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Radiation Safety Fundamentals Training Manual

This information is being provided in accordance with the state requirements outlined in the CALIFORNIA RADIATION CONTROL REGULATIONS, which in essence states, "Each user shall: Inform all individuals working in or frequenting any portion of a controlled area of the storage, transfer, or use of radioactive materials or of radiation in such portions of the controlled area; instruct such individuals in the health protection problems associated with exposure to such radioactive materials or radiation, in precautions or procedures to minimize exposure, and in the purposes and functions of protective devices employed; instruct such individuals in, and instruct them to observe, to the extent within their control, the applicable provisions of Department regulations and license conditions for the protection of personnel from exposures to radiation or radioactive materials occurring in such areas; instruct such individuals of their responsibility to report promptly to the licensee or registrant any condition which may lead to or cause a violation of department regulations or license conditions or unnecessary exposure to radiation or radioactive material, and of the inspection provisions of Section 30254; instruct such individuals in the appropriate response to warnings made in the event of any unusual occurrence or malfunction that may involve exposure to radiation or radioactive materials; and advise such individuals as to the radiation exposure reports which they may request pursuant to this section. The extent of these instructions shall be commensurate with potential radiological health protection problems in the controlled area. [17, CCR, 30255(b) (1)]

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Radiation Safety Fundamentals Training Manual

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1 Introduction

During the course of your employment you may work with radioactive isotopes or radiation producing machines. Radioactivity is used in experimental and diagnostic situations 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 and workplace, we know a great deal about the risks associated with radiation 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.

The goal of this training 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. Federal and State requirements will also be outlined.

Your facility may be licensed to possess various amounts of radioactive material and radiation producing machines that may be used in a variety of procedures. As you review this guide, please keep in mind that each worker 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 your place of employment, as at other companies, working with radioactive material is a *privilege* not a right. A serious violation or accident could result in the cancellation of the Radioactive Materials License. Therefore violations of policies or procedures regarding radiation safety must be taken very seriously.

Your Radiation Safety Officer (RSO) is available for your consultation on the safe use of radioactive materials and radioactive machines. Feel free to call the RSO with any questions.

2 Objectives

This manual is a companion to your institution's Radiation Safety Manual (RSM). The RSM describes the radiation protection program in detail. The policies and procedures contained in the RSM have been approved by the Radiation Safety Officer (RSO) and are submitted to the Nuclear Regulatory Agency (NRC) or their designee as part of your radioactive materials license.

2.1 Radiation Safety Fundamentals

This Radiation Safety Fundamentals Training Manual presents the information necessary for users of radioactive materials and radiation producing machines to properly understand and basic concepts radiation safety.

2.2 On-the-Job Training

This written guide does not replace the requirement that a laboratory supervisor or an appropriate alternate to provide practical, hands-on training in the correct storage, use, disposal, and transportation of radioactive materials. 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 facility many also require you to attend annual refresher training to keep up-to-date with the latest regulations and university policies. The RSO can assist you in meeting this requirement.

3 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.

What are the three basic parts of an atom?

Protons

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

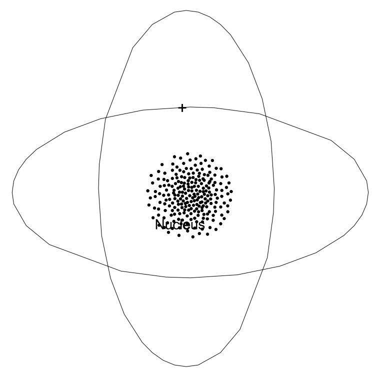


Figure 1 Atomic Model

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.

Atoms which 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.

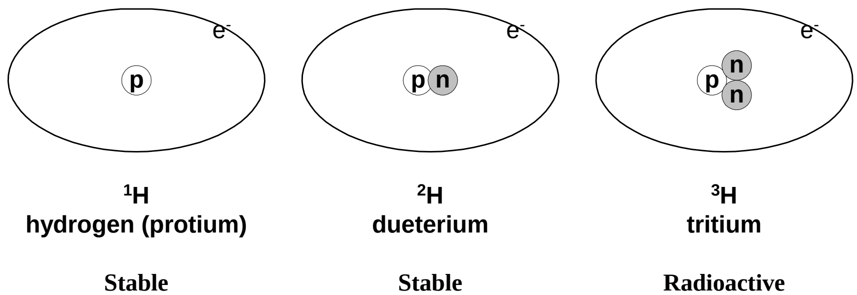


Figure 2 Isotopes of Hydrogen

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 research 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.

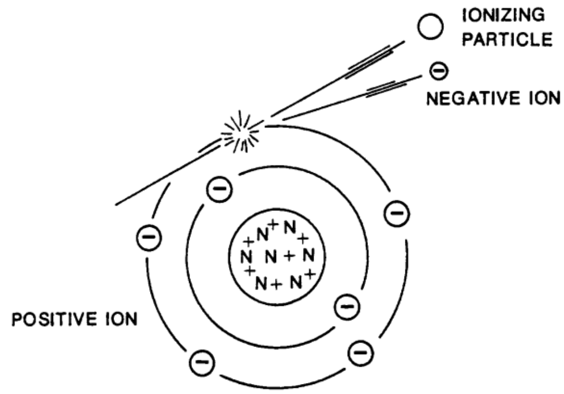


Figure 3 Ionization

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 basic parts of an atom are _______________, _______________, and _________________.
2. The process of ______________ orbital electrons from neutral atoms is called _________.
3. Radioactive material contains _______________ atoms.
4. A certain isotope of carbon has a Z number of 6 and an mass number (A) of 11. How many neutrons are present in the nucleus of this isotope?
   A) six
   B) eleven
   C) five
   D) seventeen
5. _______________ radiation doesn't have enough energy to _______________ an atom.

4 Units of Measurement

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

- The activity 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 radiation use industries. For example, the contents of radioactive vials are described in microcuries, exposure meters that measure radioactive exposure read in milliroentgens/hour, and the results of film badges are recorded in millirems.

4.1 Activity

Activity is the rate of decay (disintegrations per time) of a given amount of radioactive material.

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 Maria 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 biomedical institutions 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. 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 ionization produced in air by x-ray or gamma.

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.

Absorbed Dose is a measurement of energy deposited by radiation in a material.

