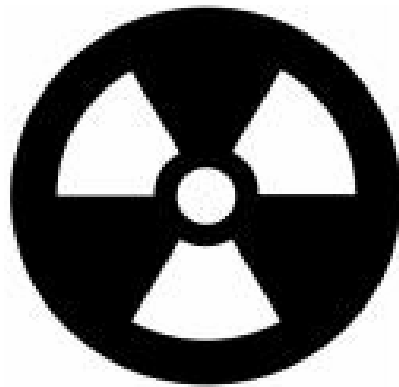


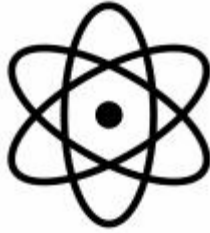
**UNIVERSITY OF CALIFORNIA, IRVINE
ENVIRONMENTAL HEALTH & SAFETY OFFICE
RADIATION SAFETY DIVISION**

**RADIATION SAFETY SYLLABUS
FOR NEW USERS OF
RADIOACTIVE MATERIALS**



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RADIATION SAFETY

I. DEFINITIONS: RADIATION

- A. Radiation:** The emission and transport of energy in the form of electromagnetic waves or high-energy subatomic particles.
- B. Ionizing Radiation:** Radiation that contains enough energy to dislodge electrons from atoms.
- C. Nuclide:** A particular species of atom defined by the constitution of its nucleus (i.e., the numbers of protons and neutrons).
- D. Radioactivity:** The property of certain unstable nuclides of spontaneously emitting ionizing radiation from the nucleus. **These nuclides are *radioactive*, and they emit *radiation*!** *Those two terms are not synonymous.*
- E. Mass Number:** The total number of protons plus neutrons in the nucleus of an atom. The mass number “A” of a nuclide “X” would normally be portrayed as ${}^A\text{X}$; thus, the mass number of ${}^{32}\text{P}$ is 32.
- F. Atomic Number:** The number of protons in the nucleus of an atom. Also equal to the number of orbiting electrons (unless the atom is in an ionized state).
- G. Types of ionizing radiation:**
1. Electromagnetic radiation (**photons**)
 - a) Gamma Rays: High-energy photons (packets of electromagnetic energy) emitted from the nucleus during radioactive decay.
 - b) X-rays: Photons emitted during energy level transitions of orbital electrons (*not emitted from the nucleus!*).
 - c) Bremsstrahlung: Secondary x-ray energy photons produced by the deceleration of charged particles (such as beta particles) as they travel through matter. The word “bremsstrahlung” is German for “braking radiation”.

2. Particle radiation

- a) Beta particles: Negatively-charged electrons emitted from the nucleus during radioactive decay. Unlike gamma rays (which are only emitted at certain defined energies), beta particles are emitted with a continuous energy distribution ranging from zero up to a maximum value ($E_{\text{avg}} \sim 0.35E_{\text{max}}$).
- b) Positrons: Positively-charged electrons emitted from the nucleus during radioactive decay.
- c) Alpha particles: Heavy, positively-charged particles, identical to helium nuclei (they contain two protons and two neutrons), emitted from the nucleus during radioactive decay.



II. DEFINITIONS: RADIOACTIVE DECAY

- A. Half-life:** The time required for one-half of the atoms of a radioisotope to decay. Radioactive decay is a random process which obeys exponential decay statistics. The number of radioactive atoms remaining at any time t can be calculated using the following equations:

$$N(t) = N_0 e^{-(693t/T)}$$

where

N_0 = original number of radioactive atoms

$N(t)$ = number remaining at time t

t = decay time involved

T = half-life of radioisotope

or

$$N(t) = (1/2)^n N_0$$

n = number of half-lives of decay = t/T

- B. Energy Units:** The kinetic energy of the emissions from radioactive atoms is measured in units of electron volts (eV). One electron volt is equal to 1.602×10^{-19} joules. *Note: 1 keV = 10^3 eV; 1 MeV = 10^6 eV.*

C. Radioactivity Units:

1. **Curie (Ci):** A quantity of any radioisotope which decays at a rate of 37 billion disintegrations per second. *Note: 1 μ Ci = 10^{-6} Ci; 1 mCi = 10^{-3} Ci. [Specific activity = radioactivity per unit mass or volume of material, such as mCi/gm, μ Ci/ml, etc.]*
2. **Becquerel (Bq):** A unit of radioactivity equal to 1 disintegration per second. *Note: 37 MBq = 1 mCi; 37 kBq = 1 μ Ci.*

Curie and Becquerel are units of radioactivity (decays per unit time) only; they do not relate in any way to the types or energies of radiation emitted during the decay process. In the U.S., mCi or Ci units are still widely used to express the quantity of radioactivity present. In most other countries, Bq units are generally used for that purpose.



