



The **U**niversity of South Dakota.

# **RADIATION SAFETY MANUAL**

Revised 2011

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## Radiation Safety Policy

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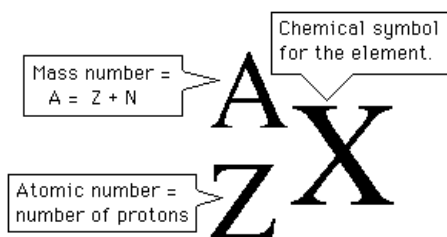
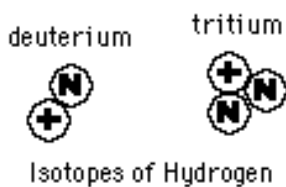
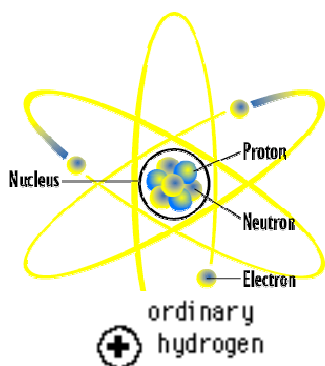
# RADIATION SAFETY MANUAL

## Introduction

The University of South Dakota has a license issued by the US Nuclear Regulatory Commission (NRC). The license authorizes faculty, staff and students to use radioactive materials in research and teaching. The NRC license number is 40-02331-19. It is a Type B license of broad scope. The license authorization does not include the use of radioactive materials in patients or human subjects. Persons working with radiation and radioactive materials should have access to a copy of this manual and use it as a reference.

Use of radioactive materials requires compliance with NRC and University policies. Faculty members become authorized to use these materials by completing appropriate forms and having their proposed use reviewed by the RSO. Persons working with radioactive material and radiation must receive training appropriate to their use and be approved by the RSO. The RSO will present a short training class covering radioactivity, radiation hazards, good laboratory practices, emergency procedures and worker responsibilities. Training will be documented by the worker completing a short quiz and returning it to the RSO.

The intent of this policy is to provide the information necessary to fully comply with NRC rules and regulations. If you have any questions about radiation safety or are thinking of using radioactive material or other radiation sources not discussed in this policy, please call the USD Radiation Safety Officer (RSO) at 677-6265. If you have an after-hours emergency, call USD Public Security at 677-5342 and state that you have a radiation emergency.



## A. Radiation and Radioactivity

The atom can be thought of as a system containing a positively charged nucleus and negatively charged electrons which are in orbit around the nucleus.

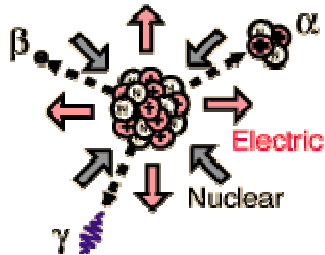
The **nucleus** is the central core of the atom and is composed of two kinds of particles: **protons** which are positively charged and **neutrons** which have a neutral charge. The neutrons are the “glue” which keeps the positively charged protons separated and prevents the nucleus from breaking apart from these charges.

**Electrons** surround the nucleus in orbitals of various energies. The farther an electron is from the nucleus, the less energy is required to free it from the atom.

A **nuclide** is an atom described by its **atomic number** ( $Z$ ) and its **mass number** ( $A$ ). The  $Z$  number is equal to the charge (number of protons) in the nucleus, which is a characteristic of the element. The  $A$  number is equal to the total number of protons and neutrons in the nucleus.

Nuclides with the same number of protons but with different numbers of neutrons are called **isotopes**. For example, deuterium ( ${}^2_1\text{H}$ ) and tritium ( ${}^3_1\text{H}$ ) are isotopes of hydrogen with mass numbers two and three, respectively. There are about 400 stable nuclides and over 1100 unstable (i.e., radioactive) nuclides. However, only about 10 or 15 radioactive nuclides are routinely used in research. Nuclides are radioactive primarily because of the number of neutrons in the nucleus is

either too few (i.e., too many protons) or too many (i.e., there is too much mass in the nucleus relative to the positive charge).

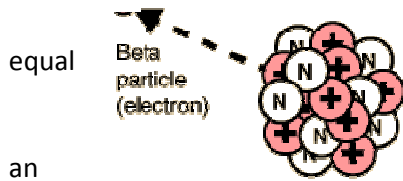
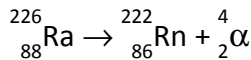


### Radioactive Decay

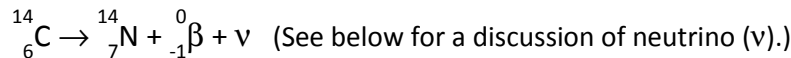
Radioactive nuclides (also called *radionuclides* or *radioisotopes*) can regain stability by nuclear transformation (i.e., *radioactive decay*) emitting radiation in the process. The radiation emitted can be particulate or electromagnetic or both. The various types of radiation and examples of decay are discussed below.



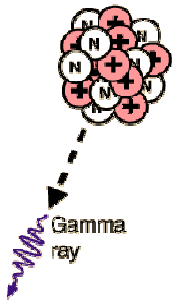
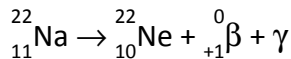
**Alpha (α) particles** have a mass and charge equal to those of helium nuclei (2 protons + 2 neutrons). Alpha particles are emitted from the nucleus during the decay of some very heavy nuclides ( $Z > 83$ ) which have an overabundance of protons. The decay increases the ratio of neutrons to protons.



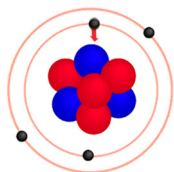
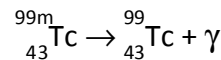
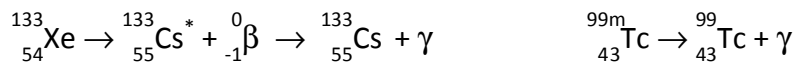
**Beta (β<sup>-</sup>, β<sup>+</sup>) particles** are emitted from the nucleus and have a mass equal to that of electrons. Betas can have either a negative charge or a positive charge. Negatively charged betas are equivalent to electrons and are emitted during the decay of nuclides which have an excess of neutrons.



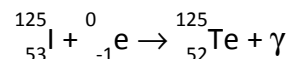
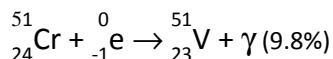
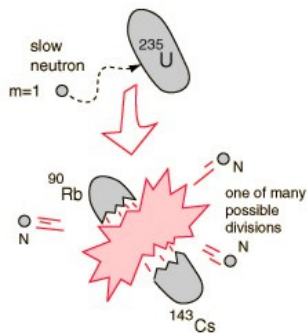
Positively charged beta particles (positrons, β<sup>+</sup>) are emitted during the decay of nuclides which have an excess of protons (i.e., neutron deficient) nuclides.



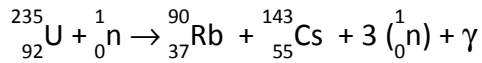
**Gammas (γ) or gamma rays** are electromagnetic radiation (photons) that are emitted from an excited (Y<sup>\*</sup>) or metastable nucleus that came about because the other modes of decay (e.g., α, β<sup>-</sup>, β<sup>+</sup>) failed to remove all the excess energy of the nucleus. The gamma is then emitted as an energy level transition within the nucleus. An “excited” nucleus usually emits the gamma within 10<sup>-12</sup> seconds of the particle emission.



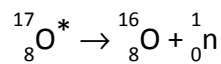
**Electron Capture (ε or EC).** In certain neutron deficient nuclides which do not have enough energy for β<sup>+</sup> decay, the nucleus will “capture” an orbital electron resulting in conversion of a proton into a neutron. This type of decay may also involve gamma emission as well as characteristic x-ray emission(see below) as other orbital electrons fall into the inner orbital energy level vacated by the captured electrons.



**Fission** is the splitting of an atomic nucleus into two smaller nuclei and usually two or three neutrons. The fission process also releases a large amount of energy in the form of gamma rays and kinetic energy of the fission fragments and neutrons. Fission is possible for a few, very heavy, naturally occurring radionuclides (e.g.,  $^{235}_{92}\text{U}$ ,  $^{238}_{92}\text{U}$ , etc.) and may occur spontaneously or after the absorption of an energetic particle.



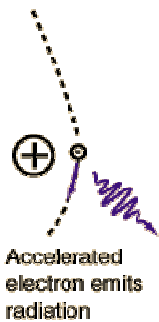
**Neutrons.** For a few, heavy radionuclides, a neutron may be emitted spontaneously. Sometimes the decay of artificially produced nuclides results in the emission of neutrons.



**X-rays.** There are two kinds of x-rays, characteristic x-rays and Bremsstrahlung x-rays.

**Characteristic** x-rays are electromagnetic radiation (i.e., photons) that is emitted during energy level transitions of orbital electrons (cf., electron capture). The energy of the x-ray is equivalent to the difference between the two shells (i.e., inner shell electrons, those nearer the nucleus require more energy to remove than outer shell electrons, so filling the vacated shell from a neighboring electron shell results in a discrete release of energy that is characteristic of the element)

**Bremsstrahlung** x-rays (i.e., braking radiation) are produced when energetic electrons or beta particles are decelerated as they travel close to a nucleus. This reaction predominates for high energy electrons and beta particles and heavy (e.g., lead) nuclei. If  $E_{\text{max}}$  is the energy of the beta particle and  $Z$  the atomic number of the absorber, then the fraction of bremsstrahlung photons produced is approximately:



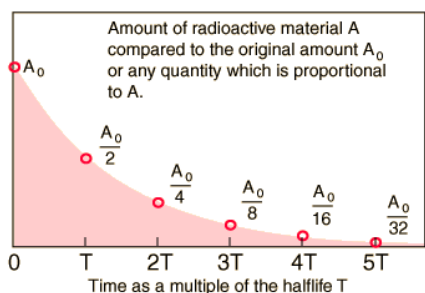
$$F = 3.5 \times 10^{-4} Z E_{\text{max}}$$

Bremsstrahlung must be considered when designing shielding for large quantities of high energy beta emitters such as P-32 and S-90.

### Characteristics of Radioactive Decay

In addition to the type of radiation emitted, the decay of a radionuclide can be described by the unique characteristics of half-life and energy.

The **half-life** of a radionuclide is the time required for one-half of the radioactive atoms of that nuclide to decay. Decay is a random process which follows an exponential curve. The number of radioactive nuclei remaining after time (t) is given by:



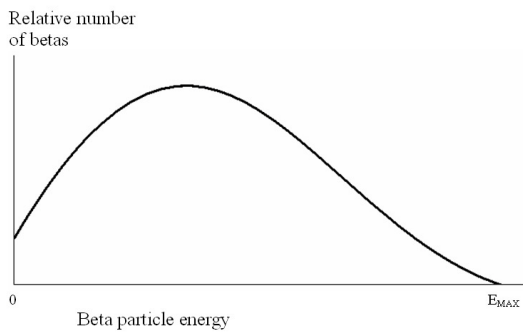
$$N_t = N_0 e^{-(0.693t/T)}$$

where  $N_0$  = original number of atoms  
 $N_t$  = number remaining at time  $t$   
 $t$  = decay time  
 $T$  = half-life

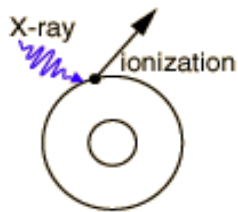
**Energy.** The basic unit used to describe the energy of an emitted particle or photon is the electron volt (eV). An electron volt is equal to the amount of energy gained by an electron passing through a potential difference of one volt and  $1 \text{ eV} = 1.602 \times 10^{-19} \text{ J}$ .

The energy of the radiation emitted is a characteristic of the radionuclide

Some radionuclides have more than one decay route. That is, there may be different possible energies that the emitted radiation may have, but there are only a few possibilities for each radionuclide.



A characteristic of beta decay is that when a beta particle is emitted, the energy is divided randomly between the beta particle and a neutrino ( $\nu$ ). A neutrino is a particle with no charge and infinitesimally small rest mass. Consequently, the beta particle may be emitted with an energy varying in a continuous spectrum from zero to a maximum energy ( $E_{\text{max}}$ ) which is characteristic of the radionuclide. The average energy carried away by the beta particle is usually about 30% to 40% percent of the maximum energy.