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 and 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 3). 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 Ionization per unit mass of air due to X or gamma radiation		Roentgen	R	1 esu/cc 87 erg/g
		none	X	2.58×10^{-4} C/kg
Absorbed Dose (D) Energy deposited in a unit mass by any radiation	CGS	Radiation Absorbed Dose	Rad	100 erg/s 0.01 Gy
	SI	Gray	Gy	1 J/kg 100 rad
Dose Equivalent (H) Measure of radiation damage in living tissue		Roentgen Equivalent Man	Rem	Equivalent biological damage as 1 R 0.01 Sv
	SI	Sievert	Sv	100 rem
Activity (A) The amount of radioactive material yielding a specific rate of decay	Historical	Curie	Ci	3.7×10^{10} dps
	SI	Becquerel	Bq	1 dps

Study Questions:

6. Complete the following tables:

Table 3 Curie Subunits

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

Table 4 Becquerel Subunits

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

7. The unit used to measure radiation exposure is the ______________.

8. The units used to measure absorbed dose are the ______________ , or the ______________.

9. Calculate the number of disintegrations per minute for one µCi.
   A) $2.22x10^{6}$
   B) $3.7x10^{10}$
   C) $6.25x10^{7}$
   D) $2.22x10^{4}$

5 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

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.

Figure 5
Henri Becquerel

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.

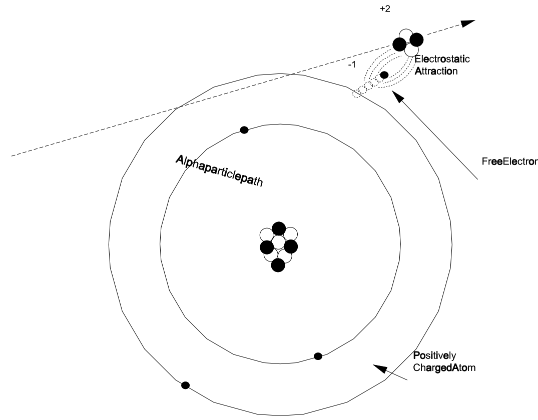


Figure 6 Ionization by an Alpha Particle

Because of its size alpha radiation does NOT represent an external hazard but it is extremely hazardous when alpha nuclides are deposited internally.

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 ($3x10^{-9}$ 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

Beta particles (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.

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

The most commonly used beta emitting radionuclides for use in bio-medical applications are ^{3}H, ^{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 travel several hundred times the distance of alpha particles in air.

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

Charged particles, including beta particles lose energy in an absorbing material by excitation, ionization, and radiation. Radiative 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.

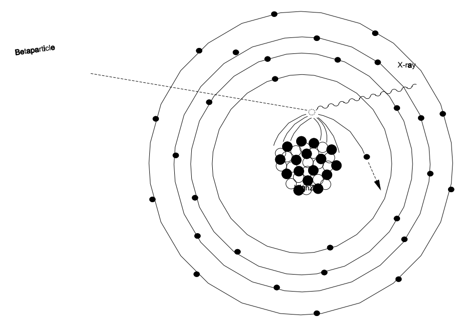


Figure 7 Bremsstrahlung Radiation

To prevent the creation of bremsstrahlung radiation, high-energy beta emitters must be shielded with material having a low atomic number (i.e. 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 of Energy Converted into Bremsstrahlung	Average Energy of Bremsstrahlung Radiation
Plexiglas	0.36 %	~ 200 keV
Lead	5.0 %	~ 200 keV

High energy Beta particles can damage the lens of the eyes and produce skin doses. They can also produce bremsstrahlung. Plastic shielding is required.

Beta radiation penetrates matter to varying distances. The higher the energy of the beta particle, the deeper the penetration into matter. Depending of 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 (^{3}H), ^{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 uCi/cm^2 of skin contamination with isotopes other than tritium. Examples of typical exposures are given on the bottom line of Table 5.

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 biomedical laboratories. 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

Gamma rays (γ)and X-rays 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 are 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 (^{133m}Ba) decays to a stable form of barium by gamma emission.

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

Orbital Electron Capture

For radionuclides having a low neutron to proton ratio, another mode of decay can occur known as orbital electron capture (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.

$$^{125}I + e^{-} \rightarrow {}^{125}Te + \nu + \mathrm{x-rays}$$

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 probabilistically interact with matter by three primarily 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.

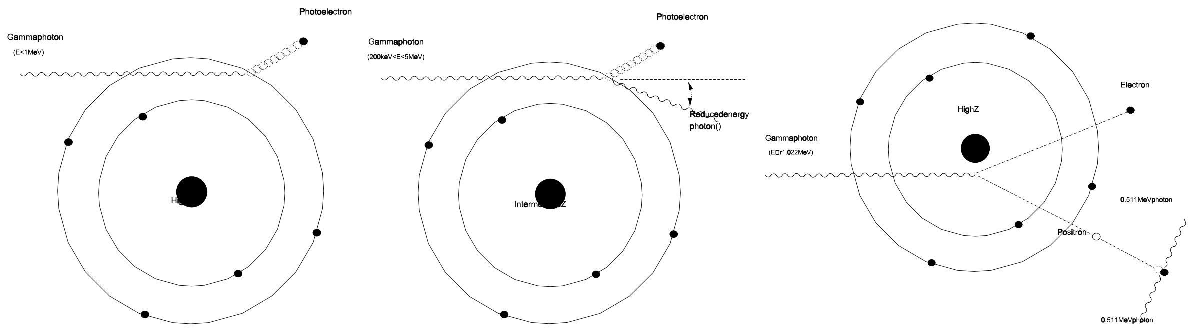


Figure 8 Photoelectric Effect, Compton Scattering and Pair Production

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 layer value (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 gamma ray's range in air is very far. It will easily go several hundred feet.

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 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 6 Radioactive Decay Characteristics

Radiation	Symbol	Form	Origin	Essential Parts	Mass (amu)	Charge	Energy Spectrum	Misc. Info.
Alpha	α	Charged particle	Nucleus	2p,2n	4	+2	MeV	Mono-energetic; from heavy radionuclides
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	

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:

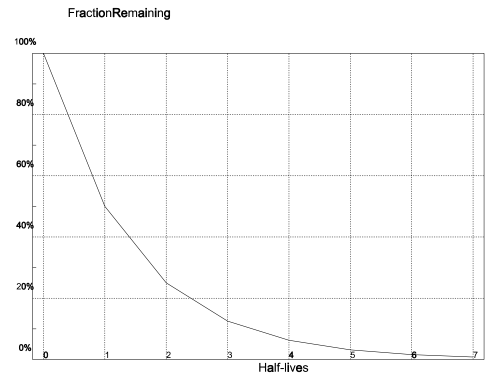


Figure 9
Radioactive Decay (Linear Scale)

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

Where:

A_o = the initial activity of the isotope
A_t = the activity of the isotope after time t
λ = the radioactive decay constant = $0.693/T_{1/2}$
$T_{1/2}$ = the half-life of the isotope
t = the time since the initial activity was measured

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.