III. ATTENUATION OF RADIATION IN MATTER

A. Particle Radiation:

1. Alpha Particles

Alpha particles are the least penetrating of the various types of ionizing radiation. In air, even the most energetic alpha particles travel only a few centimeters, while in tissue, the range of alpha particles is measured in micrometers ($1\mu\text{m} = 10^{-6}$ meter).

2. Beta Particles

Experimental data have shown that the ability of a material to absorb energy from beta particles depends primarily on the density (g/cm^3) and the thickness of the absorber. The maximum ranges of the beta particles from commonly-used radioisotopes are shown below.

[Note: mm = millimeter; cm = centimeter.]

RANGES OF BETA PARTICLES

Radioisotope	Max. beta energy	Range in air	Range in tissue
^3H	18 keV	4.5 mm	0.006 mm
^{14}C	156 keV	22 cm	0.28 mm
^{32}P	1.7 MeV	610 cm	8 mm
^{33}P	249 keV	45 cm	0.6 mm
^{35}S	167 keV	24.5 cm	0.3 mm

B. Photons (x-rays and gamma rays)

Gamma rays of the same energy are absorbed in an exponential manner:

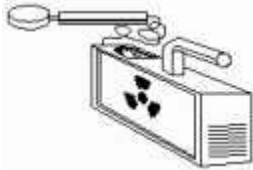
$$I = I_0 e^{-\mu x}$$

where I_0 is the original gamma ray intensity, I is the gamma ray intensity transmitted through an absorber of thickness x , e is the base of the natural logarithm system, and μ is the slope of the absorption

curve (the linear attenuation coefficient with units cm^{-1}). The linear attenuation coefficient is related to the **half-value layer (HVL)**, which is the thickness of a radiation absorbing material which will reduce the photon (gamma ray or x-ray) intensity by 1/2, in the following way:

$$\text{HVL} = 0.693/\mu$$

For a thickness of 2 HVLs, the photon intensity is reduced to 1/4 the original value. For a thickness of 3 HVLs, the photon intensity is reduced to 1/8 the original value, and so on. *A shielding thickness of 7 HVLs is needed to reduce the photon intensity to less than 1% of the original value.* This is a good rule to remember when you need to determine the amount of shielding to use to properly attenuate photon radiation.



IV. RADIATION DETECTION AND MEASUREMENT

The basic requirement for a radiation detector is that the instrument's detection medium interacts with the radiation in such a manner that the magnitude of the response of the instrument is proportional to the radiation property being measured. The commonly-used types of radiation detectors are described below.

A. Geiger-Mueller (GM) Counters

GM counters are used to detect medium and high energy beta particles, and also x-rays and gamma rays.

Major advantages of GM counters: Principle of operation very simple, relatively inexpensive, easy to use, reasonably small in size, reliable, durable, and very versatile. *They are an excellent choice to use when performing lab surveys for beta and gamma contamination.*

Major disadvantages of GM counters: Because any ionization event which occurs in the sensitive volume of the detector produces a pulse of the same magnitude, a GM counter cannot be used to measure radiation exposure directly. The sensitivity of a GM counter is dependent upon the energy of the incident radiation in a non-linear fashion; however, the response of most GM counters is approximately linear for photon energies above 100 keV.

Before each use, the batteries should be checked by the operator of the GM to ensure that they have sufficient charge. Most GM counters have a simple battery test feature, generally in the form of a button to press, or incorporated into the range adjustment switch.

B. Liquid Scintillation Counters

A liquid scintillation counter (LSC) is a radiation detector which changes the kinetic energy of an ionizing particle or photon into a flash (or flashes) of light. The light is then collected by photomultiplier tubes, and the output electronic pulses are amplified, sorted by magnitude, and counted.

Liquid scintillation counters are often used to count beta particles from radioisotopes such as ^3H , ^{14}C , ^{32}P , ^{33}P , ^{35}S and ^{45}Ca with high efficiency (>50%). Gamma rays can also be detected using an LSC, but not with near the same efficiency as for beta particles.

The counting efficiency of GM counters for low-energy beta particles is often quite low due to the fact that these beta particles do not have sufficient energy to make it through the thin window of the detector into the sensitive counting volume. This problem is overcome in an LSC by dissolving the radioactive sample in the scintillating (light-emitting) liquid, called the scintillation “cocktail”.

In some cases, such as when the cocktail is exposed to ultraviolet light from the sun, if a chemical reaction occurs between the cocktail and the sample (this happens with asphalt and other materials), or if the vial containing the sample/cocktail mixture is shaken vigorously, counts can be registered by an LSC independent of the presence of radioactive material. If there is reason to suspect that this has occurred, the samples should be counted again at a later time after these normally very short-lived (minutes to hours) interference effects have subsided.

LSCs are commonly used on campus, both for experimental analyses of radioactivity, and for counting wipe test samples.

C. Solid Scintillation Detectors

These detectors, which are found in automated **gamma counters**, employ the same principle of operation as LSCs – radiation/detector interaction \Rightarrow light flash \Rightarrow electronic pulse. However in this case, a solid scintillation crystal is used instead of a scintillating liquid.

