

Isotope	% Efficiency
^{3}H	Not Detectable
^{14}C*	<1%
^{35}S*	<1%
^{32}P	3-8%
^{125}I	<0.05%

* Not detectable if the detector window is covered with paraffin film, plastic wrap, or other material.

It is important to note that the cpm readings from survey instruments are not the true amount of radiation present, since there are factors, which decrease the detection capability of even the most sensitive instruments. Two factors influence radiation detection sensitivity: the geometry of the counting system and the energy of the radionuclide being measured.

Every counter will register some counts even when the counted sample contains no added radioactivity. This is called background and is caused by cosmic rays, natural radioactivity, radioactive fallout, and electronic noise in the circuitry of the equipment. The true cpm of a sample is therefore (sample cpm - background cpm) and the efficiency is more correctly:

$$\frac{\text{sample cpm - background cpm}}{\text{dpm}} \times 100\% = \text{Efficiency}$$

If the efficiency of the instrument is known you can accurately determine the activity of what is being measured. To determine activity, divide the instrument count rate (cpm) by the efficiency to get dpm. To convert to μCi, divide dpm by 2.22×10^6.

Example: *Your G-M counter reads 5000 cpm at one inch from a small spot of P-32 contamination on the bench. The efficiency of your counter is 5%. What is the total activity of the contamination?*

Actual disintegration rate = (5000 cpm)/(0.05 cpm/dpm) = 100,000 dpm = 1700 dps = 1700 Bq = 45 nCi

Study Questions:

57. Your G-M counter reads 15,000 cpm over a small spot of P-32 contamination (30% efficiency for P-32). How much activity is there?

A) ___________ dpm
B) ___________ Bq
C) ___________ μCi

58. Gamma (NaI) and liquid scintillation detection is based upon what physical property?

A) radiolysis of an organic solvent
B) absorption of electromagnetic energy
C) emission of visible light

16.0 Dosimetry

Each employee's external and internal dose from ionizing radiation is assessed using special types of monitoring equipment. A dosimeter is a device that is used to measure radiation dose. Dosimeters used to measure external sources of radiation are called external dosimeters. The types used depend on the radiological conditions present.

16.1 Types of Dosimetry Used on Campus

Whole Body Exposure Monitors

The dosimeter used most often on campus is the thermoluminescent dosimeter (TLD). TLD's contain a lithium fluoride chip that, when exposed to ionizing radiation, traps electrons in excited energy levels. When the dosimeter is heated, these electrons are liberated from the traps. As the electrons return to their normal levels, visible light is released. The amount of light released is measured and is proportional to the exposure of the dosimeter to radiation.

The accuracy of the TLD badge is ±10 mrem. The TLD detects β, γ, and x-ray radiations and exposure is reported as being either deep and/or shallow energy penetration. TLDs will NOT detect radiation from low energy beta emitters such as H-3, C-14, or S-35, since their betas will not penetrate the plastic covering on the dosimeter.

The badge is usually worn at the collar or chest level to measure the radiation dose received by the trunk of the body. If you wear a leaded apron during work wear the badge on the inside of the apron. When not in use, the badge should be left in a safe place on campus away from any radiation sources.. Be sure the badge is available for exchange, which is done on the first week of each month.

Finger Ring Dosimeters

To monitor hand exposure to radioactive materials, TLDs in the form of finger rings are worn. Ring dosimeters should be worn on the dominant hand with the chip facing the most likely source of radiation, usually towards the inside of the hand. Finger rings should always be worn on the same finger. Always remember to wear the ring inside your glove. It is important to ensure that the chip is in place, in the dosimeter, prior to each use.

16.2 Precautions on Use of Dosimetry

The radiation dosimeter issued to you is your responsibility. The radiation doses recorded by your dosimeter become part of your occupational radiation dose record. Make sure that this record is valid and accurate by observing the following precautions:

- Always wear your dosimeter when using radioactive materials or radiation producing machines. Primary dosimeters are worn on the chest area, between the waist and the neck in a manner directed by the Radiation Safety Officer.