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

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

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

$$A_t = 5.0 \text{ mCi } (0.125) = 0.625 \text{ mCi}$$

Study Questions:

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

11. Complete the following:

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

6 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.

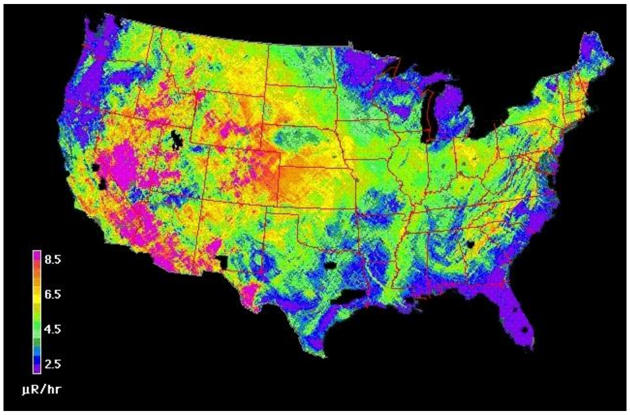


Figure 10 Terrestrial gamma-ray exposure at 1m above ground.

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 is 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 varies 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:

12. Consumer products are a man made source of environmental radiation exposure. Building material constitute approximately ______ to this source.

13. What are the four sources of natural background radiation?

    ________________ ________________ ________________ ________________

14. 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	
	Rounded Total	

7 Biological Effects

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.

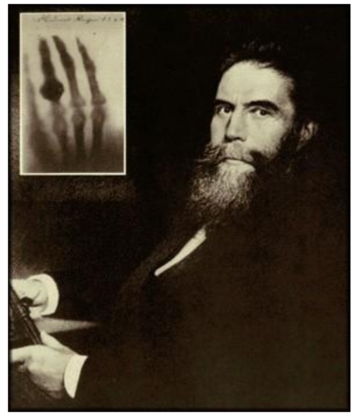


Figure 11 Wilhelm Roentgen. The insert above is a photograph of the first x-ray taken (Roentgen wife's hand).

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 are individuals who have been involved in radiation accidents, the most notable being the Chernobyl accident.
- The fourth and largest group are 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.

How does radiation cause damage to cells?

Radiation causes damage to human cells is 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 difference 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, with some cells and tissues showing exceptions.

Least Radiosensitive:

- Mature red blood corpuscles
- Liver cells
- Nerve cells
- Pituitary cells
- Thyroid cells
- Muscle cells
- Bone and cartilage cells
- Skin epithelium
- Cornea
- Squamous mucous epithelium
- Renal tubules
- Lung-tissue cells
- Lens
- Gonadal germ cells
- Bone marrow cells
- Lymphocytes

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

What are the 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 cells 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 of people undergoing radiation therapy are hair loss, nausea and fatigue.

Table 7 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 extremities is higher than for a 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 are many times higher than this.

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 to a 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

What's the difference between an "acute dose" and "chronic dose?"

A chronic radiation dose 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 should be encouraged to sign a statement that they have read and understand the NRC's Regulatory Guide 8.13 - Instruction Concerning

Prenatal Radiation Exposure available at http://www.nrc.gov/reading-rm/doc-collections/reg-guides/occupational-health/active/8-13/.

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 that 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 occupationally, 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 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.

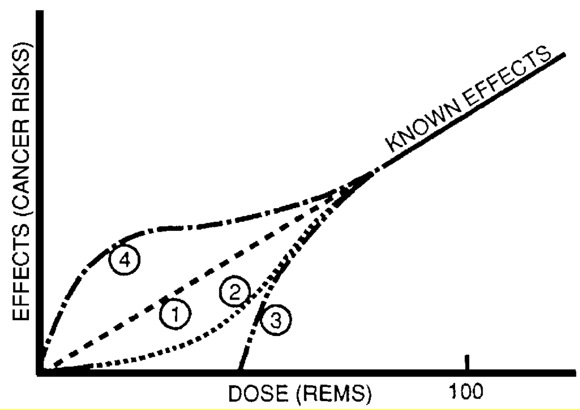


Figure 14 Dose Response Curves

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 (curve 4). Others believe that small amounts of exposure are actually beneficial (curve 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 NRC 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:

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

16. 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.

17. What are the possible effects of radiation on cells?
    a. ____
    b. ____
    c. ____
    d. ____

18. Exposure from natural background is considered to be what type of an exposure?
    ____

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

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

21. 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? ____________

22. What are the three potential effects from prenatal exposure?
    ___________________, _____________________, and _________________

23. 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

24. 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 Occupational Radiation Exposure Risks

For investigators working with radioactive materials in biomedical and research laboratories, the risk if any, to 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 governments, 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 8 below:

Table 8 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	4 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, 1,640 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 1 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 individuals lifetime is about 1,000 incidents per 10,000 live births. If each 30-year generation receives 1 rem of whole body radiation, it is *estimated* that radiation may cause an additional 5 to 75 genetic disorders in the first generation or 60 to 1,100 disorders at genetic equilibrium about four generations later.

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 9 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 9 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 an 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 in biomedical laboratories are very small when compared to the risks associated with radiation exposures for other occupations. The average annual radiation doses associated with various occupations are compared in Table 10.

Table 10 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
Biomedical lab radiation worker	<10

In Table 11 the risk of working with or around sources of ionizing radiation is compared with other risks encountered in everyday life.

Table 11 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:

25. The dangers due to low levels of exposure of ionizing radiation have been scientifically proven.
    A) True
    B) False

26. Whose responsibility is it to decide if the risks of working with radioactive material are unacceptable?
    A) The Radiation Safety Committee
    B) The RSO
    C) The PI
    D) Yours - the radiation user

9 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 National Regulatory Commission (NRC) sets federal radiation dose limits for occupational workers. The California Department of Health Services 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.

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 Federal radiation dose limit during routine conditions is 5,000 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 Federal radiation dose limit for extremities is 50,000 mrem/year.

Skin and other organs

The Federal radiation dose limit for skin and any individual organ is 50,000 mrem/year.

Lens of the eye

The federal radiation dose limit for lens of the eye during routine conditions is 15,000 mrem/year.