The solid scintillation detector used most frequently is a **sodium iodide crystal** (similar to a big salt crystal) containing a small amount of thallium [NaI(Tl)] that is optically coupled to a photomultiplier tube.

In addition to detecting gamma rays, NaI(Tl) detectors are capable of measuring the energies of the gamma rays, and this is useful in identifying unknown gamma ray emitters by comparing the gamma energies of the unknown with the known gamma ray spectra of radioisotopes.

The major disadvantage of solid crystal detectors relates to the fact that the crystals are delicate and can be destroyed if they are dropped or handled in a rough manner.

D. Ion Chambers

Ion chambers are generally used to detect x-rays and gamma rays, but they occasionally are used to detect high energy beta particles (energy > 1 MeV).

Principal advantages: Capable of measuring **very high radiation levels**. Ion chambers can be used to directly quantify the magnitude of an ionizing radiation field.

Major disadvantages: Not useful in measuring the low radiation levels that are much more commonly found in research laboratories at UC Irvine. Geiger counters are much better for that purpose.

E. Proportional Counters

Proportional counters are used to detect radiation with very short ranges in matter. Therefore, these counters are used to measure alpha particles, low energy beta particles, and extremely low energy gamma rays and x-rays.

Principal advantages: Can easily distinguish between alpha and beta particles through pulse-height discrimination. Can be used to measure very high count rates.

Major disadvantage: The need to prevent the deterioration of the counting gas. This is usually accomplished by flowing the gas through the sensitive volume of the detector during operation (these detectors are called “gas-flow proportional counters”).



V. RADIATION EXPOSURE AND DOSE UNITS

- A. **Roentgen (R):** Unit of **radiation exposure**. This unit is related to the number of ion pairs produced by x-rays or gamma-rays in air. The radiation exposure rate is generally measured in milliroentgens per hour (0.001 R/h). Most GM counters are scaled in units of mR/h. *[Some are scaled in counts per minute.]*
- B. **Rad (radiation absorbed dose):** Unit of radiation dose. This unit is related to the quantity of energy actually deposited in a medium (1 rad is equal to the deposition of 100 ergs of radiant energy per gram of medium). It turns out that if air is exposed to 1 R of x-ray or gamma-ray radiation, the equivalent energy deposition in the air would be about 0.87 rad.
- C. **Rem:** unit of **radiation dose equivalent**. The factor used for gauging the relative biological effectiveness of a given type of radiation to cause effects is known as the **Quality Factor (QF)**. The table below lists the Quality Factors of common forms of ionizing radiation.

QUALITY FACTORS

<u>Radiation</u>	<u>QF</u>
x-rays	1
gamma rays	1
beta particles	1
neutrons	3-10 (energy dependent)
protons	10
alpha particles	20
heavy ions	>20

When the absorbed dose in rads is multiplied by the quality factor, the resulting value is the dose equivalent expressed in **rems**. Thus,

$$\text{rems} = \text{dose (in rads)} \times \text{QF}$$

☞ Note: The radiation exposure/dose units above are the "**traditional**" units which have been used for many decades. These units are still commonly used in the United States. However, a new system of units [termed the **Systeme International (SI)**] was introduced in the early 1980s and has been widely adopted, especially outside of the United States. When communicating with individuals from other countries, SI units should always be used. The following two units are from that system. ☞

D. Gray: The Gray (Gy) is equal to an **absorbed dose** of 1 joule of energy per kilogram of medium. The relationship between the gray and the rad is as follows:

$$1 \text{ gray} = 100 \text{ rads}$$

E. Sievert: The Sievert (Sv) is a unit of **radiation dose equivalent**:

$$\text{sieverts} = \text{dose (in grays)} \times \text{QF}$$

$$1 \text{ sievert} = 100 \text{ rems}$$



VI. BIOLOGICAL EFFECTS OF IONIZING RADIATION

There are two types of exposure to ionizing radiation: a) **acute exposure** -- a single, accidental exposure to a high dose of radiation during a relatively short period of time, which may produce severe biological effects very soon after exposure; and b) **chronic exposure** -- long-term exposure to a level of radiation higher than the normal background level, but much lower than that needed to produce acute effects. The

observable biological effects of chronic exposure, if they occur, may not be apparent until many years (often >20 years) after the period of exposure.

Some of the major biological effects produced by acute exposures and chronic exposures to **penetrating forms of ionizing radiation** (x-rays, gamma rays) are discussed below. Less penetrating forms of radiation, such as alpha and beta particles, primarily affect the skin (providing the emitting radioisotopes are not inhaled or ingested), and do not produce many of the effects mentioned here:

A. Acute effects

Acute exposure of the human body to ionizing radiation may affect all of the organs and systems of the body. However, since the organs are not all equally sensitive to radiation, the pattern of response (disease syndrome) of a severely over-exposed individual depends upon the magnitude of the dose received. To simplify the classification process, the **acute radiation syndrome** is subdivided as follows:

1. Hemopoietic (blood system) syndrome

Changes in the blood cell count are the most sensitive biological indicators of acute radiation exposure. Radiation doses on the order of 50-100 rads (*rads = rems here*) or more damage the radiosensitive cells in the bone marrow and the lymphatic system, thereby producing reductions in the numbers of certain blood cells (including white and red blood cells, and platelets) in the circulatory system. The symptoms of this syndrome include anemia, fatigue, some gastrointestinal effects, and an increased likelihood of infection.