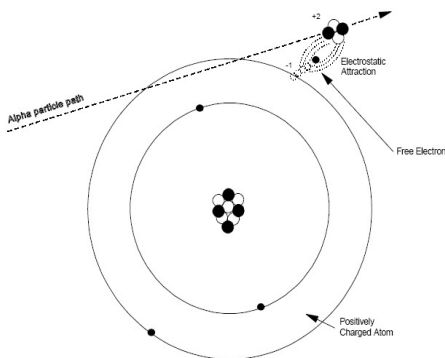
### Interactions of Radiation and Matter

There are several mechanisms involved in the transfer of energy from the radiation particle or photon to the absorbing medium. These mechanisms result in ionization and excitation of atoms or molecules in the absorber.

**Ionization** is the removal of an orbital electron from an atom or molecule, creating a positively charged ion. In order to produce ionization, the radiation must transfer enough energy to the electron to overcome the binding force on the electron. On average, it requires about 35 eV to produce each ion pair. Ionization in a molecule can also cause dissociation of the molecule.



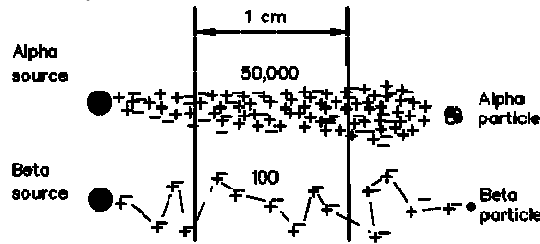
**Excitation** is the addition of energy to an orbital electron, thereby transferring the atom or molecule from the ground state to an excited state.



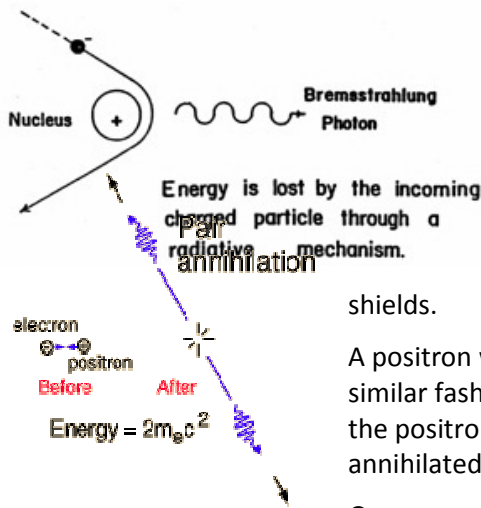
Alpha particle interaction is between the electric field of an alpha particle and an orbital electron in the absorber and can result in both ionization and excitation events. Because of their double charge and low velocity (due to their large mass), alpha particles lose their energy over a relatively short range. One alpha will cause tens of thousands of ionizations per centimeter in air. The range in air of

the most energetic alpha particles commonly emitted is only about 10 centimeters (4 inches). In denser materials, the range is much less. Alpha particles are easily stopped by a sheet of paper and can not penetrate the protective (dead) layer of the skin.

Beta particles are also charged particles and interact in a manner similar to alpha particles. However, because the beta particle has only a single charge and a much smaller mass than an alpha particle; the beta particle is emitted from the nucleus with a much higher velocity (i.e.,  $E = \frac{1}{2}mv^2$ ) and it normally



loses its energy in a large number of ionization and excitation events over a much longer range than that of an alpha particle of comparable energy. Because the mass of the beta particle is equal to the mass of an electron, after the interaction the beta particle can be scattered at any angle, so the beta particle exhibits many path changes as it passes through an absorbing medium.

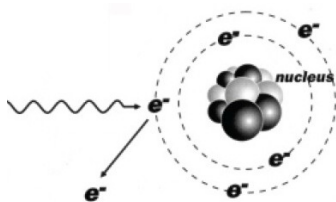


If a beta particle passes close to a nucleus, it is attracted to the large positive charge and will be diverted from its path, This change also produces a change in acceleration resulting in the emission of bremsstrahlung x-rays. The energy of the bremsstrahlung x-rays is a continuous spectrum up to the maximum kinetic energy of the betas. As noted above, the production of bremsstrahlung increases with the atomic number of the absorber and the energy of the beta.

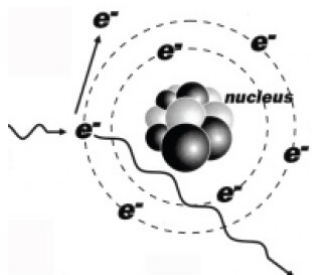
Therefore, low Z materials (e.g., Plexiglas) are used as beta shields.

A positron will lose its kinetic energy through ionizations and excitations in a similar fashion to a negative beta particle. However, when it slows down, the positron will combine with a free electron. The two particles are then annihilated, producing two photons called annihilation radiation.

Gammas and x-rays differ only in their origin, gamma-rays originate in the nucleus while x-rays are produced in the electron shell. Both are electromagnetic radiation and differ from radio waves and visible light by having much shorter wavelength. Gamma-rays and x-rays have zero rest mass and travel at the speed of light. They can be thought of as distortions in the electromagnetic field of space and interact electrically with atoms even though they have no net electrical charge. There are three ways which gamma rays and x-rays interact with atoms and lose energy.



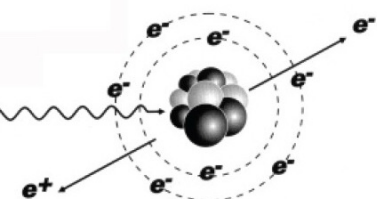
The **photoelectric effect** is an interaction in which the photon imparts all its energy to an orbital electron. The photon simply vanishes and the absorbing atom becomes ionized as an electron (i.e., the photoelectron) is ejected. This effect has the highest probability of occurring with low energy photons and high Z absorbers. For example, the k-shell electron energy level of iron ( $Z = 26$ ) is about 7 keV while that of lead ( $Z = 82$ ) is about 88 keV.



**Compton scattering** provides a means for partial absorption of photon energy by interaction with a "free" or loosely bound, outer shell electron. The electron is ejected, and the photon continues on to lose more energy in

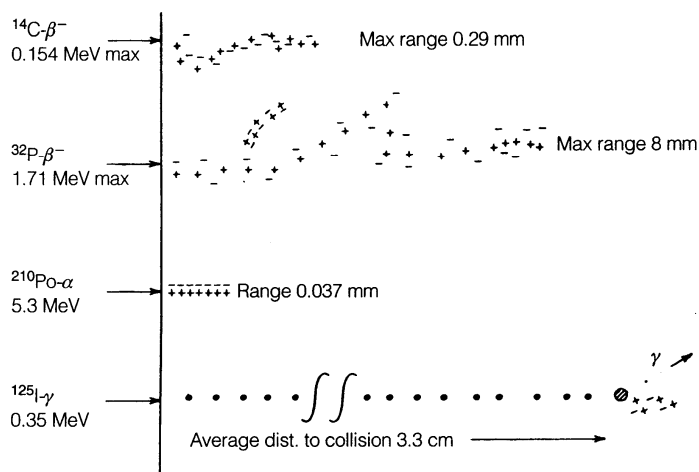
other interactions. With the Compton scattering interaction, the photons in the beam are scattered, so that radiation may appear around corners and in front of shields.

**Pair production** can occur only if the photon energy exceeds 1.02 MeV. In pair production the photon simply disappears in the electric field of a nucleus and in its place two electrons, a negatron and a



positron, are produced from the energy of the photon. The positron will eventually encounter a free electron in the absorbing medium and the two particles will annihilate each other converting their rest mass into energy. Two photons are produced and the ultimate fate of these two annihilation photons is to lose energy by Compton scattering or the photoelectric effect.

While alpha- and beta-particles have a finite maximum range and can therefore be completely stopped with a sufficient thickness of absorber, photons interact in a probabilistic manner. This means that an individual photon has no definite maximum range. However, the total fraction of photons passing through an absorber decreases exponentially with the thickness of the absorber. See Table 1, Range / Penetration of  $\beta$  Particles and  $\gamma$ -ray Shielding Consideration, below for thicknesses of lead or Plexiglas to reduce the photon exposure rate by a factor of 10 or to completely absorb the beta particle energy.



On average, it requires 34 eV (i.e., 25 – 45 eV) to produce each ion pair. A Po-210  $\alpha$ -particle with 5.3 MeV of energy will produce approximately 156,000 ion pairs. A P-32  $\beta$ -particle with the maximum energy of 1.71 MeV (max) will produce approximately 50,000 ion pairs.

Some of the electrons produced in these ionizing events are given sufficient kinetic energy to be capable of producing additional ionization and excitation events in the same way as beta particles. These energetic secondary electrons are called delta ( $\delta$ ) rays.

If the radiation does not deposit enough energy to cause ionization, an orbital electron may simply be excited. When the excited electron returns to its ground state, the atom emits low-energy radiation such as, UV [ $10^3$  eV], visible [10 eV], infrared [ $10^{-1}$  eV], or RF/microwave [ $10^{-8}$  eV].

Table 1. Range / Penetration of  $\beta$  Particles and  $\gamma$ -ray Shielding Considerations

Isotope	Symbol	Decay	Exposure (mR/hr) <sup>H</sup>	$\beta$ Particle Range (cm / in)		Thickness (mm) <sup>⊗</sup>	
				in Air	in Tissue	Lead	Plexiglas
Hydrogen-3 <sup>***</sup>	$^3\text{H}$	$^- \beta$	--	0.5 cm / 0.25"	0.0005 cm / 0.0003"	--	0.1 <sup>***</sup>
Carbon-14 <sup>***</sup>	$^{14}\text{C}$	$^- \beta$	--	25.4 cm / 10"	0.03 cm / 0.012"	--	0.3 <sup>***</sup>
Sodium-22	$^{22}\text{Na}$	$^+ \beta, \gamma$	13.3	--	--	27.9	1.6 <sup>**</sup>
Phosphorus-32	$^{32}\text{P}$	$^- \beta$	353 <sup>*</sup>	610 cm / 240"	0.76 cm / 0.35"	--	7
Phosphorus-33 <sup>***</sup>	$^{33}\text{P}$	$^- \beta$	--	51 cm / 20"	0.06 cm / 0.025"	--	0.5 <sup>***</sup>

Sulfur-35***	<sup>35</sup> S	β	--	26 cm / 10.5"	0.04 cm / 0.015"	--	0.3***
Calcium-45***	<sup>45</sup> Ca	β	--	51 cm / 20"	51 cm / 20"	--	0.5***
Chromium-51	<sup>51</sup> Cr	γ	0.18	--	--	5.6	--
Zinc-65	<sup>65</sup> Zn	ε, γ	3.0	--	--	33.2	--
Rubidium-86	<sup>86</sup> Rb	β, γ	0.56	--	--	32.5	7**
Technetium-99m	<sup>99m</sup> Tc	γ	0.8	--	--	1.0	--
Iodine-125	<sup>125</sup> I	ε, γ	0.78	--	--	0.056	--
Iodine-131	<sup>131</sup> I	β, γ	2.4	--	--	9.7	1.2**

<sup>H</sup>Unshielded exposure rate (mR/hr) 30 cm (12 inch) from 37 MBq (1.0 mCi) source

×Lead to reduce γ exposure rate by factor of 10 (two TVL reduce exposure by a factor of 100) or Lucite to stop all β

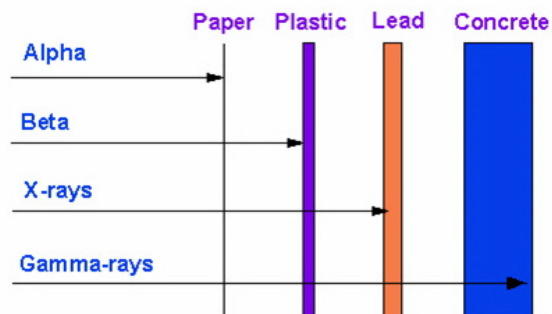
\*Radiation from pure beta emitting radionuclides is technically not measured in mR/hr and should not be shielded with lead; shield beta-particles with Lucite/Plexiglas

\*\*If gamma is attenuated by a factor of 10, dose rate from Bremsstrahlung x-rays should also be low

\*\*\*There is no need to shield low-energy β-particles <sup>3</sup>H, <sup>14</sup>C, <sup>33</sup>P, <sup>35</sup>S, <sup>45</sup>Ca

## B. Biological Effects of Ionizing Radiation

The hazards associated with the absorption of radiation in mammalian systems and tissues are related to both the type of radiation and the nature of the absorbing tissue or organ system. If radiation is to



expose tissue, it must have enough energy to penetrate to that tissue. An **external hazard** is radiation with sufficient energy to penetrate the superficial layers and deposit their energy within the body.