Minors

Federal dose limits to minors (under 18 years of age) and who are employed as radiation workers 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. It is important to do this *promptly* as the unborn child is most sensitive to radiation during the first 3 months of pregnancy. When she has done so, the employer must provide the option of a mutually agreeable job, with no loss of pay or promotional opportunity, such that further occupational exposure from penetrating radiation or volatile radiochemicals is unlikely. 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 employer 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 RSO 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 federal dose limit for adults.*

If you are pregnant now or are considering becoming pregnant refer to NRC's Regulatory Guide 8.13 - Instruction Concerning Prenatal Radiation Exposure 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 Federal radiation dose limit for visitors and the public is 100 mrem/year and 2 mrem in any one hour. 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 12 Dose Limits

	Radiation Worker Federal Limit[1]	Declared Pregnant Worker	General Public
Whole Body	5,000 mrem/yr		**100** mrem/yr[2]
Extremities	50,000 mrem/yr		
Skin/Organ	50,000 mrem/yr		
Lens (Eye)	15,000 mrem/yr		
Embyro/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:

27. What are the three principles designed to control radiation exposure ?
    1.____
    2. ____
    3. ____

28. What are the radiation worker annual dose limits for the following:
    Whole body ____________________
    Eyes ____________________
    Skin ____________________
    Extremities ____________________

29. What is dose limit to the embryo/fetus for a declared prenatal?
    ____
    ____

10 As Low as Reasonably Achievable (ALARA)

ALARA is an acronym for *<u>A</u>s <u>L</u>ow <u>A</u>s <u>R</u>easonably <u>A</u>chievable*. 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?

Simply stated, ALARA is a radiation safety philosophy that seeks to keep doses to radiation workers as low as can be reasonably achieved.

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.

Your facility 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 activities.

ALARA is achieved through both administrative and practical controls.

10.2 Responsibilities for the ALARA Program

Radiation Safety Officer

ALARA is the responsibility of all employees.

The Radiation Safety Officer (RSO) is responsible for implementing the ALARA program. They are also responsible for implementing the requirements for the entire radiological safety program.

The RSO provides a point of contact for the worker to obtain the most current radiological assessment of an experiment. They provide assistance when trying to interpret protective requirements or radiological information concerning an experiment work assignment and they address radiological questions or concerns. The RSO measures radioactivity, designates radiological areas, and ensures that their facility complies with rules and requirements for radiological safety.

10.3 Personnel Responsibilities for the ALARA Program

Radiological workers

ALARA is your responsibility.

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 in the biomedical field is usually is only a small percentage of the dose limits listed in Table 15. 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.

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

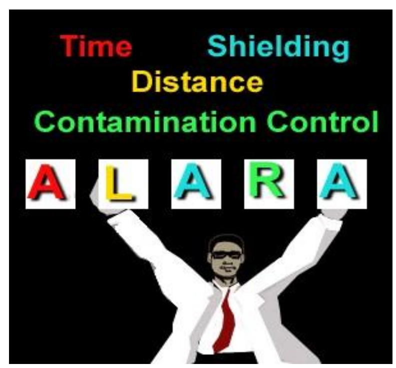
Personnel must:

- 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 the Radiation Safety Officer.
- 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:

30. ALARA applies to (check all that apply):

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

31. Radiation Safety philosophy is designed to keep radiation doses well below regulatory limits and that there is no occupational radiation dose without ___________________.

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

    ____

33. 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 Internal Radiation Protection

Radionuclides should NEVER come in contact with skin and you should never ingest or inhale radionuclides

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

Radiation is energy. Contamination is a material.

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.

Preventative 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 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.
- Label containers of radioactive material.

Figure 16 Wash your hands.

- Ensure that the ventilation system is properly functioning. Ventilation is designed to maintain airflow from areas of least contamination to areas of most contamination (e.g., 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.

11.2 Personal Protective Equipment (PPE)

Personnel Protection Equipment (PPE) is required when handling radioactive material to prevent contamination of personnel 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

The following policy must be adhered to by radioisotope principal investigators and users.

Radiation is energy. Contamination is a material.

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).

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.

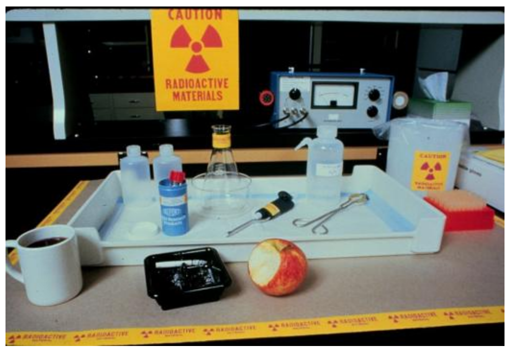


Figure 17 Some of the biggest mistakes in radiation safety.

Study Questions:

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

35. 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.

36. 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

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

38. Protective clothing must be ____________________ prior to use.

39. 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 fumehood when required by procedure.
    - ☐ Receiving a medical x-ray.
    - ☐ Working with radioactive materials that can be absorbed through the skin without protective equipment.

12 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

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

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?

$$ID^2 = id^2$$

$$30\ mR/hr \times (8\ in)^2 = i \times (2\ in)^2$$

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

$$i = 480\ mR/hr$$

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 13 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 materials (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.

- 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.

Figure 18 Use of Plexiglas shielding.

- 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

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

41. List three methods to reduce the amount of time spent in a radiation area.
    1. ____
    ____
    2. ____
    ____
    3. ____
    ____

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

43. 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)

13 Radiation Use Permits

Radioactive materials and radiation producing machines are used in a variety of research laboratories. Your facility is granted a license by the State of California, Department of Health Services to posses radioactive material.

13.1 Radiation Safety Officer

The Radiation Safety Officer (RSO), appointed by the chancellor, 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 *Radiation Safety Manual*, each individual RUA, lab postings, training session and personal communication. The *Radiation Safety Manual*, contains an in-depth presentation of the organization and requirements of the radiation safety program. You are strongly encouraged to become familiar with its contents.

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

13.2 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
- Special dose or contamination reduction considerations
- Date of issue and expiration
- Authorizing signatures
- Bioassay requirements
- Contamination monitoring requirements

13.3 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 license requirements.
4. Wear assigned personnel monitoring devices in an approved manner.
5. Comply with all sections of the Radiation Safety Manual applicable to their work.
6. Describe the nature 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 laboratory supervisor 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

44. 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

45. 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

14 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.

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

Figure 19 Radioactive Material Label

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 or non-radioactive materials with "Radioactive" stickers or labels is prohibited.

14.1 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 that use radioactive materials above a certain quantity are labeled "Caution Radioactive Materials" on the entry doors.