- The dosimeter must be stored in a safe location away from radiation sources when not in use. In each lab use a safe location where you can store your dosimeter.
- Do not take your dosimeter home. Excessive heat from leaving the dosimeter on the dashboard of a car will cause an erroneous reading, as will washing it with personal clothing.
- Do not wear your dosimeter at other institutions.
- Never wear someone else's dosimeter or let someone else wear yours.
- Do not deliberately expose a dosimeter to radiation or wear your badge when receiving medical or dental x-rays.
- Do not tamper with the TLD chip or remove it from the holder.
- Avoid subjecting the badge to high temperatures or getting it wet.
- The loss of a dosimeter should be reported to the ORC as soon as the loss is noticed. Working in a radiation area without a dosimeter is a violation of federal, state, and campus regulations.

Distribution and Use of Badges

Dosimetry badges are issued by the ORC based on the experimental protocols used and the type and amount of radioactivity used in the lab. Please call the ORC at 536-2015 for dosimetry needs.

Badges are exchanged monthly. Radiation dosimeters are collected promptly by the RSO within the first week of every month so they may be processed.

When you terminate your work assignment involving radiation at SIU, please return your dosimeter(s) to the ORC on the last day of your employment.

16.3 Internal Monitoring

A <u>bioassay</u> is a procedure used to determine the activity of radioisotopes contained in the body. One example is the bioassay for radioactive iodine. Since about 30 percent of the total activity of iodine that is inhaled or ingested during an iodine exposure is accumulated in the thyroid gland, the total iodine uptake can be determined by placing a calibrated scintillation detector on the neck directly over the thyroid gland and measuring the activity.

Bioassays for other types of radioisotopes involve a urinalysis. For this type of test a urine sample is submitted to ORC for analysis by a method that will determine the amount of radioactive material present. An internal dose may be calculated from these measurements.

16.4 Dosimetry Records

The radiation dosimeter is SIU's guide to your occupational radiation exposure. The dosimetry reporting company, an independent contractor, will report exposures per individual. Should your monthly body dosimeter exceed 10% of the occupational limit (500 mrem) you will be notified and an investigation into the cause will be initiated.

All dosimetry records are on file at the Office of Radiological Control. Upon your request, we will supply you with your dosimetry history. Terminating personnel can request a report of the radiation dose received at SIU. Notify the RSO of any radiation dose received at another facility so that dose records can be updated.

16.5 State Notification

The dosimeter vendor and SIU are required by law to report to the Illinois Division of Nuclear Safety (IDNS) any personal dosimeter, which shows a dose higher than the state occupational dose limits. It is a violation of the Illinois Radiation Control Regulations and the conditions of our Radioactive Material License to deliberately expose a personnel dosimeter to a radiation source (except when being used as intended). The dose recorded by the dosimeter will become part of the dose record of the individual to whom it was issued unless it can be proven to IDNS that the individual did not actually receive the dose.

Study Questions:

59. The primary use of a dosimeter is to:

    A) measure dose from all ionizing radiation
    B) measure dose from natural sources of ionizing radiation
    C) measure dose from occupational radiation
    D) measure dose from medical sources

60. Dosimeters should be worn

    A) Generally, between the neck and the waist.
    B) Only by the person to whom it was issued.
    C) For extremity monitors, on the inside of protective gloves.
    D) All of the above.

61. A dosimeter will not record dose from which beta emitters?

    ☐ ^{32}P
    ☐ ^{14}C
    ☐ ^{35}S
    ☐ ^{3}H

62. (T/F) Dose reports are provided on a monthly basis.

63. Workers may get their current dose record via:

    A) asking their supervisor
    B) going to the SIU Human Resources Department
    C) written request to the ORC
    D) written request to department

64. (T/F) It is permissible to share a single personal dosimeter with a colleague as long as you are both working on a radiation project together.