Alpha particles are stopped by the dead layers of skin, so they are not external hazards. However, many alpha emitters also emit gamma rays which are an external hazard. Internally, alpha particles can be very damaging because they deposit all of their energy in a very small volume. Based on their chemical properties,

alpha emitting elements can also be concentrated in specific tissues or organs.

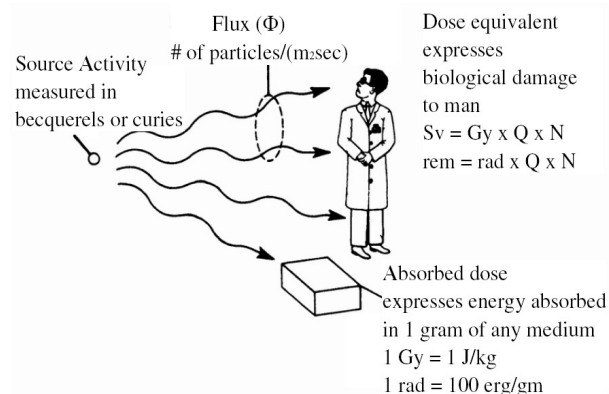
Beta particles can deliver a dose to the skin or the tissues of the eye. For a beta particle to penetrate the skin, it must have energies in excess of 300 keV. Thus, beta particle energies are divided between low energy (i.e.,  $E_{\max} < 300$  keV) and high energy ( $E_{\max} > 300$  keV). Many beta emitting nuclides also emit gamma rays and large activities (i.e.,  $> 5$  mCi) of a high energy beta emitter can produce significant exposure from bremsstrahlung x-rays created in shielding material. Internally, beta particle emitters can be concentrated in specific tissues or organs depending on their chemical nature.

The hazard from low energy ( $< 30$  keV) gamma rays and x-rays is primarily to the skin or the tissues of the eye. Higher energies are more penetrating and therefore a whole body hazard. Internally, gamma

emitters can affect not only the tissues or organs in which they are deposited, but also surrounding tissues.

### Activity, Exposure & Dose

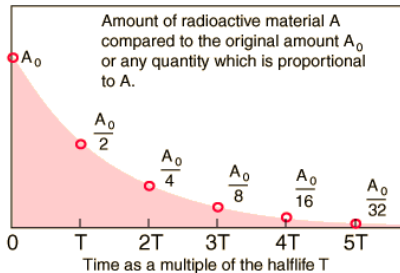
**Activity** is the rate of decay (disintegrations per unit time) of a given amount of radioactive material.



There are two units of activity used in the US. The Curie is the historic unit. It was defined in 1928 to be 1 **Curie (Ci)** =  $3.7 \times 10^{10}$  disintegrations per second (dps). The **Becquerel (Bq)** replaced the Curie in the *International System of Units (SI)* as a measure of activity where 1 Bq = 1 dps,  $3.7 \times 10^{10}$  Bq = 1 Ci, and 1 mCi = 37 MBq.

### Calculating Activity

The **half-life** of a radionuclide is the time required for one-half of a collection of atoms of that nuclide to decay. This is the same as saying it is the time required for the activity of a sample to be reduced to one-half the original activity. The half-life equation in Section 2 can be rewritten as:



$$A_t = A_0 e^{-(0.693t/T)}$$

where  $A_0$  = original activity

$A_t$  = activity at time  $t$

$t$  = decay time

$T$  = half-life

### Example:

P-32 has a half-life of 14.3 days. On January 10, the activity of a P-32 sample was 10  $\mu$ Ci. What will the activity be on February 6?

February 6 is 27 days after January 10 so:  $A_{2/6} = A_{1/10} e^{-[0.693(27/14.3)]} = 2.7 \mu\text{Ci}$

A quick estimate could also have been made by observing that 27 days is about two half-lives (28.6 days). So the new activity would be about one-half of one-half (i.e. one-fourth) of the original activity.

**Exposure** is a measure of the ionization produced in air by x-ray or gamma radiation. The term exposure, with its "normal" definition is sometimes used to mean dose (e.g. "He received a radiation exposure to his hand.") The unit of radiation exposure in air is the **roentgen (R)**. It is defined as that quantity of gamma or x-radiation causing ionization in air equal to  $2.58 \times 10^{-4}$  coulombs per kilogram. Exposure applies only to absorption of gammas and x-rays with energies less than 3 MeV in air. The roentgen is not defined in the SI system of units. The SI unit of exposure is the **X unit**, defined as the production of 1 coulomb of charge in 1 kg of air (i.e.,  $X = 1 \text{ C/kg air}$ ). Because the X unit is equivalent to 3876 R, a very large exposure, most exposure measurements are reported in roentgen (R).

**Dose** is a measure of energy deposited by radiation in a material, or of the relative biological damage produced by that amount of energy given the nature of the radiation.

The **rad** is a unit of absorbed dose. One rad is equal to an absorbed dose of 100 ergs/gram (1 erg =  $6.24 \times 10^{11}$  eV), regardless of material. The SI unit of absorbed dose is the **Gray (Gy)**, 1 Gy = 1 joule/kilogram = 100 rad. Historically, an exposure of 1 R resulted in an absorbed dose of 0.87 rad.

However, dose for dose, not all radiation produces the same amount of biological damage in people. The **quality factor (Q)** is used to compare the biological effectiveness of various types of radiation, given equal amounts absorbed dose (rad). The effectiveness of radiation in producing damage is related to the energy loss of the radiation per unit path length, often expressed as the **linear energy transfer (LET)**, in units of keV/ $\mu$ . Generally, the greater the LET in tissue, the more effective the radiation is in

producing biological damage. The quality factors for radiations frequently encountered are:

Radiation	Q
Gammas and x-rays	1
Beta particles & electrons	1
Alpha particles & fission fragments	20
Neutrons	10

The **rem** is the unit of dose equivalent and is equal to the absorbed dose in rad multiplied by the quality factor (i.e.,  $\text{rem} = Q \times \text{rad}$ ). Dose equivalent determinations for internally deposited radioactive materials also take into account other factors such as the non-uniform distribution of some radionuclides (e.g. I-125 in the thyroid). The SI unit for dose equivalent is the Sievert (Sv) which is calculated the same as the rem (i.e.,  $\text{Sv} = Q \times \text{Gy}$ ).  $1 \text{ Sv} = 100 \text{ rem}$ .

### Calculating Exposures

The gamma exposure constants ( $\Gamma$ ) is the exposure rate in R/h at 1 cm from a 1 mCi point source. The  $\Gamma$  constant for many radionuclides can be found on the internet.

An empirical rule rule-of-thumb which may be used is the **6CEn** rule. This states that exposure rate in R/h at one foot in air from C curies of a radionuclide that emits n photons of energy E (MeV), where  $0.07 < E < 4$ , per disintegration is:

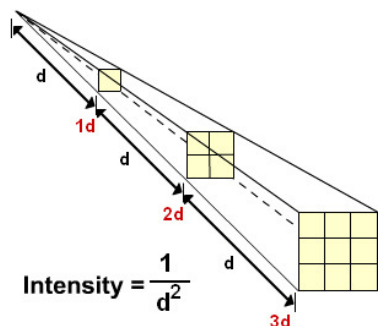
$$6 \times C \times E \times n = \text{R/hr @ 1 foot,}$$

where C = source strength in curies  
 E = energy of the emitted photons in MeV  
 n = fraction of decays resulting in photons with an energy of E

It should be noted that this formula and the gamma constants are for exposure rates from gammas and x-rays only. Any dose calculations would also have to include the contribution from any particulate radiation that may be emitted.

For example, for each decay, Co-60 emits 2 gamma rays one at 1.173 MeV and one at 1.332 MeV. The exposure at 1 foot from a 1 mCi source ( $1000 \text{ mCi} = 1 \text{ Ci}$ ) would be:

$$\text{ER} = 6 C E n = 6 \times (0.001) \times (1.173 + 1.332) \times 1 = 0.015 \text{ R/hr @ 1 foot or } 15 \text{ mR/hr @ 1 foot.}$$



### Inverse Square Law

Exposure rate varies inversely with the square of the distance from a point source of radiation. This is often referred to as the inverse square law (or  $1/r^2$  rule).

$$\text{ER}_2 = \text{ER}_1 \times (d_1/d_2)^2$$

where  $\text{ER}_2$  = exposure rate at distance 2  
 $\text{ER}_1$  = exposure rate at distance 1  
 $d_1$  = distance 1  
 $d_2$  = distance 2

Using this rule you can see that the exposure rate at 6 feet will only be 3% of the exposure rate at 1 foot (i.e.,  $1/6^2 = 2.8\%$ ) and as a practical rule, if you are not directly working with an external hazard (e.g., P-32, Cr-51, I-125), a 6-foot distance will result in essentially no exposure.

Consider another example of the inverse square law, the  $\Gamma$  for Co-60 is 13.2 R/hr @ 1 cm per mCi. Therefore, the exposure rate at 1 cm from a 1 mCi source would be 13.2 R/hr. At 30 cm from the same source, the exposure rate would be  $(13.2 \text{ R/hr})(1/30)^2 = 0.0147 \text{ R/hr} = 14.7 \text{ mR/hr}$ . Notice that this exposure rate correlates closely with the 6CEn example above.

**Beta Dose Rates.** For a beta emitting point source, the dose rate in air can be calculated using an empirical equation:

$$300 \times \text{Ci} = \text{rad/hr @ 1 foot, where Ci} = \text{source strength in curies.}$$

This calculation neglects any shielding provided by the air, which can be significant for low energy beta particles. For example, the maximum range in air for a beta from S-35 is less than one foot (see Table 2), so the dose rate at one foot is zero for any activity S-35 source (neglecting bremsstrahlung).

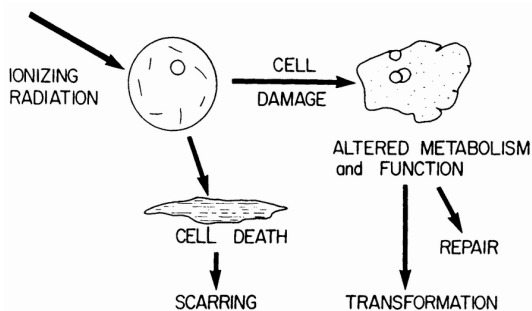
Because beta particles are emitted in a spectrum of energies and the low energy beta particles are rapidly attenuated, beta radiation does not follow the inverse square law. Table 2 provides an approximation of the beta dose rate versus distance.

Table 2. Beta dose rate (rad/hr) from a 37 MBq (1 mCi) point source

Radionuclide	Energy (MeV)	Distance (cm)							
		0	0.2	0.5	10	10	30	50	100
$^{14}\text{C} / ^{35}\text{S}$	~0.160	2035.7	241.7	21.3	1.78	0.04	--	--	--
$^{33}\text{P} / ^{45}\text{Ca}$	~0.250	1532.3	219.0	26.6	4.23	0.40	0.05	--	--
$^{32}\text{P} / ^{86}\text{Rb}$	1.710	350.0	87.0	13.8	3.44	0.87	0.39	0.14	0.03

**Skin Dose.** Because nearly all of the energy from beta particles with energies below 0.3 MeV (e.g., H-3, C-14, P-33, S-35, Ca-45) is deposited within the dead layer of the skin, there is essentially zero skin dose from these radionuclides. For energies above 0.3 MeV, a practical estimate of the dose rate to the skin from a uniform deposition of  $1 \mu\text{Ci}/\text{cm}^2$  of a beta emitter on the skin is about 9 rad/hr. Empirically, the skin dose rate from P-32 is 6 rad/hr per  $\mu\text{Ci}$  or 0.1622 rad/hr per kBq.

**Internal Dose Calculations** are beyond the scope of this manual. If you have questions, please contact the Radiation Safety Officer.



### Biological Effects of Radiation

As discussed earlier, radiation causes atoms and molecules to become ionized or excited. These ionizations and excitations can result in:

- Production of free radicals.
- Breakage of chemical bonds.
- Production of new chemical bonds and cross-linkage between macromolecules.
- Damage to molecules which regulate vital cell processes (e.g. DNA, RNA, proteins).

**Tissue Sensitivity.** In general, the radiation sensitivity of a tissue varies directly with the rate of proliferation of its cells and inversely with the degree of differentiation. Table 3 list some cell radiosensitivities.