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

14.2 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 14 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 to abnormal situations 3) No eating, drinking, chewing or use of tobacco in the area	No – Restricted Area

Study Questions:

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

47. 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.

15 Radiation Survey Meters

There are several types of portable radiation survey instruments. 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 meters in your laboratory. During your on-the-job training, you will learn how to operate the instruments in your lab. You should know their capabilities and limitations and be able to interpret the meter readings.

15.1 Geiger-Mueller Detector

The Geiger-Mueller (G-M) counter is the most common radiation detection instrument. 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 "Pancake" Detector

Handle the G-M counter carefully to prevent damaging the thin window.

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 counter.

15.2 NaI Scintillation Detector

Scintillation detectors which incorporate a sodium iodide (NaI) crystal are used in some laboratories for the detection of low energy gamma emitters such as I-125. Some survey meters allow the use of either a G-M detector or a scintillation detector. 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.

15.3 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.

15.4 Calibration

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

15.5 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 at 1 cm from a point source are given in Table 15

If the efficiency of an 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

Table 15 G-M "Panckake" Efficiencies

Isotope	% Efficiency
^{3}H	Not Detectable
^{14}C*	1%
^{35}S*	2%
^{33}P*	12%
^{32}P	32%
^{125}I	0.05%

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

Example: Your G-M counter reads 5000 cpm at one inch from a small spot of P-33 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

48. 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) ____________ uCi

16 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

Whole Body Exposure Monitors

The dosimeter used most often is the thermoluminescent dosimeter (TLD). TLDs contain a lithium fluoride chip that when exposed to ionization 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 away from any radiation sources. (Use the dosimeter rack if one is provided.) Be sure the badge is available for exchange, which is done on the first day of each quarter.

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 assure 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 dosimeters 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 radiological control personnel
- The dosimeter must be stored in a safe location away from radiation sources when not in use. In each lab there is a special rack on which 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.
- Return dosimeters for processing periodically.
- The loss of a dosimeter should be reported to the RSO as soon as the loss is noticed. Working in a radiation area without a dosimeter is a violation of federal, state, regulations.

Distribution and Use of Badges

Dosimetry badges are issued based on the experimental protocols used and the type and amount of radioactivity used in the lab. Please contact the RSO for dosimetry needs.

Badges are exchanged quarterly. Return all radiation dosimeters promptly at the end of the quarterly rotation period so they may be processed. When you terminate your work assignment involving radiation, please return your dosimeter(s) to the "dosimeter contact person" for your group or to the RSO on the last day of your employment.

16.3 Internal Monitoring

A bioassay 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 glad and measuring the activity.

Bioassays for other types of radioisotopes involve a urinalysis. For this type of test a urine sample is submitted to 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 measures and records your occupational radiation exposure. The dosimetry reporting company, an independent contractor, will report exposures per individual. Should your quarterly body dosimeter exceed 125 mrem or your ring exceed 1,250 mrem you will be notified and an investigation into the cause will be initiated

All dosimetry records are on file with the Radiation Safety Officer. Upon your request, they will supply you with your dosimetry history. Each year, you will receive an annual written summary of your radiation exposure even if your exposure has been zero for the entire year. Terminating personnel can request a report of the radiation dose received at that facility. 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 your employer are required by law to report to the California Department of Health Services (DHS) any personnel dosimeter, which shows a dose higher than the federal occupational dose limits. It is a violation of the California 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 DHS that the individual did not actually receive the dose.

Study Questions

49. The purpose of external dosimetry 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

50. 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.

51. Internal monitoring provides detection of the following:
    - ☐ natural sources - food, soil, etc.
    - ☐ man-made sources – medical
    - ☐ occupational sources
    - ☐ non-ionizing sources

52. (T/F) Dose reports are provided on an annual basis.

53. Workers may get their current dose record via:
    - A) asking their supervisor
    - B) going to an physician practicing in occupational medicine
    - C) written request to the Radiation Safety Officer
    - D) written request to department

54. (T/F) Radiological workers must notify the Radiation Safety Officer after a dose is received at another site.

17 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 RSO as soon as possible of any accident involving ionizing radiation. This includes, but is not limited to, accidental direct radiation exposure, or contamination of laboratory personnel, and 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 Radiation Safety Officer should be notified as soon as possible, however, the emergency may demand other immediate action be taken by those on the scene 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 contact the RSO. A health physicist and an occupational medicine physician should collaborate in developing a suitable bioassay procedure to determine the extent of your exposure and whether any special corrective measures are needed.

17.1 Personnel Contamination and Exposure

First aid treatment is much higher priority than decontamination

1. First and foremost, determine the need to administer first aid to any injured personnel and administer it as needed. If a medical emergency exist activate 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 counter in cases where 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 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 ^{125}I, >1 mCi of other radionuclides)

For large spills the minimum response is as follows:

You can remember this as SWIM

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 the RSO 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 ^{125}I, ≤1 mCi of other radionuclides)

Spills of radioactive materials can happen at any time. Minor contamination, 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 RSO for assistance.

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 box.
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 RSO.
10. Inform the laboratory PI and the Radiation Safety Officer within 24 hours.

Study Questions

55. Define the letters in the following acronym:

    S ________________________________

    W ________________________________

    I ________________________________

    M ________________________________

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

57. Personnel decontamination is normally accomplished by:

    A) Scrubbing with a wire brush.

    B) Acidic based chemicals.

    C) Mild soap and tepid water.

    D) Mild soap and hot water.

18 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.

A

Radiological Signs

Figure A-1 Examples of some of the types of common radiological signs

B Answers to Study Questions

1. Protons, neutrons, electrons
2. Removing, ionization
3. Unstable
4. C) Five
5. Non-ionizing, ionize
6.

Table 16 Curie Subunits

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

Table 17 Becquerel Subunits

Unit	Abbr.	dps	dpm
becquerel	Bq	1	60
kilobecquerel	kBq	$1 x 10^{3}$	$6 x 10^{4}$
megabecquerel	MBq	$1 x 10^{6}$	$6 x 10^{7}$

7. Roentgen
8. Rad or Gray
9. A) (3.7×10^4 dis/sec) x (60sec/minute) = 2.22×10^6 dpm
10. Alpha, beta, gamma, X, neutron
11.

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	hundreds of feet	hundreds of feet
Shielding	paper, outer layer of skin	Plastics, wood, glass	lead, concrete, iron	water, polyethylene concrete
Hazard	internal	Skin, eye, or internal	external / internal	external / internal

12. 70 %

13. Cosmic, Terrestrial, Radon, Internal

14.