2. Gastrointestinal syndrome

Radiation doses on the order of 500 rads or more produce severe effects on the **radiation-sensitive cells which line the stomach and intestines**. All of the symptoms of the hemopoietic syndrome occur, with the addition of severe nausea, vomiting and diarrhea (sometimes bloody) which begin very soon after the radiation exposure. Secondary effects include infection and nutritional impairment. Death within 1-2 weeks after the exposure is quite possible.

3. Central nervous system syndrome

Radiation doses on the order of 2000 rads or more damage the less radiosensitive central nervous system, as well as most of the other organ systems of the body. Extreme confusion, followed by unconsciousness, is observed within minutes of the exposure, and death occurs in a matter of hours to several days.

B. Chronic effects:

The following effects are possible for individuals exposed to moderate levels of radiation (much higher than standard background levels) for extended periods of time (often many years), or for those who survive acute high-level exposures to radiation:

1. Cancer (including leukemia)

Exposure to ionizing radiation has been found to increase the likelihood of developing cancer, including bone cancer, skin cancer and leukemia, years (sometimes as many as 50 years!) after the exposure.

2. Cataracts

Exposure of the eyes to ionizing radiation over an extended period of time may produce cataracts (clouding of the lenses of the eyes). This occurs for types of radiation capable of penetrating human tissue to a depth of about 0.3 cm – the depth of the lens of the eye.

3. Genetic effects

Radiation exposure of the DNA in human sperm or eggs, or of the cells which produce them, may produce genetic damage, leading to mutations. Consequences of this include the increased likelihood of miscarriage or birth defects. Geneticists have estimated that the "doubling dose", which is the dose of radiation that would eventually lead to a doubling of the mutation rate, is on the order of 50-250 rads.

☞ **Considering the relatively low quantities of radioisotopes used in the laboratories on the UC Irvine campus, and the results of radiation dosimetry monitoring of exposed individuals (very few individuals receive detectable radiation doses while at UC Irvine), it is *very unlikely* that anyone here will incur any harmful biological effects, providing that the proper radiation safety precautions are followed!!!!** ☞



VII. METHODS TO MIMIMIZE RADIATION EXPOSURE

The major goal of the Radiation Safety Division of the EH&S Office at UC Irvine is to ensure the radiation exposures of the faculty, staff, students, visitors, and the general public are reduced to levels which are **as low as reasonably achievable (ALARA)**. The three primary means at our (and your) disposal to reduce radiation exposures are discussed below:

A. Time: It is readily apparent that the less time one spends working with, or in the vicinity of, radioisotopes, the lower will be the radiation exposure. Therefore, it is recommended that individuals working with radioisotopes reduce the amount of time that they must actually handle them as much as is practical.

This does not mean that experiments should be performed in a hurried manner, since the likelihood of accidents (spills, etc.) increases substantially in such cases. However, by following established protocols, seeking advice from other knowledgeable colleagues, and performing "dry runs" (practice runs before using actual radioisotopes), it is possible to greatly improve the efficiency of studies, and thereby reduce the radiation exposure time. Also, if individuals who are performing the studies are concentrating on their work (as opposed to talking with friends, etc.), experiments can be completed more quickly and efficiently.

It may also be possible to perform experiments by substituting non-radioactive tracers (such as *fluorescent or colorimetric materials*) for the radioisotopes. In this manner, the time spent using radioisotopes can be greatly reduced. Contact the Radiation Safety Division of EH&S (☎ 949-824-6904 or 949-824-6098 ☎) for more information.

- B. Distance:** The greater the distance between the researcher and the source of radiation, the lower will be the radiation exposure. Alpha and beta particles are readily absorbed in air (shielding is still needed when working with high-energy beta emitters such as ^{32}P , however). For point-source gamma-ray emitters, the exposure rate falls off as $1/d^2$, where d is the distance between the researcher and the radiation source. **This is the inverse square law.** If you double your distance from a gamma-ray source, your radiation exposure falls to one-fourth of the original value!
- C. Shielding:** One of the simplest means of protecting laboratory personnel from radiation exposure is to place appropriate shielding between the researcher and the radiation source. The types and quantities of shielding needed for working with the various types of ionizing radiation are discussed below.

1. *Alpha particles*

Since these particles have such short ranges in air, generally **no shielding is required.**

2. *Beta particles*

Beta particles have very short ranges in solid or liquid materials.