Table 3. Radiosensitivity of Normal Cells

Very High	High	Intermediate	Low
Lymphocytes	Urinary bladder epithelium	Endothelium	Mature hematopoietic cells
Immature hemato- poietic cells	Esophageal epithelium	Growing bone fibroblasts	Muscle cells
Intestinal epithelium	Gastric mucosa	Glandular epithelium of breast	Mature connective tissues
Spermatogonia	Mucous membranes	Pulmonary epithelium	Mature bone and cartilage
Ovarian follicular cells	Epidermal epithelium	Renal epithelium	Ganglion cells
	Optic lens Epithelium	Thyroid epithelium	

**High Dose Effects.** A whole body radiation dose of greater than 25 to 50 rem received in a short time results in the clinical "acute radiation syndrome." This syndrome, which is dose related, can result in disruption of the functions of the bone marrow system (> 25 rem), the gastro-intestinal system (> 500 rem), and the central nervous system (> 2000 rem). An acute dose exceeding 300 rem can be lethal.

**Low Dose Effects.** There is no disease that is uniquely associated with low radiation doses. Immediate (i.e., acute) effects are not observed below doses of 25 rem. Latent effects may appear years after a dose is received. The effect of greatest concern is the development of some form of cancer.

The National Academy of Sciences Committee on Biological Effects of Ionizing Radiation (BEIR) issued a report in 1990 entitled "Health Effects of Exposure to Low Levels of Ionizing Radiation," also known as BEIR V. The following is an excerpt from the Executive Summary of the report:

On the basis of the available evidence, the population-weighted average lifetime risk of death from cancer following an acute dose equivalent to all body organs of 0.1 Sv (0.1 Gy of low-LET radiation) is estimated to be 0.8%, although the lifetime risk varies considerably with age at the time of exposure. For low LET radiation, accumulation of the same dose over weeks or months, however, is expected to reduce the lifetime risk appreciably, possibly by a factor of 2 or more. The Committee's estimated risks for males and females are similar. The risk from exposure during childhood is estimated to be about twice as large as the risk for adults, but such estimates of lifetime risk are still highly uncertain due to the limited follow-up of this age group. ....

The Committee examined in some detail the sources of uncertainty in its risk estimates and concluded that uncertainties due to chance sampling variation in the available epidemiological data are large and more important than potential biases such as those due to differences between various exposed ethnic groups. Due to sampling variation alone, the 90% confidence limits for the Committee's preferred risk models, of increased cancer mortality due to an acute whole body dose of 0.1 Sv to 100,000 males of all ages range from about 500 to 1200 (mean 760); for 100,000 females of all ages, from about 600 to 1200 (mean 810). This increase in lifetime risk is about 4% of the current baseline risk of death due to cancer in the United States. The Committee also estimated lifetime risks with a number of other plausible linear models which were consistent with the mortality data. The estimated lifetime risks projected by these models were within the range of uncertainty given above. The committee recognizes that its risk estimates become more uncertain when applied to very low doses. Departures from a linear model at low doses, however, could either increase or decrease the risk per unit dose.

If a worker were to receive 10% of the maximum allowable dose each year for twenty years, the total dose received would be 10 rem (0.1 Sv). According to the BEIR V report, the worker's chance of death

from cancer would increase by approximately 0.4%. This is fairly small compared to the normal chance of death from cancer in the U. S. of about 20%.

The BEIR committee has issued several reports since BEIR V, however they have remained conservative in their estimate, assuming that risk varies linearly with dose and that for cancer risk, there is no dose below which there is no risk (i.e., no threshold). This is called the Linear, No Threshold model.

### Radiation Dose Limits

Thus, radiation exposure, especially acute exposures (i.e., large exposures in a short period of time),

Table 4. Maximum Permissible Dose Limits

Dose to:	mSv/yr	mrem/yr	rem/yr
Radiation worker Whole body	50	5,000	5
Radiation worker Lens of eye	150	15,000	15
Radiation worker Skin	500	50,000	50
Radiation worker hands, wrist, feet, ankles	500	50,000	50
Radiation worker thyroid	500	50,000	50
Minor (under 18 years old) radiation worker	5	500	0.5
Unborn child of radiation worker	5 <sup>H</sup>	500 <sup>H</sup>	0.5 <sup>H</sup>
Members of the general public	1	100	0.1

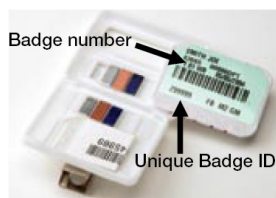
<sup>H</sup>over entire gestation period for declared pregnant worker

have produced physical injury and have been linked to cancer. To protect both workers and the population at large, dose limits have been established. The current limits are listed in Table 4. These dose limits are set by the EPA with input from both the scientific community and public

interest groups. The last major whole body dose reduction in the US was about 1960. Prior to this, the whole body dose limit was 15 rem/yr. This was reduced to 5 rem/yr, not because 15 rem/yr was associated with excess cancers in radiation workers, but because the average radiation worker dose was only about 2 - 3 rem/yr and the lower dose would not have a significant impact on industry nor defense.

### C. Radiation Monitoring

Radiation can not be detected with our normal senses. Special devices called dosimeters are needed to measure worker exposure and radiation survey meters are used to detect radioactive contamination.



#### Personal Dosimeter

A dosimeter is used to measure a worker's whole body dose and shallow dose. There are several kinds of dosimeter material. Some use film and are usually called film badges while others use thermoluminescent

materials and are called TLD badges. The film in a film badge is similar in size to dental x-ray film. Because it is sensitive to light, if the film packet is opened or damaged, the reading will be invalid. The film holder usually has aluminum and copper filters which are used to determine the type and energy of radiation. The badge will detect gamma and x-rays, high energy beta particles (i.e.,  $E_{max} > 300$  keV), and in certain special cases, neutrons. It does not register radiation from low energy beta emitters such as  $^3\text{H}$ ,  $^{14}\text{C}$  and  $^{35}\text{S}$ , because these beta particles will not penetrate the paper covering on the film packet.

The badge is usually worn between the collar and waist to measure the radiation dose received by the trunk of the body. When not in use, the badge should be left in a low background area, away from any radiation sources. Be sure the badge is available for the film packet exchange which is done monthly or quarterly.



### **TLD Ring**

The TLD ring is used to measure dose to the fingers and hand. They are issued to individuals who may use multiple millicurie amounts of a gamma or high energy beta emitter (e.g.,  $^{32}\text{P}$ ,  $^{51}\text{Cr}$  or  $^{125}\text{I}$ ). The TLD is a small crystal which absorbs the energy from radiation. When heated, it releases the stored energy in the form of visible light. The crystal is mounted in a ring which should be worn on the hand which is expected to receive the larger dose. Wear the ring inside your glove with the label facing towards your palm.

### **Precautions**

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

- Always wear your badge when using radioactive materials or radiation-producing machines. Wear your ring when using gamma or high energy beta emitters.
- Keep your dosimeters away from radiation sources when not in use.
- Do not deliberately expose a dosimeter to radiation or wear your badge when receiving medical or dental x-rays.
- Do not tamper with the dosimeter packet or remove it from the holder.
- Never wear someone else's dosimeter or let someone else wear yours.
- Do not subject the badge to high temperatures or get it wet.

Notify your supervisor or the Radiation Safety Officer if your badge or ring has been damaged or lost, or if you have reason to believe that you or your dosimeter has received an accidental high dose.

### **High Exposure Notifications**

The University is required by law to report to the Nuclear Regulatory Commission (NRC) any personnel dosimeter exposures which show a dose higher than the occupational dose limits. It is a violation of federal regulations and the conditions of our Radioactive Material Licenses to deliberately expose a personnel dosimeter to radiation. The dose recorded by the dosimeter will become part of your dose record unless it can be proven that the individual did not actually receive the dose.

### **Bioassays**

The University's license requires that individuals using certain amounts of volatile radionuclides be included in a bioassay program. Whether or not a bioassay is required depends on the nuclide, form, and activity of the radioactive material being used. If a bioassay will be required, you will be notified when your radionuclide is delivered.

### **Pregnancy Surveillance Program**

Studies have shown that the fetus is a bit more sensitive to acute, high-dose exposures. As seen in Table 4, lower limits are applied to the fetus. The pregnancy surveillance program is designed to insure the fetal dose of declared pregnant workers is below the limit of 500 mrem during the entire gestation period. The program consists of a review of the worker's workplace to include radionuclides and past exposure history and a briefing on techniques to keep radiation exposures as low as reasonable achievable (ALARA). If appropriate, dosimetry will be provided to monitor the worker's fetal exposure. Contact the RSO if you wish to discuss this program.

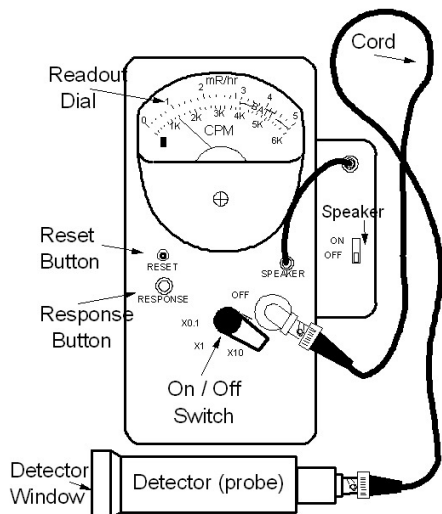
### **Radiation Survey Meters**

There are several types of portable radiation survey instruments used on campus. Each type of meter will have different qualities and can 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

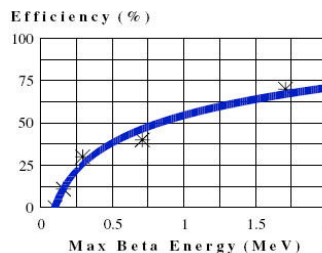
laboratory. During your initial training, you will learn how to operate the instruments in your lab. You should know their capabilities and limitations and be able to interpret the meter readings.

### Geiger Counter (GM Survey Meter)

The Geiger-Mueller (G-M) counter is the most common radiation



detection instrument on campus. In this type of meter, an ionization in the detector results in a large output pulse that causes meter to click and the needle to move on the readout. Because of the way the detector works, all ionizing events produce the same size output pulse. Therefore, the meter does not differentiate among types or energies of radiation.



Most G-M detectors have a thin mylar film "window" at one end. This window is very fragile. Hold the thin window about 1 cm from the surface when you are detecting alpha emitters, pure beta emitters and low energy photons (e.g.  $^{32}\text{P}$ ,  $^{35}\text{S}$ ,  $^{14}\text{C}$ ,  $^{55}\text{Fe}$ ,  $^{125}\text{I}$ ,  $^{210}\text{Po}$  and x-rays less than 40 keV). The aluminum wall of a thin window probe should be used only for the detection of

penetrating x-rays and gamma radiation. In this latter instance, the reading will not be valid, but is often used to determine if gamma rays are present since particulate radiation will not penetrate the aluminum walls.

Very low energy beta emitters such as  $^3\text{H}$  and  $^{63}\text{Ni}$  can not be detected with a GM because these beta particles do not have enough energy to penetrate the detector window. They are best detected by using liquid scintillation counting. Both  $^{14}\text{C}$  and  $^{35}\text{S}$  emit beta particles that energetic enough to pass through the thin window, however, if you are using  $^{14}\text{C}$  or  $^{35}\text{S}$ , do not cover the window of your GM to protect against contamination. *Covering the window with plastic wrap or paraffin film will prevent most or all of the  $^{14}\text{C}$  or  $^{35}\text{S}$  beta particles from entering the detector.* Experiments have shown that cling film results in a 50% decrease in efficiency for C-14 / S-35 and Parafilm M stops all C-14 / S-35 beta particles from entering the detector. The effect, especially for Parafilm M, is not quite as dramatic for P-33 / Ca-45. High-energy beta particles from P-32 are relatively unaffected.

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, that is:

$$\text{actual decay rate} = \text{meter reading} / \text{efficiency}$$

Some examples of approximate G-M efficiencies through the end window at 1 cm ( $\sim \frac{1}{2}$  inch) from a point source are given below:

$^3\text{H}$	$\beta$ , 0.018 MeV	not detectable
$^{14}\text{C}$ , $^{35}\text{S}$	$\beta$ , 0.160 MeV	5 % - 10 %
$^{33}\text{P}$ , $^{45}\text{Ca}$	$\beta$ , 0.250 MeV	10 % - 20 %
$^{32}\text{P}$	$\beta$ , 1.710 MeV	30 % - 45 %
$^{125}\text{I}$	$\gamma$ , 0.030 MeV	0.01% - 0.03%

There are many factors that affect efficiency. These include distance (e.g., inverse square effects), detector geometry (e.g., end-window versus pancake detector), detector age, etc. The numbers listed should serve as a guide to relate radiation energy with detector efficiency. You should use your meter to indicate the presence of contamination, then clean contaminated areas exceeding limits in Appendix C of the Radiation Safety Manual.