	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
	Rounded Total	**360**

15. Ionization

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

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

18. Chronic

19. Acute

20. Somatic

21. Heritable

22. Small head size, Mental retardation, and childhood cancer

23. D) All of the above

24. B) Carcinogenesis

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

26. D) Yours- the radiation workers

27. 1) justification 2) optimization (ALARA) 3) dose-limitation.

28. 5000 mrem/yr., 15,000 rem/yr., 50,000 rem/yr., 50,000 rem/yr.

29. 500 mrem/gestation

30. ☑ Radiation exposures
    ☑ Contamination exposures
    ☑ Asbestos exposures
    ☑ Chemical exposures

31. Justification or benefit

32. The Radiation Safety Officer (RSO)

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

34. Contamination

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

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

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

38. Inspected

39. ☑ 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.

40. Time, distance and shielding.

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

42. 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

43. 5 HVL or 4.0 cm of lead

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

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

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

47. **a.** Radiation Area
    b. Radioactive Materials Area

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

49. C) Measure dose from occupational radiation

50. D) All of the above.

51. ☑ Natural sources - food, soil, etc.
    ☑ Occupational sources

52. True

53. C) Written request to the Radiation Safety Officer

54. True

55. **S** **S**top or secure the operation causing the spill
    W **W**arn others in the area, notify the RSO
    I **I**solate the spill area if possible
    M **M**inimize individual exposure and contamination

56. Stop the spill and Warn others in the area, including notifying the RSO

57. C) Mild soap and tepid water.

^{14}C Nuclide Safety Data Sheet Carbon-14 ^{14}C

I. PHYSICAL DATA

Radiation:	Beta (100% abundance)	
Energy:	Max.: 156 keV; Average: 49 keV	
Half-Life [$T_{½}$] :	Physical $T_{½}$:	5730 years
	Biological $T_{½}$:	12 days
	Effective $T_{½}$:	Bound - 12 days; unbound - 40 days
Specific Activity:	4.46 Ci/g [0.165 TBq/g] max.	
Beta Range:	Air:	24 cm [10 inches]
	Water/Tissue:	0.28 mm [0.012 inches]
	[~1% of ^{14}C betas transmitted through dead skin layer, i.e. 0.007 cm depth]	
	Plastic:	0.25 mm [0.010 inches]

II. RADIOLOGICAL DATA

Radiotoxicity[1]:	6.36E-12 Sv/Bq [0.023 mrem/μCi] of $^{14}CO_2$ inhaled;
	5.64E-10 Sv/Bq [2.09 mrem/μCi] organic compounds inhaled/ingested
Critical Organ:	Fat tissue [most labeled compounds]; bone [some labeled carbonates]
Exposure Routes:	Ingestion, inhalation, puncture, wound, skin contamination absorption
Radiological Hazard:	External Exposure - None from weak ^{14}C beta
	Internal Exposure & Contamination - Primary concern

III. SHIELDING

None required - mCi quantities not an external radiation hazard

IV. DOSIMETRY MONITORING

Urine bioassay is the most readily available method to assess intake [for ^{14}C, no intake = no dose]
Consider performing a urinalysis after any accident/incident in which an intake is suspected.

V. DETECTION & MEASUREMENT

Portable Survey Meters:	Geiger-Mueller [e.g. Bicron PGM, ~10% efficiency];
	Beta Scintillator [e.g. Ludlum 44-21, ~5% efficiency]

Wipe Test: Liquid Scintillation Counting is the best readily available method for counting ^{14}C wipe tests

VI. SPECIAL PRECAUTIONS

- Avoid skin contamination [absorption], ingestion, inhalation, & injection [all routes of intake]
- Many ^{14}C compounds readily penetrate gloves and skin; handle such compounds remotely and wear double gloves, changing the outer pair at least every 20 minutes.

[1] Federal Guidance Report No. 11 [Oak Ridge, TN; Oak Ridge National Laboratory, 1988], p. 122, 156

^{3}H Nuclide Safety Data Sheet Hydrogen-3 [Tritium] ^{3}H

I. PHYSICAL DATA

Radiation:	Beta (100% abundance)	
Energy:	Max.: 18.6 keV; Average: 5.7 keV	
Half-Life [$T_{½}$] :	Physical $T_{½}$:	12.3 years
	Biological $T_{½}$:	10 - 12 days
	Effective $T_{½}$:	10 - 12 days*

* Large liquid intake (3-4 liters/day) reduces effective $T_{½}$ by a factor of 2+; ^{3}H is easily flushed from the body

Specific Activity:	9650 Ci/g [357 TBq/g] max.	
Beta Range:	Air:	6 mm [0.6 cm; 0.25 inches]
	Water:	0.006 mm [0.0006 cm; 3/10,000 inches]
	Solids/Tissue:	insignificant [No ^{3}H betas pass through the dead layer of skin]

II. RADIOLOGICAL DATA

Radiotoxicity[2]: Least radiotoxic of all nuclides; CEDE, ingestion or inhalation:
Tritiated water: 1.73E-11 Sv/Bq (0.064 mrem/µCi) of ^{3}H intake
Organic Compounds: 4.2E-11 Sv/Bq (0.16 mrem/µCi) of ^{3}H intake

Critical Organ: Body water or tissue

Exposure Routes: ingestion, inhalation, puncture, wound, skin contamination absorption

Radiological Hazard: External Exposure - None from weak ^{3}H beta
Internal Exposure & Contamination - Primary concern

III. SHIELDING

None required - not an external radiation hazard

IV. DOSIMETRY MONITORING

Urine bioassay is the only readily available method to assess intake [for tritium, no intake = no dose]
Be sure to provide a urine sample to Radiation Safety whenever your monthly ^{3}H use exceeds 100 mCi, or after any accident/incident in which an intake is suspected

V. DETECTION & MEASUREMENT

Liquid Scintillation Counting is the only readily available method for detecting ^{3}H
NOTE: PORTABLE SURVEY METERS WILL NOT DETECT LABORATORY QUANTITIES OF ^{3}H

VI. SPECIAL PRECAUTIONS

- Avoid skin contamination [absorption], ingestion, inhalation, & injection [all routes of intake]
  - *Many tritium compounds readily penetrate gloves and skin; handle such compounds remotely and wear double gloves, changing the outer pair at least every 20 minutes.*
- While tritiated DNA precursors are considered more toxic that $^{3}H_2O$, they are generally less volatile and hence do not normally present a greater hazard
- The inability of direct-reading instruments to detect tritium and the slight permeability of most material to [tritiated] water & hydrogen [tritium] facilitates undetected spread of contamination. Use extreme care in handling and storage [e.g. sealed double or multiple containment] to avoid contamination, especially with high specific activity compounds.