If thin shielding composed of high-density materials such as lead is used, the beta particles are stopped, but in the process x-ray energy radiation (termed "bremsstrahlung") is produced. In other words, although the beta particles have been attenuated, *considerably more penetrating radiation is generated. Therefore, high-energy beta particles should always be shielded with a low-density material such as Lucite®, Plexiglas®, or polyethylene.* This minimizes the generation of the bremsstrahlung radiation, since the betas are stopped much more gradually.

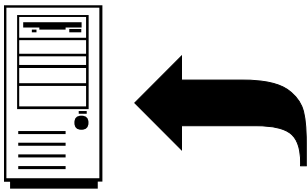
The appropriate shielding for the most common beta-emitting radioisotopes is presented in the table below:

<u>Beta-emitting Radioisotope</u>	<u>Sufficient Shielding</u>
^3H	<i>None needed</i>
^{14}C	<i>None needed</i>
^{32}P	0.5 inch of Lucite
^{33}P	<i>None needed</i>
^{35}S	<i>None needed</i>
^{36}Cl	0.5 inch of Lucite
^{45}Ca	<i>None needed</i>

3. Gamma rays

Since gamma rays are so penetrating, very high density materials are needed to shield against them. Generally, **lead shielding** is used. **Recall that a good rule to follow is that in order to attenuate a beam of gamma rays such that less than 1% of them make it through the shielding, a thickness of lead equivalent to 7 half-value layers (HVLs) is required.** The HVLs in lead for the gamma rays from commonly-used radioisotopes are given below:

<u>Gamma-emitting Radioisotope</u>	<u>HVL (lead)</u>	<u>Sufficient Shielding (lead)</u>
^{22}Na	9 mm	2 inches
^{51}Cr	2 mm	0.5 inch
$^{99\text{m}}\text{Tc}$	0.25 mm	2 mm
^{125}I	0.02 mm	1 mm
^{137}Cs	6 mm	2 inches
^{60}Co	10 mm	At least 2 inches



VIII. RADIATION DOSIMETRY

Radiation dosimeters are devices which are capable of measuring an accumulated absorbed dose of ionizing radiation. **Dosimeters are distributed by the EH&S Office to all individuals on campus who have a *reasonable likelihood* of receiving measurable doses, and also to those who do not work with high quantities of radioisotopes which generate penetrating radiation, but who strongly desire dosimetry anyway.**

Dosimetry is *never* needed by those who only work with low-energy beta emitters such as ^3H , ^{14}C , ^{33}P , ^{35}S , and ^{45}Ca . Beta particles from these radioisotopes are readily absorbed by air or by the outside "dead" layer of human skin, and their range in air is only a few feet at most.

A. Radiation Dosimeters

Some crystals emit light if they are heated after having been exposed to radiation. Therefore, they are called *thermoluminescent crystals*. Absorption of energy from the radiation excites the atoms in the crystal, and heating the crystal releases the excitation energy as light. The total amount of light emitted is proportional to the number of excited electrons, which is in turn proportional to the dose of radiation received.

TLDs respond to high-energy beta particles, protons, x-rays, and gamma-rays. **Body badges** containing TLDs are often distributed to campus radiation users instead of film badges due to their advantages over the film dosimeters (longer life of stored dose information, smaller size). In fact, **due to their small size, they are often used in dosimeter rings which are intended to measure the radiation dose to the hands.** TLD rings should always be worn on the hand which is expected to receive the greater dose, *inside of the plastic glove*, with the crystal in the front part of the ring facing the radioactive item being handled.

TLD rings are normally assigned for 3 month-long periods.

☞ Note: *Radiation dosimeters assigned at UC Irvine must only be used on the UC Irvine campus.* They are not to be worn at other facilities (including the UC Irvine Medical Center, which has its own dosimetry program). In addition, **dosimeters may only be worn by the person to whom they are assigned** (the person whose name is inscribed on the dosimeter). **Never intentionally expose your dosimeters to radiation fields just to see if they work!!** Since dosimetry results constitute legal records, such actions cause serious problems *for you* and the University. Make sure that nothing (such as a liquid) is spilled onto the dosimeters, and that they are not exposed to extremes in temperature (do not leave them in a hot car, etc.). ☞

IX. EXTERNAL RADIATION DOSE GUIDELINES

The U.S. government and the California Department of Health Services (DHS) have established external radiation dose limits which may not be exceeded under most circumstances (some provisions for higher doses during *extreme* radiation-related emergencies are also written into the regulations). **In an effort to reduce all radiation exposures to levels as low as reasonably achievable (*ALARA*), the UC Irvine campus' administrative guidelines have been set at levels equivalent to 10% of the legal limits for adults and 20% for minors.** A brief, simplified listing of the legal limits and the associated guidelines is provided below. More detailed information can be found in the UC Irvine Radiation Safety Manual.