17.0 Emergency Procedures

An important aspect of radiation safety is being prepared for the unexpected. An accident is defined as any unplanned event, which could affect radiation safety. Often the most difficult problem is the recognition that an accident has occurred. **The main priorities after an accident are human safety and the protection of the environment.**

Note: *Notify the ORC as soon as possible of any accident involving ionizing radiation. This includes, but is not limited to, accidental direct radiation exposure, contamination of laboratory personnel, extensive contamination of floors, difficulty in cleaning up a contaminated area, loss of radioactive material and receiving a high radiation exposure.*

In each case, the Office of Radiological Control (536-2015) must be notified as soon as possible; however, the emergency may demand those on the scene take other immediate action before this can be done. It is impossible to draw up a set of specific rules and procedures, which would cover each eventuality. Therefore, the following paragraphs present a set of general guidelines, which each individual faced with an unexpected hazardous situation, will remember and modify as circumstances and common sense direct.

If you believe you may have inhaled or ingested radioactive materials, IMMEDIATELY phone the RSO or 911 emergency for prompt medical attention. If after hours, contact SIU Police (453-1381) for assistance.

17.1 Personnel Contamination and Exposure

1. First and foremost, determine the need to administer first aid to any injured personnel and administer it as needed. If a medical emergency exists, phone 911 IMMEDIATELY.

2. Notify other personnel in the lab so they can assist you.

3. Determine if any personnel have been contaminated with radioactive material. Contaminated personnel should immediately remove any contaminated clothing (this is no time for modesty **-** use a clean lab coat).

4. Wash the contaminated area immediately with tepid water using a mild soap. The face and extremities can be easily washed in a sink. While decontaminating the face, special care must be taken not to contaminate the eyes or lips. Decontamination of the eyes should be undertaken immediately by irrigating with copious amounts of water or eye wash solution. After this initial treatment, further treatment should be continued by medical personnel. Whole body contamination needs to be washed under a safety shower.

5. The skin should be washed a few minutes at a time and monitored.

6. If contamination persists repeat washing several times checking the areas with a G-M detector in cases where the contaminating radionuclide can be detected with one.

7. Stop washing if there is any indication of skin damage or after 10 minutes. DO NOT abrade the skin. Intact skin is an excellent barrier. Do not abrade the skin by using any abrasives, strong detergents or brushes. Doing so may de-fat or injure the skin causing not only external but also internal contamination.

8. Keep dosimetry badges free of contamination.

9. Call the Radiation Safety Officer (536-2015) or Police at 453-1381 after hours) immediately if any person has been contaminated.

10. Keep all persons out of the accident area until help arrives and do not remove anything from the accident area.

17.2 Large Radioactive Spills (> 0.1 mCi 125I, >1 mCi of other radionuclides)

For large spills the minimum response is as follows:

1. **S**top or secure the operation causing the spill but only if this can be done with minimal risk of spreading contamination or contaminating yourself. Try to prevent further spread of the spill with paper towels or other absorbent. Turn off any instrument or machine that could enhance the spill.

2. **W**arn others in the area and notify the RLS and ORC that a spill of radioactive material has occurred.

3. **I**solate yourself from the spill. Evacuate personnel from immediate danger, but do not allow evacuated personnel to leave the immediate area.

4. **M**inimize exposure to radiation and contamination. If needed, remove shoes outside the spill area to prevent tracking contamination all over the area.

17.3 Small Radioactive Spills (≤ 0.1 mCi 125I, ≤1 mCi of other radionuclides)

Spills of radioactive materials can happen at any time. Minor contamination in μCi amounts involving no immediate hazards, can be cleaned by trained users in the lab. If you have any doubt about your ability or means to effectively clean up a radioactive materials spill, promptly contact the ORC for assistance at 536-2015.

If you have determined that the spill can be managed by individuals in your lab, there are several steps you can take to ensure timely and thorough clean up of the contamination:

1. Notify everyone in the area that a spill of radioactive material has occurred.

2. Try to prevent further spread of the spill with paper towels or other absorbent materials, but only if this can be done with minimal risk of spreading contamination or contaminating yourself.