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[2] Federal Guidance Report No. 11 [Oak Ridge, TN; Oak Ridge National Laboratory, 1988], p. 122, 156; Radionuclide and Radiation Protection Data Handbook [Delacroix, et al; Radiation Protection Dosimetry, Kent, England: Nuclear Technology Publishing 1998], p. 19.

^{125}I Nuclide Safety Data Sheet Iodine-125 ^{125}I

I. PHYSICAL DATA

Radiation:	Gamma - 35.5 keV (7% abundance)	
	X-ray - 27 keV (113% abundance)	
Gamma Constant:	0.27 mR/hr per mCi @ 1.0 meter [7.432E-5 mSv/hr per MBq @ 1.0 meter][3]	
Half-Life [$T_{½}$] :	Physical $T_{½}$:	60.14 days
	Biological $T_{½}$:	120-138 days (unbound iodine)
	Effective $T_{½}$:	42 days (unbound iodine)
Specific Activity:	1.73E4 Ci/g [642 TBq/g] max.	

II. RADIOLOGICAL DATA

Radiotoxicity[4]:	3.44E-7 Sv/Bq (1273 mrem/µCi) of ^{125}I ingested [Thyroid]
	2.16 E-7 Sv/Bq (799 mrem/µCi) of ^{125}I inhaled [Thyroid]
Critical Organ:	Thyroid Gland
Intake Routes:	Ingestion, inhalation, puncture, wound, skin contamination (absorption);
Radiological Hazard:	External & Internal Exposure; Contamination

III. SHIELDING

	Half Value Layer [HVL]	Tenth Value Layer [TVL]
Lead [Pb]	0.02 mm (0.0008 inches)	0.07 mm (0.003 inches)

- The accessible dose rate should be background but must be < 2 mR/hr

IV. DOSIMETRY MONITORING

- Always wear radiation dosimetry monitoring badges [body & ring] whenever handling ^{125}I
- Conduct a baseline thyroid scan prior to first use of radioactive iodine
- Conduct thyroid bioassay measurement [at neck just above collar bone] no earlier than 6 hours but within 72 hours of handling 1 mCi or more of ^{125}I or after any suspected intake

V. DETECTION & MEASUREMENT

Portable Survey Meters:

Geiger-Mueller [e.g. Bicron PGM,] to assess shielding effectiveness

Low Energy Gamma Detector [e.g. Ludlum 44-21, ~19% eff. for ^{125}I] for contamination surveys

Wipe Test: Liquid Scintillation Counter

VI. SPECIAL PRECAUTIONS

- Avoid skin contamination [absorption], ingestion, inhalation, & injection [all routes of intake]
- Use shielding [lead or leaded Plexiglas] to minimize exposure while handling mCi quantities of ^{125}I
- Avoid making low pH [acidic] solutions containing ^{125}I to avoid volatilization
- For Iodinations:
  - Use a cannula adapter needle to vent stock vials of ^{125}I used; this prevents puff releases
  - Cover test tubes used to count or separate fractions from iodinations with parafilm or other tight caps to prevent release while counting or moving outside the fume hood.

[3] Health Physics & Radiological Health Handbook, 3rd Ed. [Baltimore, MD; Williams & Wilkins, 1998], p. 6-11
[4] Federal Guidance Report No. 11 [Oak Ridge, TN; Oak Ridge National Laboratory, 1988], p. 136, 166

^{32}P Nuclide Safety Data Sheet Phosphorous-32 ^{32}P

I. PHYSICAL DATA

Radiation:	Beta (100% abundance)	
Energy:	Maximum: 1,710 keV; Average: 695 keV	
Half-Life [$T_{½}$] :	Physical $T_{½}$:	14.29 days
	Biological $T_{½}$:	Bone ~ 1155 days; Whole Body ~ 257 days[5]
	Effective $T_{½}$:	14.29 days
Specific Activity:	286,500 Ci/g [10,600 TBq/g] max.	
Beta Range:	Air:	610 cm [240 inches; 20 feet]
	Water/Tissue:	0.76 cm [0.33 inches]
	Plastic:	0.61 mm [3/8 inches]

II. RADIOLOGICAL DATA

Radiotoxicity[6]: Inhaled: 2.6E-8 Sv/Bq [95 mrem/µCi] Lung; 4.2E-9 Sv/Bq [16 mrem/µCi] CEDE
Ingested: 8.1E-9 Sv/Bq [30 mrem/µCi] Marrow; 2.4E-9 Sv/Bq [8.8 mrem/µCi] CEDE

Critical Organ: Bone [soluble ^{32}P]; Lung [Inhalation]; GI Tract [Ingestion - insoluble compounds]

Exposure Routes: Ingestion, inhalation, puncture, wound, skin contamination absorption

Radiological Hazard: External Exposure [unshielded dose rate at 1 mCi ^{32}P vial mouth[7]: approx. 26 rem/hr], Internal Exposure & Contamination

III. SHIELDING

Shield ^{32}P with 3/8 inch Plexiglas and monitor for Bremstrahlung; If Bremstrahlung X-rays detected outside Plexiglas, apply 1/8 to 1/4 inch lead [Pb] shielding outside Plexiglas
The accessible dose rate should be background but must be < 2 mR/hr

IV. DOSIMETRY MONITORING

Always wear radiation dosimetry monitoring badges [body & ring] whenever handling ^{32}P

V. DETECTION & MEASUREMENT

Portable Survey Meters: Geiger-Mueller [e.g. Bicron PGM];
Beta Scintillator [e.g. Ludlum 44-21]

Wipe Test: Liquid Scintillation Counting is an acceptable method for counting ^{32}P wipe tests

VI. SPECIAL PRECAUTIONS

- Avoid skin contamination [absorption], ingestion, inhalation, & injection [all routes of intake].
- Store ^{32}P (including waste) behind Plexiglas shielding [3/8 inch thick]; survey (with GM meter) to check adequacy of shielding (accessible dose rate < 2 mR/hr; should be background); apply lead [Pb] shielding outside Plexiglas if needed.
- Use 3/8 inch Plexiglas shielding to minimize exposure while handling ^{32}P.
- Use tools [e.g. Beta Blocks] to handle ^{32}P sources and contaminated objects; avoid direct hand contact.
- Always have a portable survey meter present and turned on when handling ^{32}P.
- ^{32}P is not volatile, even when heated, and can be ignored as an airborne contaminant[8] unless aerosolized.
- White vinegar can be an effective decontamination solvent for this nuclide in most forms.