DOSE EQUIVALENT LIMITS FOR ADULTS

<u>Category</u>	<u>Measured Using</u>	<u>Legal Limit (rems/year)</u>	<u>Campus Guideline (rems/year)</u>
Total effective dose *	Body badge + bioassays	5	0.5
Skin dose	Body badge	50	5
Hand dose	TLD ring	50	5

Note: 1 rem = 1000 millirems

* Total effective dose = Deep dose (from radiation which can penetrate 1 cm of tissue) + weighted dose due to **radioisotopes taken internally** (*measured by bioassays*).

Although minors under the age of 18 years of age rarely work with radioactive materials on the UC Irvine campus, there are reduced legal dose limits and UC Irvine guidelines that relate to such instances. The legal limits for minors are 10 % of the limits for adults, and the UC Irvine guidelines are 20 % of the campus guidelines for adults.

In addition, dose limits and guidelines have also been established which are related to the exposure of the embryo/fetus of a **Declared Pregnant Woman**. A woman who becomes pregnant (and who works with radioisotopes or a radiation-producing machine on campus) needs to inform the UC Irvine Radiation Safety Officer, in writing, of her pregnant status and the estimated date of conception in order to become a Declared Pregnant Woman. This would ensure that all necessary precautions are followed for the protection of her developing embryo/fetus. Briefly stated, women in this category may only receive on the order of 10% of the total effective dose allowed for other adults; skin and hand dose limits and guidelines are not affected.

Before starting to work with radioisotopes or a radiation-producing machine, all women of child-bearing age are required to be instructed regarding the risks attendant to **prenatal exposure to radiation**.

It must be noted that substantial safety factors are incorporated into the dose limits/guidelines given above. For example, the legal limit total effective dose for an adult is 5 rem/year. Even if an adult received this dose from a single (acute) exposure to gamma radiation, he/she would probably not demonstrate any clinically/medically-observable effects. In fact, it would normally take an acute dose of about 50-100 rems (or rads) to produce observable effects on the human body (in this case, effects on the blood cell-forming system, perhaps leading to anemia and an increased susceptibility to infection).

Note: For penetrating forms of radiation such as x-rays and gamma rays, a radiation exposure of 1 R (Roentgen) is approximately equivalent to an absorbed radiation dose of 1 rad and a dose equivalent of 1 rem.



X. RADIATION SAFETY IN RESEARCH LABORATORIES

There are many laboratories on campus in which radioisotopes are used in research studies. **It is the responsibility of the principal investigators in the laboratories and the persons involved in the studies, in consultation with EH&S, to make sure that they are performed safely.** This is not a difficult task, as long as the campus' radiation safety rules, regulations and recommendations are understood and followed.

A. Radiation Use Authorizations (RUAs)

Principal investigators (PIs) on the UC Irvine campus may apply for the authorization to use radioisotopes or radiation-producing machines by applying to the EH&S Office for a **Radiation Use Authorization (RUA)**. RUAs are only valid for research conducted on the UC Irvine campus or in UC Irvine leased research space. The UC Irvine Medical Center has its own radiation safety program.

An RUA gives the responsible principal investigator permission to use specified radioisotopes in particular experiments performed by authorized, trained individuals in specific locations (rooms), while taking specified radiation safety precautions. Deviations from the conditions spelled out on the RUA are not allowed unless EH&S is first notified and approves the changes.

If the radioisotope purchase limits for a research laboratory are greater than what is really needed for the research, the result may be more costly safety requirements for the laboratory and more frequent radiation safety reviews and surveys by EH&S.

B. Radiation safety training

All individuals who will be working with sources of ionizing radiation on the UC Irvine campus must be trained in the related safety procedures. Prior to starting the work, such individuals must come over to the EH&S Office to view a 30 minute radiation safety video, complete an open-book quiz, and fill out the necessary paperwork (*this training is completed in about 90 minutes on the average*). Registration through TED is required where the days and times are listed.

Preferably before starting to work with the radiation sources, but at least within 4 months of starting the work, individuals must attend the **Radiation Safety Seminar**. *General discussions* of all major safety-related aspects of the use of radiation sources are presented in this Seminar, including types of radiation, the acquisition, transfer and disposal of radioisotopes, radiation dosimetry, safe handling procedures, radiation survey meters, radioactive waste disposal, shielding, common errors that cause accidents, etc. Registration through TED is required where the days and times are listed.

In order to document that all individuals are adequately trained in the safety aspects related to the *specific procedures* that they will be performing in the course of their research studies, all individuals who will be working with ionizing radiation sources must complete, in conjunction with their principal investigator, an *On-the Job Training Form*. This is completed and returned to EH&S after 20 hours of training on the radioisotope techniques performed in the laboratory.