### Example

Your G-M meter reads 5000 cpm at 1 cm from a small spot of P-32 contamination on the bench. What is the total activity of the contamination (assume a 25% efficiency)?

$$\begin{aligned} \text{actual disintegration rate} &= (5000 \text{ cpm}) / (0.25 \text{ cpm/dpm}) \\ &= 20,000 \text{ dpm} = 333 \text{ dps} \\ &= 333 \text{ Bq} = 9 \text{ nCi} \end{aligned}$$

Because of the randomness of radioactive decay, the meter reading at low count rates (e.g., < 100 cpm) 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.

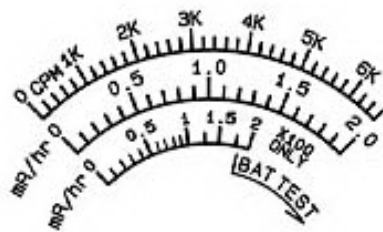
Very high radiation fields may temporarily overload the detector circuit resulting in the needle moving off scale (i.e., the needle pegs). If this happens, remove the meter and yourself from the area and push the reset button or turn the meter off then back on. The meter should resume normal operation. Always turn on a survey meter before entering an area that might have high radiation levels.

### Scintillation Detector

Scintillation detectors (or low energy gamma [LEG] probes) incorporate a sodium iodide crystal and are used in some laboratories for the detection of low energy gamma emitters such as <sup>125</sup>I. 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 <sup>125</sup>I is about 25% at 1 cm (½ inch), more than one hundred times better than a G-M probe.

### Survey Meter Calibration

Most survey meters have scales of milliRoentgen per hour (*mR/hr*) and/or counts per minute (*cpm*) or counts per second (*cps*). After detector efficiency is taken into consideration, the cpm or cps scales give



an indication of the quantity of radioactivity. The mR/hr scales give an indication of the radiation exposure rate. There is an important difference in these measurements. *Exposure rate measurements are only valid for x- or γ radiation.*

Radiation Safety calibrates all of the portable radiation survey instruments on campus. One of two types of calibration procedures is used. One is for GM survey meters that are used for detection and measurement of particulate radiation. Another is for meters used for detection and measurement of x- and γ radiation. The two procedures are explained briefly below so that you will know what to expect.

Survey meters used in biology and chemistry research labs are calibrated for the detection and measurement of particulate radiation. These meters are calibrated using a pulse generator so that the cpm or cps scales read correctly (i.e., one pulse in = one meter count). If the meter also reads in mR/hr, those readings will not be accurate for the measurement of x- or gamma radiation. After calibration, for γ-ray exposures, a reading of approximately 2,000 - 4,000 cpm will be about 1 mR/hr).

Survey meters that are used for radiation exposure (i.e., mR/hr) measurements are calibrated with a gamma ray source such as Cs-137. The mR/hr scale will read correctly when the detector is exposed to electromagnetic radiation greater than 100 keV.

## D. Facilities, Posting and Security

The University's license allows for relatively generic use of unsealed radioactive material in research laboratories. Use of larger quantities or highly toxic materials (e.g., Plutonium) may require Nuclear Regulatory Commission approval and special facilities such as a glove box. Most labs which are suitable for use of hazardous chemicals are suitable for routine radioactive material use. Some uses (e.g., Na<sup>125</sup>I or <sup>3</sup>H<sub>2</sub>O) may require a fume hood. At the time that your protocol is submitted, the Radiation Safety Officer will review the proposed use and the adequacy of your workplace.

### Posting

To alert members of the general public about possible radiation hazards, all laboratories which are approved to use radioactive material must be posted with the following information:

- A notice on the inside and outside of the laboratory door stating "Caution, Radioactive Materials." Some doors may have this permanently attached. The radiation symbol must be imprinted on the notice. The NRC rules include a color requirement - yellow and black symbol/lettering or yellow and magenta lettering.
- A notice on the inside of the laboratory door stating that the laboratory is to be kept locked when it is unoccupied.
- For emergency purposes, a schematic drawing of each laboratory is to be posted on the outside of the door listing the isotopes present and with the locations or areas of typical use or storage highlighted. This sheet should also give the name and telephone numbers, office and home, of the authorized user and the RSO.
- The NRC form 3, **Notice to Radiation Workers**, which informs workers of their rights and responsibilities, must be posted on either side of the door or, in large research facilities, may be posted conspicuously on department bulletin boards.
- An inventory, updated monthly to give current activity, is to be posted in each laboratory on or adjacent to the door. When a user has more than one research laboratory in a building, one area may be selected as the primary storage area.



If a laboratory has two or more doors accessible to the public, one door is to be posted as above. The other doors are to be posted with the warning sign, the locking statement, and the schematic drawing.

Two documents are to be prominently displayed in the vicinity of each radioactive use lab. One is NRC Form 3, "Notice to Employees ...." The other is "Responsibilities of USD Administration for Radiation Safety." These documents can serve several adjacent laboratories.

### Security

NRC rules require that radioactive materials be secured from unauthorized access. The rules have been interpreted differently by different NRC inspectors. One inspector might walk down the hall checking doors of radioactive labs. If a door is unlocked and the lab unoccupied, he enters the lab and uses a survey meter to see if he can detect radioactive material on bench tops or unlocked refrigerators. If he detects material, then the room is unsecured. Other inspectors have stated that absences of 5 - 10

minutes for personal business might be acceptable if the quantities in use are small (i.e., below quantities listed in one of the NRC tables). If the lab will be unoccupied for longer than 5 minutes, the lab should be locked unless the radioactive material is locked in a refrigerator or lockable storage area.

## **E. Obtaining Radioactive Materials**

Authorized workers must get approval from the RSO before getting any radioactive materials. This approval includes material received by transfer from another authorized user or by purchase from a commercial vendor. Once received, the radioactive material remains the responsibility of the authorized user until they have been transferred or disposed. Internal transfers are documented using a Transfer of Radiochemicals form (Appendix B).

Most radioactive material is ordered from commercial vendors (e.g., MP, PerkinElmer, ICN, etc.). Prior to ordering material, notify the RSO or a designee (5553 or 6265). The RSO assigns a USD inventory number to each radionuclide order and records the name of the authorized user, the date, the vendor, the isotope and the activity ordered. Each radionuclide ordered will be identified by its catalog number (e.g., NEG513A) and the name of the radiochemical or an abbreviation (e.g. dCTP).

For telephone orders, the RSO gives verbal approval and provides a lot number. In the event no one is in the RSO office and no special authorization is required, the radionuclide information is to be left as a voice mail on 5553 or 6265) or via eMail ([ehs@usd.edu](mailto:ehs@usd.edu)). When special authorization is required, the RSO signs purchase orders or requisitions prior to their forwarding to the purchasing office.

When placing your order, instruct the vendor to deliver the material to: University of South Dakota, Radiation Safety Office, Davidson Building, 414 E. Clark St., Vermillion, SD, 57069. If you receive a shipment that did NOT come from Radiation Safety, notify the RSO and they will provide the needed lot information and perform any required surveys.

The NRC has specific requirements for receiving or shipping radioactive material. Each shipment is inspected for container integrity and the maximum dose rate level (mrem/hr) on the container surface is measured and recorded. Additionally, a wipe of approximately 300 cm<sup>2</sup> (about 48 sq inches or 8" x 6") is performed to assess whether there is removable contamination on the outside surface. The RSO or another member of the Radiation Safety Office initials and dates the packing slip and notifies the authorized user that the shipment has been received and may be picked up. Generally, surface wipe count rates in excess of about 300 cpm should indicate contamination. Depending upon the isotope, excessive contamination levels must be reported to the NRC.

If you need to send radioactive material to another researcher who is off campus, call the RSO. You will need to provide your FedEx shipping account and a suitable container, but the RSO will perform all tests and package the material so the shipment satisfies NRC rules and regulations.

## **F. Radioactive Material Handling and Laboratory Safety**

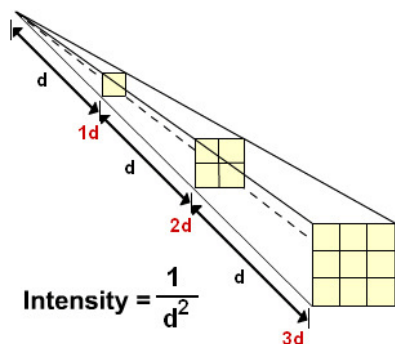
Many safety standards and exposure limits are specified in federal regulations. Not all of these standards are quantitative. One of the more important requirements is that radiation exposures are to be kept "as low as reasonably achievable." This requirement is denoted by the acronym ALARA and requires workers balance the degree and nature of workplace risks with the benefits of their work. The following are methods to reduce dose and keep exposures ALARA.

**Time:** Because it is assumed that radiation damage is cumulative (i.e., linear, no threshold), your radiation risk is linearly proportional to the total dose you receive. Carefully plan your activities in order

to minimize the length of time spent handling or in the vicinity of radiation sources. Practice unfamiliar procedures to reduce the time needed to perform them.

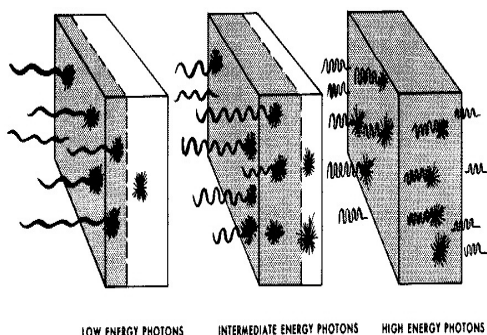
**Distance:** Recall the inverse square law, increasing the distance from a radiation source by the use of tongs or forceps will reduce the dose received, since exposure rate decreases as  $1/r^2$ , where  $r$  is the distance from a point source. For example, at 10 cm, a 5 mCi  $^{125}\text{I}$  source has an exposure rate of 75 mR/hr. Moving to 30 cm would reduce the exposure rate to

$$(75 \text{ mR/hr}) (10/30)^2 = 8.3 \text{ mR/hr}$$



Note that the  $1/r^2$  formula (also known as the inverse square law) does not take into account shielding provided by air. This can be significant for alpha and beta radiation. Even the most energetic alpha particles have a range in air of only about 4 inches. A beta from the decay of  $^{14}\text{C}$  or  $^{35}\text{S}$  has a maximum range in air of about 12 inches.

If you are not directly working with radioactive material, stay about 6 feet (2 meters) away. From the inverse square law, the exposure at 6 feet will be about 2.7% of the exposure at 1 foot (i.e., an exposure of 100 mR at 1 foot will only be 2.7 mR at 6 feet).



**Shielding:** As gamma rays and x-rays pass through an absorber, they decrease in number through processes discussed in Section A. The amount of reduction is governed by the energy of the radiation, the density of the absorber medium, and the thickness of the absorber. This can be expressed approximately as:

$$I = I_0 e^{-\mu x}$$

where  $I_0$  is the intensity (number of photons per unit area) of the initial radiation,

$I$  is the radiation intensity after it has passed through the absorber,

$\mu$  is a factor called the linear absorption coefficient. The value of  $\mu$  depends on the energy of the incident radiation and the density of the absorbing medium.

$x$  is the thickness of the absorber.

### Half-Value Layer (HVL) and Tenth-Value Layer (TVL)

The thicknesses of an absorber needed to reduce the radiation intensity by factors of two and ten are called the *half-value layer (HVL)* and the *tenth-value layer (TVL)*, respectively. Approximate lead TVL's, HVL's and linear attenuation coefficients ( $\mu$ ) for some radionuclides are listed below.

Nuclide	$\gamma$ Energy (MeV)	HVL (mm)	TVL (mm)	$\mu$ ( $\text{cm}^{-1}$ )
I-125	0.035	0.05	0.16	150
Am-241	0.060	0.14	0.45	51
Co-57	0.122	2.0	6.7	3.4
Cs-137	0.662	6.5	21	1.1
Na-22	1.28	9.6	32	0.72
Co-60	1.17 & 1.33	12	40	0.58

### Example

At 30 cm, a 10 mCi Co-60 source produces an exposure rate of 150 mR/hr. How much lead shielding is needed to reduce the rate to 4 mR/hr?

From the table, for Co-60, one TLV of lead, 40 mm, will reduce the rate by a factor of 10, from 150 mR/hr to 15 mR/hr. Adding 12 mm (one HVL) of lead will make it 7.5 mR/hr. One more HVL will reduce the rate to about 4 mR/hr. So the total lead shielding needed is  $40 + 12 + 12 = 64$  mm.