3. Assemble clean-up materials, which include paper towels, plastic bags, gloves, lab coats, radiation survey meter (if needed), and cleaning solution (soapy water works well most of the time).

4. Don proper personal protective equipment when cleaning the spill. Do not step in the spill or contaminate personnel.

5. Using the most sensitive setting on your detector, monitor the spill and equipment to determine the extent of the contamination and mark the boundaries with tape or rope to restrict traffic.

6. Starting with the least contaminated areas, work inward towards the most contaminated areas of the spill, cleaning all areas as you proceed. Wipe up the spill in one direction as you clean, folding up the paper towels after each swipe of the contaminated surface. Deposit waste towels in appropriate disposal container.

7. Periodically check the cleaned area with your survey meter or by taking wipes and counting them on a liquid scintillation counter. Clean until all removable contamination is cleaned up. Be aware that widespread amounts of contamination may cause a high background level that can lead to difficulty in localizing areas of contamination.

8. Clean up your work area. Monitor your work area including the floor, shoes, clothing and hands.

9. If any removable contamination remains greater than twice background, notify the ORC for assistance.

10. Inform the RLS and the Radiation Safety Officer at 536-2015 within 24 hours.

Study Questions:

65. Define the letters in the following acronym:

S ______________________________
W ______________________________
I ______________________________
M ______________________________

66. The first two actions an employee should take for personal contamination by radioactive material is __________________________ and ___________________________.

67. What is the best method of skin decontamination?

A) Scrubbing with a wire brush.
B) Acidic based chemicals.
C) Mild soap and tepid water.
D) Mild soap and hot water.

68. Who do you contact first in the event of a radiological incident late at night?

A) ORC
B) Campus Security
C) RLS
D) Human Resources

18.0 Summary

You must be aware of potential radiological risks and take appropriate protective measures to minimize them. Through an enhanced awareness of radiological risks and a sense of personal responsibility for minimizing those risks, you can contribute to maintaining exposures to radiation and radioactive material as low as reasonably achievable. You will be asked to complete a Certification Examination that consists of questions and short essays on the material covered in this manual. The exam may be scheduled by calling the ORC at 5-7581.

After successfully completing the Certification Examination authorization to use radionuclides may be granted. Minimum passing scores consist of the following:

Radiation Workers	80%
Radiological Laboratory Supervisors	90%
Use of Radionuclides in Live Animals	90%

Appendix A

Radiological Signs

Figure A-1 Examples of some of the types of radiological signs at SIU

Appendix B

Answers to Study Questions

1. Protons, neutrons, electrons

2. isotopes

3. Removing, ionizing

4. Unstable

5. C) Neutrons

6. Non-ionizing, ionize

7. **Table 3 Curie Subunits**

Unit	Abbr.	dps	dpm
curie	Ci	$3.7x10^{10}$	$2.2x10^{12}$
millicurie	mCi	$3.7x10^{7}$	$2.22x10^{9}$
microcurie	µCi	$3.7x10^{4}$	$2.22x10^{6}$
nanocurie	nCi	$3.7x10^{1}$	$2.22x10^{3}$
picocurie	pCi	$3.7x10^{-2}$	2.22

Table 4 Becquerel Subunits

Unit	Abbr.	dps	dpm
becquerel	Bq	1	60
kilobecquerel	kBq	$1x10^{3}$	$6x10^{4}$
megabecquerel	MBq	$1x10^{6}$	$6x10^{7}$

8. Roentgen

9. Rad or Gray

10. A) (3.7×10^4 dis/sec) x (60 sec/minute) = 2.22×10^6 dpm

11. Alpha, beta, gamma, X, neutron

12. A) $0.693/T_{1/2}$

13.