C. Access Control/Security

Rooms in which only very small quantities of radioisotopes are used and/or stored are subject to normal building security procedures. *It is always good practice to keep these rooms locked when they are not occupied.*

If more substantial quantities of radioisotopes are present, such as vials with 1 mCi or more of ^{32}P and/or ^{125}I , or 10 mCi or more of ^3H , ^{14}C , ^{33}P and/or ^{35}S , the room access doors must be locked at all times that the room is not occupied (*even for short absences*), unless the sources are further secured in locked, non-removable (physically-secured) storage containers, such as those described below for two common situations:

- In unlocked cold rooms, the above quantities of radioisotopes in storage must be stored in a locked box physically secured to the inside of the cold room, or in a locked cabinet or shield.
- In large multi-PI laboratories, the above quantities of radioisotopes in storage must be stored in a locked cabinet, shield, refrigerator or freezer -- or in a locked box which is physically secured to the inside of an unlocked cabinet, shield, refrigerator or freezer.

Make sure that all individuals who enter your laboratory are known to you. *All strangers must be challenged!* This is especially important if they attempt to open a refrigerator, freezer or other storage container of radioisotopes or radioactive waste.

D. Clean Areas

Clean areas are areas within laboratories which are free of radioactive materials, biohazardous materials, chemicals, and other hazardous agents. If they are labeled with EH&S-supplied "Clean Area" signs, beverages and food items may be stored and consumed at these locations. **These areas should not be immediately adjacent to radioisotope work areas, and must not be considered to be safe havens for items to be consumed while in the process of handling radioisotopes in other areas of the lab.**

E. Shielding

Appropriate quantities of radiation shielding must be used in all cases in which there is a risk of significant external radiation exposure. See *Section VIIC* for information on the types and thicknesses of shielding needed for specific applications.

In some cases, syringes, vials, centrifuge tubes, etc., which contain substantial quantities of radioisotopes such as ^{32}P or a gamma emitter should be shielded to prevent a substantial dose to the hands of the individual manipulating the object containing the radioactivity. Special shielding is available for these applications. Contact EH&S for more information.

F. Posting and labeling

The outside of each door to a room in which radioisotopes are used or stored must be labeled with a sign which reads "Caution--Radioactive Material". In cases in which a door is propped open for extended periods of time such that the sign on the outside of the door is not visible to those entering the room, another such sign must be affixed to the inside of the door.

All work areas in which radioisotopes are used must be properly labeled (with radiation label tape or an appropriate substitute). All contaminated or potentially-contaminated items must also be labeled and kept within the labeled work areas.

Radioisotope storage enclosures (such as refrigerators, freezers, fume hoods, etc.) must be appropriately labeled to indicate that radioactive materials are stored inside. **No food or beverages may be stored in those refrigerators!!!!**

All containers of radioactive waste must be labeled with the name of the radioisotope contained, even if only one radioisotope is used in the laboratory, and if only one person is disposing of the waste.

G. Surface contamination control

1. Protective clothing

All individuals handling radioisotopes must be wearing *buttoned* lab coats, impermeable gloves (which are generally made of vinyl, latex, nitrile, or another type of plastic), enclosed/closed-toed shoes (no sandals, etc.), and long pants to cover the legs. EH&S recommends that nitrile gloves be used, when possible. These gloves are more impermeable to common organic solvents, are more resistant to tearing than are vinyl gloves, and are not as slippery as latex gloves when they are wet. **Gloves should be changed frequently to avoid contaminating clean items. Make sure that the gloves are removed prior to handling the telephone, notebooks, doorknobs, etc.**

Remember that even when it is hot it is required that closed-toed shoes and long pants be worn when radioisotopes are handled. It is much easier to remove contaminated shoes or pants than it is to decontaminate the skin between your toes or on your legs!

2. Protective paper

Absorbent, plastic-backed paper (available from the UC Irvine central storehouse) must be placed on all surfaces upon which radioisotopes will used or stored. When it gets contaminated, it should be replaced as soon as possible. In addition, if the paper is torn or otherwise damaged, it must be replaced immediately. Make sure that the paper is placed on the surface *plastic side down/paper side up!*

3. Airborne radioactivity

Any experiment in which radioactive gases or aerosols can be generated must be specifically authorized by EH&S, and must be conducted in such a manner that radioactive materials are not present in the air to be inhaled. In addition, special precautions must be taken to avoid the related contamination problems due to radioactive materials depositing on surfaces in the laboratory.

In general, such experiments must be conducted in properly functioning fume hoods (certified by the Industrial Hygiene Division of EH&S [949-824-5730]; average air velocity at face of hood \approx 100 feet per minute). All radioactive effluents must be captured and disposed of as radioactive waste.

It is always best to employ *secondary containment chambers* around the primary equipment when generating airborne radioactivity. The secondary containment should be at a negative pressure with respect to the laboratory around it.

H. Radiation and contamination monitoring

Areas in which radioisotopes are used must be monitored to make sure that they are free of contamination. **Wipe testing must be conducted every 30 days during periods in which radioisotopes are used in studies.** If contamination is suspected, wipe testing and/or a GM counter survey of the areas involved should be performed *immediately*.