When using shielding there are several points to be kept in mind.

- 1/3 inch (1 cm) of Plexiglas will stop all high energy beta particles from P-32.
- Persons outside the shadow cast by the shield are not necessarily protected.
- A wall or partition may not be a safe shield for people on the other side. If storing a gamma emitter (e.g., Cr-51), verify exposures all around the container are low.
- Radiation can be "scattered" around corners.

### Bremsstrahlung

The absorption of high energy beta particles (e.g.  $^{32}\text{P}$  and  $^{90}\text{Sr}$ ) in high Z materials such as lead and tungsten results in the production of bremsstrahlung x-rays (see Section A) which are more penetrating than the beta radiation that produced it. Low Z materials such as plastics (e.g., Plexiglas, Lucite, etc.) and glass minimize the production of bremsstrahlung.

Below are some of the radiological characteristics and special precautions associated with some radionuclides commonly used on campus. In addition to the specific precautions for each nuclide, these general precautions should always be followed when working with hazardous materials.

- Whenever practical, designate special areas for radioactive material use. Clearly label the area and all containers with "Caution Radioactive Material" stickers.
- Use absorbent paper and spill trays to minimize and confine contamination.
- Use a fume hood to work with potentially volatile materials.
- Do not smoke, eat, or drink in rooms where radioactive materials are used. Do not store food or drink in refrigerators, freezers, or cold rooms used for radioactive material storage.
- Use a survey meter to detect radioactive contamination. Regularly survey the work area. Always survey yourself, your work area, and equipment for contamination when your experiment or operation is completed. Decontaminate when necessary.
- Use correct shielding when handling millicurie quantities of gamma or high energy beta emitters. Remember that waste containers may also need shielding.
- Wear dosimeters issued to you when working with radioactive materials.
- Clean any spills immediately, this will reduce the risk of spreading contamination.
- Wash your hands before leaving the lab, using a telephone, typing, eating, etc.

### H-3 (tritium) Information

Radioactive half-life	12.4 years
Decay mechanism	Beta emission
Energy	$E_{\text{max}} = 18.6$ keV
Contamination monitoring	Liquid scintillation counter for wipe surveys
Dosimetry	Urinalysis

1. Because the beta emitted has a very low energy, tritium can not be detected with the usual survey meters found in the lab. Therefore, special care is needed to keep the work area from becoming contaminated. Tritium can be detected by doing a wipe survey and counting the wipes in a liquid scintillation counter.
2. Many tritiated compounds readily penetrate gloves and skin. Wearing two pairs of gloves and changing the outer pair every fifteen or twenty minutes will reduce the chances of cross contamination and absorption through the skin.
3. Tritium bound to amino acids, DNA, RNA and their precursors will be metabolized differently than tritiated water. It is estimated that the dose from tritiated thymidine may be 8 – 10 times more damaging than from tritiated water.

### C-14 Information

Radioactive half-life	5730 years
Decay mechanism	Beta emission
Energy	$E_{\max} = 0.156 \text{ MeV}$
Contamination monitoring	Thin window Geiger-Mueller detector, liquid scintillation counter for wipe surveys
Dosimetry	None needed

1. Some C-14 labeled compounds can penetrate gloves and skin. Wearing two pairs of gloves and changing the outer pair every fifteen or twenty minutes will reduce the chances of absorption through the skin.
2. C-14 may be difficult to distinguish from S-35. If both nuclides are being used in the same laboratory, establish controls to ensure they are kept separate. If "unknown" contamination is found, treat it as C-14.
3. If working with potentially volatile C-14 compounds, use a fume hood.

### P-32 Information

Radioactive half-life	14.3 days
Decay mechanism	Beta emission
Energy	$E_{\max} = 1.709 \text{ MeV}$
Contamination monitoring	thin window Geiger-Mueller detector
Shielding	1 cm Lucite / Plexiglas
Dosimetry	Whole body badge, TLD ring

P-32 Decay Table

days	0	1	2	3	4	5	6
0	1000	953	908	865	824	785	748
7	712	679	646	616	587	559	533
14	507	483	460	439	418	398	379
21	361	344	328	312	298	284	270
28	257	245	234	223	212	202	192

35	183	175	166	159	151	144	137
42	131	124	119	113	108	102	98
49	93	89	84	80	77	73	70
56	66	63	60	57	55	52	50

1. The dose rate on the surface of a 1 mCi vial can be on the order of 1000 mrad/hr. If possible, avoid direct hand contact with vials and sources. When working with 100  $\mu$ Ci or more of P-32, work should be done behind a 1 cm Plexiglas shield.
2. One microcurie of P-32 in direct contact with 1 cm<sup>2</sup> of bare skin gives a skin dose rate of about 9 rem/hr. Always protect your skin and eyes, wear gloves, lab coats, safety glasses and shoes.
3. A thin window G-M survey meter should always be near the work area. Survey the area immediately after use and decontaminate any hot spots.
4. A whole body dosimeter must be worn for all P-32 work. If you have been issued a TLD ring, it should be worn whenever working with P-32.
5. Handle and store your radioactive waste carefully. Place the liquid waste polyethylene bottles in a secondary container (e.g. a bucket or tray) to contain spills or leaks. When more than a millicurie is involved, place 1 cm thick Plexiglas shield around the waste container.

### P-33 Information

Radioactive half-life	25.3 days
Decay mechanism	Beta emission
Energy	$E_{\max} = 0.249$ MeV
Contamination monitoring	Thin window Geiger-Mueller detector, liquid scintillation counter for wipe surveys
Dosimetry	None needed

P-33 Decay Table

days	0	1	2	3	4	5	6
0	1000	973	947	921	897	872	849
7	826	804	782	761	741	721	701
14	683	664	646	629	612	595	579
21	564	549	534	520	506	492	479
28	466	453	441	429	418	406	395
35	385	374	364	355	345	336	327
42	318	309	301	293	285	277	270
49	263	256	249	242	236	229	223

1. P-33 can be used in any P-32 protocol. Because it is lower in energy (i.e., 0.249 MeV) than P-32, no shielding is required.
2. P-33 range in tissue is only 0.6 mm. Dosimeters are not issued for P-33 work and the beta particle will not penetrate a double layer of disposable gloves.
3. Counting efficiency should be higher than the efficiency for S-35 / C-14. While not as easy to

detect with a GM as P-32, it is still relatively easy to detect if survey meters are used properly.

### S-35 Information

Radioactive half-life	87.4 days
Decay mechanism	Beta emission
Energy	$E_{\max} = 0.167$ MeV
Contamination monitoring	Thin window Geiger-Mueller detector, liquid scintillation counter for wipe surveys
Dosimetry	Urinalysis

S-35 Decay Table

days	0	1	2	3	4	5	6
0	1000	992	984	976	969	961	954
7	946	939	931	924	916	909	902
14	895	888	881	874	867	860	853
21	847	840	833	827	820	814	807
28	801	795	788	782	776	770	764
35	758	752	746	740	734	728	722
42	717	711	705	700	694	689	683
49	678	673	667	662	657	652	646
56	641	636	631	626	621	616	612

1. Radiolysis of S-35 labeled amino acids may lead to the release of S-35 labeled volatile impurities. Delivery vials should be opened in a fume hood.
2. The addition of stabilizers (buffers) will reduce, but not eliminate, the S-35 volatiles from tissue culture media and procedures which involve heating and thawing. Incubators and water baths should be checked for contamination after using S-35 methionine or other volatile compounds.
3. S-35 and C-14 are similar in energy. If both nuclides are used in the same lab, have procedures to ensure they are used in separate areas. If unknown contamination is found, treat it as C-14.

### Ca-45 Information

Radioactive half-life	163 days
Decay mechanism	Beta emission
Energy	$E_{\max} = 0.257$ MeV
Contamination monitoring	Thin window Geiger-Mueller detector, liquid scintillation counter for wipe surveys
Dosimetry	None needed

Ca-45 Decay Table (5-day interval)

days	0	5	10	15	20	25	30
0	1000	979	959	939	919	900	881
35	863	844	827	810	793	776	760
70	744	728	713	698	684	669	655

105	642	628	615	602	590	577	565
140	553	542	531	519	509	498	488
175	477	467	458	448	439	430	421
210	412	403	395	386	378	370	363
245	355	348	340	333	326	320	313

1. Ca-45 is a bone seeker with a long residence time (i.e., effective half-life is 162.7 days). Work with more than 1 mCi will require special precautions and survey procedures.
2. Ca-45 is similar in energy to P-33. It can be readily detected with a thin-window GM and LSC counter.

### I-125 Information

Radioactive half-life	59.6 days
Decay mechanism	Electron capture (gamma and x-ray emission)
Energy	27 - 35 keV
Contamination monitoring	Thin crystal NaI detector, liquid scintillation counter for wipe surveys
Shielding	Thin lead
Dosimetry	Film badge, TLD ring, thyroid scan

I-125 Decay Table

days	0	1	2	3	4	5	6
0	1000	988	977	966	955	944	933
7	922	911	901	890	880	870	860
14	850	840	830	821	811	802	792
21	783	774	765	756	748	739	731
28	722	714	705	697	689	681	673
35	666	658	650	643	635	628	621
42	614	606	599	593	586	579	572
49	566	559	553	546	540	534	527
56	521	515	509	504	498	492	486

The following precautions are applicable to iodination procedures or the handling of radioiodine in activities higher than typically found in RIA kits.

1. The dose rate at 1 cm from a 1 mCi point source is about 1.5 rem/hr. From the inverse square law, a small amount of I-125 held for a short time can result in a significant dose to the hands, a relatively short separation distance reduces the dose rate significantly.
2. The volatility of iodine requires special handling techniques to minimize internal radiation doses. Solutions containing iodide (e.g., NaI) should not be made acidic or be frozen. Both lead to formation of volatile elemental iodine. Once bound to a protein, the volatility of the radioiodine is reduced.
3. Always work in a fume hood with a minimum face velocity of at least 100 linear feet per minute when working with NaI. The sash should be below the breathing zone.

4. Avoid opening the septum of delivery vials. It is preferable to remove radioiodine using a hypodermic needle and syringe.
5. A radiation survey meter should be available in the immediate area. A low energy scintillation detector is better than a G-M. Do a wipe survey in your work areas after each use.
6. Dosimeters must be worn for all radioiodine work. If you have been issued a TLD ring, it should be worn whenever working with I-125.
7. Use lead to shield quantities of 1 mCi or more. 1 mm of lead will block all of the radiation emitted from I-125.
8. Until waste is picked up by Radiation Safety, keep the waste container in a fume hood.

## G. Disposal and Transfer

Commercial low-level radioactive waste (LLRW) disposal facilities are either no longer accepting USD generated radioactive waste or will stop in the near future. Therefore, researchers and the Radiation Safety Officer keeps accumulated waste to a minimum through decay-in-storage, sanitary sewer disposal of miscible liquids and incineration. Appendix C has a diagram summarizing disposal.

### Decay-in-Storage

Radioactive waste can be segregated by radioactive half-life. The three categories for segregation are:

- Half-life less than 15 days (P-32)
- Half-life between 15 and 120 days (P-33, S-35, Ca-45, Cr-51, I-125)
- Half-life greater than 120 days (H-3, C-14, Ca-45)

Isotopes with half-lives less than 120 days can be held for decay either in the lab or by Radiation Safety. For decay-in-storage, it is important that waste is placed in the proper container. If a waste contains two different radionuclides (e.g., P-32 and P-33), place it in the container labeled for the longer half-life.

The USD license allows for decay in storage for isotopes with half lives less than 120 days and requires that the waste be kept for at least ten half lives or until the activity is no longer readily distinguishable from the background levels using a sensitive survey meter. When 10 half-lives have elapsed and a measurement demonstrates background levels, the materials in the box may be disposed of as ordinary waste. However, before disposal, you must deface any radiation symbol or words denoting radioactivity on boxes, vials, etc. You will need to keep a log book which includes the following for each box:

- the radioisotope
- the date placed in storage or the calibration date (if all the material is from the same vial)
- the total activity in the box
- the date measured for disposal (i.e., 10 half-lives)
- the background count rate and the highest count rate on the box
- the initials / name of the person who disposed of the material

The RSO will accept solid waste for decay in storage. When transferring the material to the RSO, complete a Transfer of Radiochemicals form (Appendix B). Additionally, when radioactive wastes are transferred to the RSO, they should be double-bagged and placed in a durable cardboard box. Sharp objects which may puncture thin bags (e.g., pipette tips, etc.) should be placed in small cardboard boxes or sharps containers before being placed in the waste box. Solid wastes transferred to the RSO must

also be properly tagged or labeled. Tags and labels are available from the RSO. The information provided on the tags or label includes:

- The radioisotope
- The transfer date
- An estimate of the total activity

The estimate of the total activity may be uncertain. Try to give an estimate accurate to within a factor of two. Bear in mind, you received a vial with a quantity of radioactive material, that quantity must be accounted for among your solid and liquid waste streams. Decay-in-storage will insure that no radioactive material is disposed until it has decayed. As mentioned above, unless required by experimental procedures, segregate your waste by isotope.