Type of Radiation	Alpha	Beta	Gamma / X-ray	Neutron
Mass	large	small	none	large
Charge	2^+	1^-	none	none
Range	1-2 inches	10 ft/Mev	100's of feet	100's of feet
Shielding	paper, outer layer of skin	plastics, wood, glass	lead, concrete, iron	water, concrete, polyethylene
Hazard	internal	skin, eye, or internal	external / internal	external / internal

14. Their origin; x-rays come from electron shells and gamma-rays from the nucleus

15. .0563 / year

16. 893.4 μCi

17. 4199.0 dpm

18. 70 %

19. Cosmic, Terrestrial, Radon, Internal

20.

	Source	Annual dose (mrem / year)
Natural Background	Terrestrial	28
	Cosmic	27
	Internal Emitters	39
	Inhaled (Radon)	200
Man-made Background	Nuclear Fallout	<1
	Medical Exposures	53
	Consumer Products	10
	Nuclear Facilities	<1
	Estimated Total	**360**

21. Ionization

22. A) Directly proportional to the growth rate and inversely proportional to the degree of specialization

23. a. No damage
b. Damaged, repair itself properly, and operate normally
c. Damaged, repair itself improperly, and operate abnormally
d. Die

24. Chronic

25. Acute

26. Somatic

27. Heritable

28. 0.5 rems / gestation period (500 mrem / gestation period)

29. D) All of the above

30. B) Carcinogenesis

31. False-They are extrapolations from high levels of radiation. They could be low estimates or high.

32. D) Yours- the radiation workers

33. To ensure the federal radiation dose limits are not exceeded.

34. 10

35. Pregnant workers are encouraged to declare themselves pregnant to the RSO. This will allow the University to limit their unborn child dose to acceptable levels.

36. ☑ Radiation exposures
    ☑ Contamination exposures

37. Justification or benefit

38. ORC Radiation Safety

39. ☑ Minimizing time in an area
    ☑ Maximizing distance in an area
    ☑ Maximizing shielding in an area
    ☑ Minimizing contamination in an area

40. Contamination

41. Fixed = Contamination that cannot be readily removed from surfaces.
    Removable = Contamination that can transferred by casual contact.

42. ☑ Poor housekeeping
    ☑ Excessive movement in contamination areas
    ☑ Leaks or breaks in radioactive waste containers.

43. 200 dpm / $100cm^2$

44. Contamination control, personal protective measures, not eating or drinking in radiation use areas.

45. Inspected

46. ☑ Chewing gum in a contamination area
☑ Not covering wounds prior to handling radioactive material
☑ Not using a fumehood when required by procedure
☑ Working with radioactive materials that can be absorbed through the skin without protective equipment.

47. Radiological Control Committee (RCC) and the Laboratory Animal Care and Use Committee (LACUC)

48. Solid, liquid, gas

49. Time, distance and shielding.

50. Plan and discuss the experiment before performing it. Use practice runs until the procedure is routine. Work efficiently and swiftly.

51. I_1 = 1.3 mR/hr, D_1 = 200 cm, I_2 = ?, D_2 = 50 cm
$I_2 = (1.3 \text{ mR/hr} \times (200 \text{ cm})^2) / (50 \text{ cm})^2$
I_2 = 20.8 mR/hr

52. 5 HVL or 4.0 cm of lead

53. ☑ Work area radiological conditions
☑ Description of protocols
☑ Dosimetry requirements
☑ Protective clothing
☑ Authorizing signatures

54. ☑ Workers must read the RUA
☑ Workers must comply with the RUA requirements

55. Magenta or black radiation symbol on a yellow background.

56. a. Radiation Area
b. Radioactive Materials Area

57. A) 50,000 dpm
B) 833 Bq
C) 0.02 uCi

58. C) emission of visible light

59. C) Measure dose from occupational radiation

60. D) All of the above.

61. ☑ ^{14}C
☑ ^{35}S
☑ ^{3}H

62. True

63. C) Written request to the Office of Radiological Control

64. False

65. **S S**top or secure the operation causing the spill
W Warn others in the area, notify the ORC
I Isolate the spill area if possible
M Minimize individual exposure and contamination

66. Stop the spill and warn others in the area, including notifying the ORC

67. C) Mild soap and tepid water.

68. B) Campus Security