[5] NCRP Report No. 65, p.88
[6] Federal Guidance Report No. 11 [Oak Ridge, TN; Oak Ridge National Laboratory, 1988], p. 122, 156
[7] Dupont/NEN, Phosphorous-32 Handling Precautions [Boston, MA; NEN Products, 1985]
[8] Bevelacqua, J. Contemporary Health Physics [New York; John Wiley & Sons, 1995], p. 282

^{35}S Nuclide Safety Data Sheet Sulfur-35 ^{35}S

I. PHYSICAL DATA

Radiation:	Beta (100% abundance)	
Energy:	Maximum: 167.47 keV; Average: 48.8 keV	
Half-Life [$T_{½}$] :	Physical $T_{½}$:	87.44 days
	Biological $T_{½}$:	623 days [unbound ^{35}S]; 90 days [bound ^{35}S]
	Effective $T_{½}$:	44 - 76 days [unbound ^{35}S]
Specific Activity:	42,707 Ci/g [1,580 TBq/g] max.	
Beta Range:	Air:	26 cm [10.2 inches]
	Water/Tissue:	0.32 mm [0.015 inches]
	Plastic:	0.25 mm [0.010 inches]

II. RADIOLOGICAL DATA

Radiotoxicity[9]:	2.48 mrem/µCi [CEDE] of ^{35}S inhaled 0.733 mrem/µCi of ^{35}S ingested
Critical Organ:	Testis
Exposure Routes:	Ingestion, inhalation, puncture, wound, skin contamination absorption
Radiological Hazard:	External Exposure - None from weak ^{35}S beta Internal Exposure & Contamination - Primary concern

III. SHIELDING

None required - mCi quantities not an external radiation hazard

IV. DOSIMETRY MONITORING

Urine bioassay is the most readily available method to assess intake [for ^{35}S, no intake = no dose]
Provide a urine sample to Radiation Safety whenever your monthly ^{35}S use exceeds 5 mCi, or after any accident/incident in which an intake is suspected

V. DETECTION & MEASUREMENT

Portable Survey Meters: Geiger-Mueller [e.g. Bicron PGM, ~10% efficiency]
Beta Scintillator [e.g. Ludlum 44-21, ~5% efficiency]

Wipe Test: Liquid Scintillation Counting is the best readily available method for counting ^{35}S wipe tests

VI. SPECIAL PRECAUTIONS

- Avoid skin contamination [absorption], ingestion, inhalation, & injection [all routes of intake]
- Many ^{35}S compounds and metabolites are slightly volatile and may create contamination problems if not sealed or otherwise controlled. This occurs particularly when ^{35}S amino acids are thawed, and when they are added to cell culture media and incubated. Therefore vent thawing ^{35}S vials in a hood by inserting the needle of a charcoal packed syringe through the septum seal, and vent incubated ^{35}S-labelled tissue culture through charcoal-impregnated filter paper.

9 Federal Guidance Report No. 11 [Oak Ridge, TN; Oak Ridge National Laboratory, 1988], p. 122, 156

Radionuclide Precautions and Practices

VII. GENERAL PRECAUTIONS

1. Maintain your occupational exposure to radiation As Low As Reasonably Achievable [ALARA].
2. Ensure all persons handling radioactive material are trained, registered, & listed on an approved protocol.
3. Review the nuclide characteristics on (reverse side) prior to working with that nuclide. Review the protocol(s) authorizing the procedure to be performed and follow any additional precautions in the protocol. Contact the responsible Principal Investigator to view the protocol information.
4. Plan experiments to minimize external exposure by reducing exposure time, using shielding and increasing your distance from the radiation source. Reduce internal and external radiation dose by monitoring the worker and the work area after each use of radioactive material, then promptly cleaning up any contamination discovered. Use the smallest amount of radioisotope possible so as to minimize radiation dose and radioactive waste.
5. Keep an accurate inventory of radioactive material, including records of all receipts, transfers & disposal. Perform and record regular lab surveys.
6. Provide for safe disposal of radioactive waste by following Waste Handling & Disposal Procedures. Avoid generating mixed waste (combinations of radioactive, biological, and chemical waste). Note that lab staff may not pour measurable quantities of radioactive material down the drain.
7. If there is a question regarding any aspect of the radiation safety program or radioactive material use, contact Radiation Safety.

VIII. LAB PRACTICES

1. Disposable gloves, lab coats, and safety glasses are the minimum PPE [Personal Protective Equipment] required when handling radioactive material. Remove & discard potentially contaminated PPE prior to leaving the area where radioactive material is used.
2. Clearly outline radioactive material use areas with tape bearing the legend "radioactive". Cover lab bench tops where radioactive material will be handled with plastic-backed absorbent paper; change this covering periodically and whenever it's contaminated. Alternatively cover benches with thick plastic sheeting (i.e., painter's drop cloth), periodically wipe it clean and replace it if torn.
3. Label each unattended radioactive material container with the radioactive symbol, isotope, activity, and, except for waste, the ICN [inventory control number]. Place containers too small for such labels in larger labeled containers.
4. Handle radioactive solutions in trays large enough to contain the material in the event of a spill.
5. Never eat, drink, smoke, handle contact lenses, apply cosmetics, or take/apply medicine in the lab; keep food, drinks, cosmetics, etc. out of the lab entirely. Do not pipette by mouth.
6. Never store [human] food and beverage in refrigerators/freezers used for storing radioisotopes.
7. Prevent skin contact with skin-absorbable solvents containing radioactive material.
8. Fume hoods and biological safety cabinets for use with non-airborne radioactive material must be approved (through the protocol) and must be labeled "Caution Radioactive Material".
9. All volatile, gaseous, or aerosolized radioactive material must be used only in a properly operating charcoal and/or HEPA filtered fume hood or Biological Safety Cabinet bearing a Caution Airborne Radioactivity hood label, unless otherwise specified in writing by the Radiation Safety Officer. In particular, radioactive iodination must be performed only in these specially designed fume hoods. The Radiation Safety Officer (through a protocol) must approve all such use.
10. Take special precautions when working with radioactive compounds that tend to become volatile [e.g. ^{35}S labeled amino acids, ^{125}I - iodine tends to volatilize in acidic solutions]. These precautions may include: using the materials only within an approved fume hood, protecting the house vacuum system with primary and secondary vapor trapping devices, and covering active cell cultures with carbon-impregnating paper.
11. Use sealed containers and appropriate secondary containment to carry radioactive material between rooms Notify Radiation Safety staff before taking any radioactive material off site.