### **Long-lived Radioactive Wastes**

Solid wastes involving materials with a half-life more than 120 days must be transferred to the RSO. Wastes containing  $^3\text{H}$  and  $^{14}\text{C}$  are combusted in the University incinerator. Depending on isotope, other solid wastes may also be incinerated.

### **Liquid Radioactive Wastes**

Disposal via sanitary sewer is acceptable only if the material is either readily soluble in water or “readily dispersible biological material.” Solid material may not be disposed of to the sanitary sewer if it has a size and density that might cause it to be trapped within the sewer system. Plant or animal remains must be reduced in size sufficiently for them to move readily through the sewer system. Further comments on the disposal of animal remains are given in the section on the use of animals. Tissues containing more than 50 nCi/g of  $^3\text{H}$  or  $^{14}\text{C}$  must be incinerated (i.e., 10 CFR 20.2005 exempts  $^3\text{H}$  and  $^{14}\text{C}$  animal tissues or sewerable LSC cocktail in concentrations less than 0.050  $\mu\text{Ci/g}$ ).

Given the University’s sewage water volume, an authorized user may dispose of up to 100  $\mu\text{Ci}$  via the sanitary sewer on any day but no more than 100  $\mu\text{Ci}$  each week. The RSO can provide a special, one-time authorization for disposal of up to up to 1 mCi.

Sink traps contain about a pint of water, so after pouring your material into the sink drain, flush the radioactive waste with a few gallons of water to adequately clear the waste from the drain trap and the building’s sewer system.

Liquid radioactive waste includes the radioactive material and the first rinse of its experimental container. After the first rinse, container can be considered not radioactive and washed in the sink.

Liquid radioactive waste is to be stored in a container designated for that purpose. Its disposal date and the activity at the time of disposal are to be recorded in the lab’s waste log book. The estimate of liquid waste activity should be relatively accurate since you can measure the activity on a liquid scintillation counter. Remember, the activity sewered may be different than your inventory since the sewered amount will include radioactive decay while the inventory must account for the total activity you received.

### **Mixed Hazardous/Radioactive Waste**

Radioactive waste containing hazardous chemicals is regulated by both the NRC and EPA. It may require special handling. If your procedure generates these “mixed” wastes, contact Radiation Safety before you generate any waste so we can keep waste disposal costs low.

## **Waste Minimization**

Because radioactive waste must be stored on campus until it decays or until it is sewerred, it is important that the amount of waste generated be kept to a minimum. Some ways to minimize waste are:

- Design experiments to use as little radioactive material as possible.
- Use proper handling techniques to reduce the chance of contamination.
- When practical, use techniques which do not involve radioactive materials. There are many new techniques and products available which can be used in place of radioactive materials.
- Monitor material for contamination and dispose as little as possible as radioactive waste. If there is a spot of contamination on a piece of absorbent paper, cut out that spot and dispose of it rather than the whole piece. Don't automatically place your gloves in the radioactive waste. Monitor them. If there is no detectable contamination, throw them in the normal (black-bag) waste container.

## **Prohibited Items**

Solid waste can not be picked up by Radiation Safety if it contains any of the following:

- Hazardous material (e.g. lead, hazardous chemicals, toxins). Lead shipping containers and other lead shielding should not be disposed of as ordinary trash or placed in solid radioactive waste containers. Lead should be separated and boxed, it will be picked up by Radiation Safety and recycled.
- For biohazard bags or other similar hazardous materials, inactivate and overpack any formerly biohazardous waste.
- Sharps (e.g. needles, razor blades), double box sharps and present separately.

## **H. Use of Animals**

Radiochemical work with animals must be done within an approved area and only by an authorized user or trained radiation worker. Procedures used with the animals, descriptions of caging, procedures for their decontamination, and for the disposal of solid wastes and carcasses must be approved by Radiation Safety and a copy kept in the same file as the laboratory notebook. A copy of the application made to the Animal Care Committee will suffice if live animals are involved since such applications require the RSO review. Signage will be required on the animal room as well as the individual animal cages stating "Caution Radioactive Materials."

## **I. Radiation Emergencies**

No matter how carefully you try to work, accidents can happen. With adequate training, preparation, and effort, any radiation worker can safely handle any emergency that could occur in normal work procedures. Important phone numbers for incidents for which you need assistance include:

Radiation Safety: 677-6265

USD Public Safety: 677-5342

Radiation Safety personnel home phone numbers are available at Public Safety. Safety personnel will respond to assist you regardless of the hour.

## **General Procedures**

Preparedness can make the difference between a controlled situation and a disaster. Knowing what to do in an emergency and having the proper materials on hand are essential for safe, efficient handling of spilled radioactive materials in the laboratory. Plan ahead and equip your lab with a spill kit that contains supplies needed to handle the most likely spill, incident, or emergency. The kit should include

several pairs of disposable gloves, thick rubber (e.g., Playtex) gloves, absorbent material, disposable shoe covers, radioactive waste bags, etc. These items can be kept in a ½-gallon or gallon size zip lock plastic bag and should be inventoried at least once each year.

The response to a spill depends upon the seriousness of the spill. Therefore, immediately following a spill or dispersion of radioactive materials, assess the situation by asking, "Can I handle this myself or do I need help?" Regardless of the assessment, the four key steps applicable for most laboratory emergencies are:

- ✓ **Notify others of the spill.** Control access to the area and instruct all persons present in the lab to leave the immediate area, but to remain within the laboratory area to prevent possible spreading of the contamination. For major spills, the area should be cleared of all persons not involved in the spill and Radiation Safety should be notified immediately.
- ✓ **Contain the spill.** For large spills put on proper clothing. In serious accidents, close off and vacate the area; contact Radiation Safety immediately. Prevent the spread of liquid spills by placing absorbent material such as paper towels, tissues, cloth, etc. If the material is a powdered solid, attempt to contain its spread by covering the area with a protective barrier such as a tray, beaker, or kraft paper. If appropriate, close doors and windows and turn off the room ventilation fans, but keep any fume hood turned on to exhaust any contaminated air. Limit movement of persons who may be contaminated.
- ✓ **Decontaminate the area.** Wear appropriate clothing. Insure a survey meter is present. Gather any material needed for decontamination and, for large spills, organize the decontamination by task. Absorb all standing liquids, apply a decontaminating solution and allow it to loosen the contamination before wiping the area. Assume all material used in the decontamination are contaminated and treat as radioactive waste.
- ✓ **Monitor the area.** Using proper techniques, check the area of the spill for contamination beginning well away from the spill to determine where the contamination actually starts and whether contamination has been spread elsewhere. Monitor all persons (hands, clothing, and shoes - especially the soles). It is prudent to consider anything over twice background or above 100 cpm as being contaminated.

Contact Radiation Safety at the first opportunity. Radiation Safety will follow-up the lab's cleanup, document the incident, and, if necessary, contact the NRC. While most spills should be relatively minor, some things to bear in mind about health and safety include:

- In all cases of physical injury, even minor injuries, medical attention and hospitalization take precedence over contamination concerns.
- Serious injury and life-or-death situations always take priority over radiological concerns.
- Do not risk external or internal exposure to save equipment or an experiment.

### **Injury Involving Radioactive Material**

In the event of a serious injury (heavy bleeding, heart attack, etc.), obtain medical assistance immediately. Do not attempt to decontaminate before seeking (or rendering) first aid. After necessary first aid has been given, notify your supervisor and Radiation Safety. For minor injuries (e.g., puncture wound, suspected inhalation or ingestion, skin contamination, etc.), first attempt to decontaminate before seeking medical care.

1. Call USD Public Safety, 677-5342 and request emergency medical services. Tell the dispatcher that it is a radiation emergency and request notification of the Radiation Safety Officer.
2. When emergency personnel arrive, inform them of the possibility of radioactive contamination.
3. Follow the steps for a major or minor spill, if appropriate.
4. Try to determine the radionuclide, activity, and chemical form of the material involved.

### **Major Spill**

A major spill is one which may require more skill or equipment than your lab has available. Have all persons not involved in spill leave the area immediately. Survey all persons leaving the room and control the movement of these persons to prevent possible spread of contamination. The goal is to minimize the area of the spill and prevent the spread of contamination.

- ✓ If a liquid has spilled from a container, return container to an upright position using gloves or a lever and prevent further spread of the liquid.
- ✓ If material is volatile (e.g., dusts, fumes, gases), turn off all fans and shut off room ventilation system, but keep fume hood on to exhaust possibly contaminated air from the room. Evacuate and secure the room. Close and lock doors and/or post guards to prevent entry.

Once the area is secured, use a survey meter to monitor all persons suspected of being contaminated. Consider anything over twice background or above 100 cpm as being contaminated. Take immediate steps to decontaminate those workers found contaminated.

- ✓ If skin is contaminated, wash with mild soap and water.
- ✓ If the spill is on clothing, remove / cut contaminated clothing, as appropriate. Safety will assist in decontaminating clothing and returning cleaned items to their owners.
- ✓ Report known or suspected inhalation or ingestion of radioactive material to Radiation Safety.
- ✓ Re-monitor to verify decontamination efforts have reduced contamination to below 100 cpm.

After stabilizing the spill and insuring personnel are free of contamination, notify Radiation Safety (677-6265) or call USD Public Safety (677-5342) after hours telling them that you need assistance from Radiation Safety. Do not panic. Do NOT call the Fire Department unless there is a fire. When Radiation Safety arrives, they will assist you in developing a decontamination plan. Some of the issues that enter this plan are:

- An evaluation of the hazard and any safety devices needed for reentry.
- An assessment of the cause of the contamination and methods to correct the condition.
- Determination whether air monitoring is needed.

In a major spill, it is essential that all other work in the area stop until Radiation Safety has verified the area is clean. Safety will provide guidance regarding residual radioactive contamination. Remember, before leaving, monitor persons involved in spill / cleanup. Lastly, prepare a history of the spill and cleanup and forward the report to Radiation Safety.

### **Minor Spill**

A minor spill is one that is relatively small, well contained, and well within the capabilities of all radiation workers to clean with common cleaning materials. To keep people out of the possibly contaminated area, immediately notify all persons in the room or area of the spill and limit access to the spill area to those persons needed for cleanup purposes. Do not ask housekeeping staff to help in the cleanup or to lend you their equipment.

Prepare to decontaminate. First monitor yourself, insure you are not contaminated. Then, get cleaning supplies (e.g., paper towels, scouring power, detergent, etc.). Wear protective clothing (heavy-duty rubber gloves, lab coat, safety glasses) and begin clean-up. The basic goal is to confine the spill and prevent the spread of contamination.

- ✓ Liquid spill - place absorbent paper on the spill.
- ✓ Dry spill - dampen absorbent paper with water (or oil if a reaction producing air contamination could occur from using water) and cover the spill.

Use a survey meter to identify and then label the boundaries of the spill area with either "Caution Radioactive Material" tape or label the contaminated spots with a magic marker. Begin cleaning at the edges of the spill and work towards the center (lowest to highest level of contamination). Minimize the amount of water used to reduce runoff. Dispose of all cleanup materials as radioactive waste. Monitor all persons involved in the incident.

- ✓ Do not let persons leave the area until they have been surveyed and found to be contamination free. This includes those personnel not involved but in the area. The action level with a survey meter is twice background or about 100 cpm above background. If contamination is found, have workers change clothes and wash as needed, then re-monitor.
- ✓ Keep others out of the area until Safety approves access or the spill is decontaminated.

At the first convenient opportunity after the spill has been cleaned, write a report of the spill and subsequent remedial or protective measures taken and send it to Radiation Safety. However, if you need help, call Safety and ask for assistance / guidance.

### **Considerations for Reducing Accident Risk or Mitigating Emergencies**

Many laboratory accidents occur from a failure to follow basic general laboratory safety procedures. Some of these considerations are listed below.

- When working with high-energy radionuclides (e.g.,  $^{32}\text{P}$ ,  $^{125}\text{I}$ ), wear dosimetry to monitor exposures and survey work areas at the conclusion of the work or at the end of the day.
- Wear lab coats and protective gloves when handling hazardous materials in the laboratory.
- Store radioactive materials and hazardous wastes in designated areas within the laboratory.
- Laboratory surfaces where radioactive materials are used should be covered with absorbent paper.
- Transfer of unsealed radioactive materials from one lab to another is to be done in closed containers and carried in deep trays lined with absorbent paper.
- Operations involving exposures in excess of 10 mR/hr are to be performed behind lead shielding.
- When working with more than one millicurie of  $^{32}\text{P}$ , work behind a Plexiglas shield and wear a ring dosimeter in addition to a body badge.
- Personnel handling more than 20 millicurie of organic forms of  $^3\text{H}$  or more than 10 mCi of tritiated-water will have a pre and post urine count and report the results to the Radiation Safety Office. Discuss counting techniques with the RSO to preclude false positives.
- No mouth pipetting, not even water.
- Use fume hoods for hazardous materials or procedures that may produce dust, vapors or gasses.
- Have and use survey meters when working with radioactive material. Survey yourself, your work surfaces and other laboratory equipment for contamination. At the end of the day and before leaving the lab, wash hands and record the monitoring results in the laboratory notebook.
- No food or drink in the laboratory except for areas separated from chemical and radiochemical activities that have been specifically designated and are so marked.

- Members of the general public may enter restricted areas if they are accompanied, remain reasonably distant from any laboratory activities involving radiochemicals, and keep away from areas of possible contamination.

## J. Records, Reports, and Inspections

Your laboratory notebook, its electronic extensions, and instrumental output serve as the primary evidence to document good laboratory practice and compliance with the University's NRC license requirements. These records are to be kept for at least three years after the radioactive material has been disposed and five years is advisable. Periodic review of the records of authorized users by the RSO is a license requirement and normally occurs annually.

Three regular reports are required of each active authorized user, two monthly reports and an annual report. New users or reactivated workers are to begin providing reports for the first month during which a radionuclide shipment has been received.

- **Inventory Report:** this report is due the first week of each month and lists the identity and activity at the end of the previous month of each radioisotope that the authorized user possesses. The amount is to include liquid and solid waste still within the user's lab. The activities reported are to be based on the nominal activity ordered (e.g. 250  $\mu\text{Ci}$ ); the error in not correcting for "fresh lots" of short-lived material will be insignificant.
- **Survey Report:** this reports the results of the required monthly laboratory surveys and is also due the first week of each month. If a laboratory diagram identifying the sites to be checked for possible contamination is on file with the RSO, this report need be no more than a signed listing of sites with the observed survey levels. The number of points surveyed can be reduced when radioisotopes have not been used in the laboratory during the prior month. However, a minimum of 5 sites must be surveyed even in the absence of radioisotope use as long as a user remains and active user. Except for authorized user's who are only authorized  $^3\text{H}$ , this survey should consist of a survey meter result and an LSC result. The LSC survey is primarily a check for removable contamination, but will also register  $^3\text{H}$  levels.
- **Annual Report:** this report includes a worker information form for all new workers. All users who have been active during a calendar year and all workers monitored with dosimetry receive an annual report of their annual exposure. Thus the names and addresses of all workers who have left the University are needed for forwarding the report.

## **A. Reference Documents**

1. *Notices, Instructions, and Reports to Workers: Inspection and Investigations*, Title 10, Chapter 1, CFR, Part 19.
2. *Standards for Protection against Radiation*, Title 10, Chapter 1, CFR, Part 20,
3. *Rules of General Applicability to Domestic Licensing of Byproduct Material*, Title 10, Chapter 1, CFR, Part 30.
4. *Specific Domestic Licenses of Broad Scope for Byproduct Material*, Title 10, Chapter 1, CFR, Part 33.
5. *Packaging and Transportation of Radioactive Material*, Title 10, Chapter 1, CFR, Part 71.
6. *Consolidated Guidance about Materials Licenses: Program-specific Guidance about Academic, Research and Development, and Other Licenses of Limited Scope*, NUREG-1556, Vol. 7.
7. *Consolidated Guidance about Materials Licenses: Program-Specific Guidance about Licenses of Broad Scope*, NUREG-1556, Vol. 11.

## **B. Forms**

1. University of South Dakota, Radiation Worker Information Form.
2. University of South Dakota, Radiation Worker Annual Report.
3. Transfer of Radiochemicals.
4. Protocol Summary
5. Disposal Pathways (Appendix C).

**UNIVERSITY OF SOUTH DAKOTA  
RADIATION WORKER INFORMATION FORM**

**NAME:**  
**FACULTY SUPERVISOR:**

**DEPARTMENT:**

**DEGREE(s) (Give institutions and dates for degrees earned or being pursued:**

1.

2.

**RADIOCHEMICAL COURSEWORK:**

TITLE	DATE	INSTITUTION	CR HRS

**SHORT COURSES/INSTITUTES/WORKSHOPS:**

TITLE	DATE	PROVIDER	HRS

**EDUCATIONAL MATERIALS YOU HAVE STUDIED: USD Radiation safety manual (required), books, guides, federal regulations, etc.**

**DIDACTIC AND HANDS-ON TRAINING: Describe and include the time devoted to your training before unsupervised use of radiochemicals was permitted.**

\_\_\_\_\_/\_\_\_\_\_  
(Worker signature) (Date)

\_\_\_\_\_/\_\_\_\_\_  
(Supervisor signature) (Date)

UNIVERSITY OF SOUTH DAKOTA  
RADIATION WORKER ANNUAL REPORT

NAME: \_\_\_\_\_

FACULTY SUPERVISOR: \_\_\_\_\_

1. Isotopes with which you have worked this past year: \_\_\_\_\_
2. Briefly characterize your work responsibilities and activities during the last year.
  
3. You are required to have read the Radiation Safety Manual once carefully and then to review it at least annually. Please give the date of last review.  
\_\_\_\_\_
4. Provide a brief description of any new educational experiences you have had during the past year (Formal instruction, hands on training by your supervisor, independent reading).

\_\_\_\_\_/\_\_\_\_\_  
Worker Signature      Date

\_\_\_\_\_/\_\_\_\_\_  
Supervisor Signature      Date

## TRANSFER OF RADIOCHEMICALS

FROM:     Faculty User             Radiation Safety Officer

Signature \_\_\_\_\_

Date: \_\_\_\_\_

TO:         Faculty User             Radiation Safety Officer

Signature: \_\_\_\_\_

FOR:       Storage     Decay in Storage             Disposal

Current or Future Use

1. Isotope(s):   $^3\text{H}$      $^{12}\text{C}$      $^{32}\text{P}$      $^{35}\text{S}$      $^{125}\text{I}$     \_\_\_\_\_

2. USD Lot Number(s): \_\_\_\_\_

3. Activity Transferred: \_\_\_\_\_

4. Transfer No. (RSO) \_\_\_\_\_

**All radiochemicals are the responsibility of either a faculty user or the Radiation Safety Officer.** When the transfer is between users, a copy is to be forwarded to the Radiation Safety Officer.

If the transfer is to the Radiation Safety Officer for decay in storage or disposal, attach a tag giving a rough estimate of the activity, one that exceeds the amount transferred.

## PROTOCOL SUMMARY SHEET

(Use a separate sheet for each proposed use)

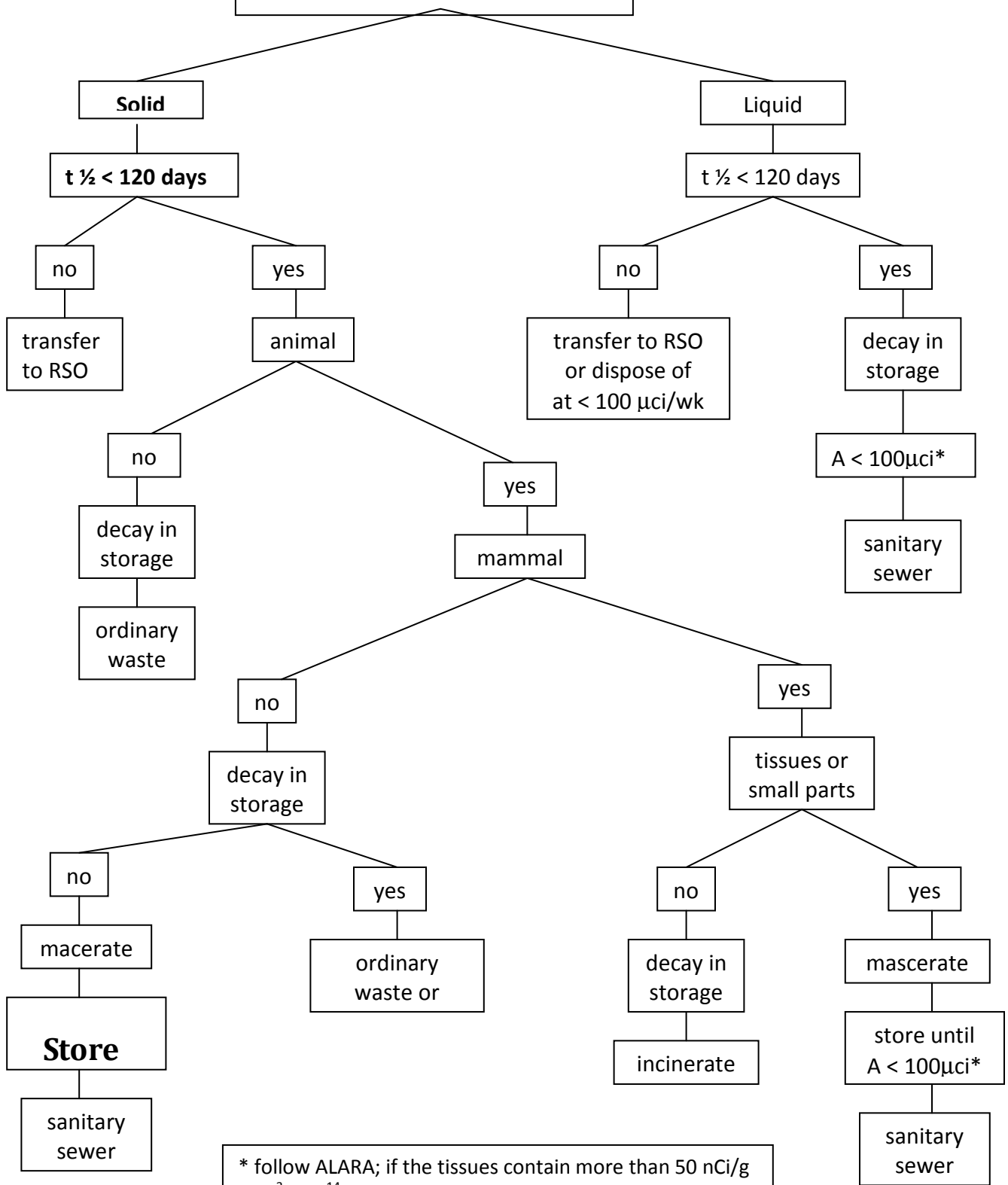
P I: \_\_\_\_\_ DATE: \_\_\_\_\_

ADDRESS: \_\_\_\_\_ PHONE: \_\_\_\_\_

1. Radionuclide:
2. Chemical and Physical Form:
3. Substance is volatile: YES \_\_\_\_ (explain) NO \_\_\_\_
4. Procedure is performed at Standard Temperature and Pressure (STP): YES \_\_\_\_ NO \_\_\_\_ (explain)
5. Protocol: Provide a brief description of the procedure (for routine procedures, it is appropriate to state "triphosphates for DNA sequencing & transcription" or "orthophosphates for cell labeling" or "RIA kits." Also include information on chemical and physical form generated, any special equipment used to handle, shield or contain the radioactivity, and unusual hazards associated with the procedure.
6. Total Activity Per Experiment (e.g.,  $\mu\text{Ci}/\text{run}$ ).
7. Frequency of Experiment (e.g., 1 per week, 1 per month):
8. Comments:
9. Mixed hazardous and radioactive waste or unusual waste will be generated: YES \_\_\_\_ NO \_\_\_\_  
(i.e., chemical, biological, or genetic hazardous material mixed with radioactive waste).
10. Vertebrate Animals will be used: YES \_\_\_\_ NO \_\_\_\_

(Return to Radiation Safety, Davidson Bldg. or FAX 6242)

# Disposal Pathways



\* follow ALARA; if the tissues contain more than 50 nCi/g of <sup>3</sup>H or <sup>14</sup>C, they must be incinerated.