It is not necessary to perform wipe tests if no radioisotopes were used in the lab during the previous 30 day period (since your previous wipe test); however, a dated inscription must be made in the records stating "no radioisotopes were used in the lab during the last 30 days". After three consecutive such periods (after 90 days in which radioisotopes were not used, but just stored), the storage areas (and waste areas) must be wipe tested for contamination, and the results documented in the wipe test records.

I. External radiation dosimetry

As was mentioned before (see Section VIII), radiation dosimetry is distributed by EH&S to personnel on campus who have a *reasonable likelihood* of receiving a detectable external radiation dose.

This dosimetry must be worn on all occasions in which radiation exposure could occur. Remember that dosimeters are intended to measure external radiation exposure, and must be protected from contamination (which would continue to expose the dosimeter even when it is not worn). **If you suspect that your dosimetry has been contaminated, notify the EH&S Office immediately.**

J. Internal radiation exposure

While not all radioisotopes have sufficient energy to present an external radiation hazard, all radioisotopes can produce damage if substantial quantities somehow get inside of the human body. Therefore, radioactive materials must be kept away from all foodstuffs and areas in which food and

beverages are prepared or consumed. **No food or beverage must ever be stored in a refrigerator, freezer or cold room that contains radioisotopes! Microwave ovens used to heat hazardous substances must not also be used to heat food!** In addition, gum chewing and the applying of makeup are not permissible while actively handling radioactive materials, due to the hand-to-mouth manipulations required for these actions.

Individuals who handle very large quantities of ^3H or radioiodine (^{125}I , ^{131}I , etc.) may be asked to submit to **bioassays**. As mentioned earlier, bioassays are either urine counts (for the case of ^3H) or thyroid counts (for radioiodine) which are performed periodically to measure the quantity of radioisotope which has been taken into the body.

K. Radioactive waste disposal

All radioactive waste must be disposed of through EH&S. Radioactive waste must be segregated by radioisotope, and stored in appropriately-labeled EH&S-supplied containers, as described below.

For dry, solid waste, EH&S supplies 2 ft³ cardboard waste boxes with thick plastic liners. Liquid waste may be stored either in plastic-lined 1 gallon glass bottles, or in 5 gallon Nalgene® carboys (both supplied by EH&S). **Containers of liquid waste must never be completely filled; some room for thermal expansion of the liquid (~1-2 inches of space at the top of the bottle or carboy) must be provided.** Liquid waste must be kept in secondary outer containers of sufficient size to contain a spill from the primary container.

☛ **It is forbidden to dispose of liquid radioactive waste through the sanitary sewer system (down the drain), since all campus water is recycled by the Irvine Ranch Water District.** ☛

There are a variety of options available regarding the disposal of liquid scintillation fluids and vials. Guidelines and disposal costs vary depending upon whether "environmentally safe" scintillation cocktail is used (as opposed to solvent-based cocktails), whether the vials are full or empty, whether the vials contain H-3 and C-14 or other radioisotopes, etc. Contact the EH&S Office at 949-824-4578 for more information concerning these matters.

Radioactive sharps such as needles, etc., must be deposited in puncture-proof containers such as labeled soft drink (soda) cans or plastic sharps containers. Once these containers are nearly filled, the tops of the containers can be taped shut (be careful!) and the containers may be placed into the solid radioactive waste box. *[No biohazardous materials or anything labeled as a biohazard may be placed into a radioactive waste container!!]*

All radioactive waste must be labeled with the following: the name of the RUA holder (responsible principal investigator), the date, the radioisotope(s) (types and amounts), and other non-radioactive hazards (flammable, etc.).

To save money on the disposal of radioactive waste, short half-life radioisotopes (^{32}P , ^{33}P , ^{51}Cr) should be segregated from intermediate half-life (^{125}I , ^{35}S) and long half-life (^3H , ^{14}C , ^{45}Ca) radioisotopes.

Boxes in which radioisotope shipments were received need not be disposed of as radioactive waste. These boxes are checked for contamination by EH&S prior to releasing them to laboratory

personnel. Once all of the "radioactive" symbols and inscriptions (including the word "radioactive", etc.) are defaced, such boxes may be disposed of in the regular trash -- unless they have somehow become contaminated in your laboratory! If you suspect that you may have contaminated a box, wipe test it prior to disposal.

L. Recordkeeping procedures

Radiation safety-related records must be maintained in a *neat and orderly fashion*, and must be available for inspection by EH&S personnel and outside regulatory agencies. The various categories of records required are described below:

1. Contamination monitoring records

Results of the wipe tests performed at the intervals described earlier must be maintained. These records should be in chronological order, and must contain the date of the monitoring, a map or description of the areas wiped (a map at the front of the monitoring records is sufficient), the counting results (normally the LSC printout), and evidence that areas initially determined to be substantially contaminated have been cleaned and re-wiped to make sure that the contamination has been removed.

2. Receipt, use and disposal records

Records must be kept which indicate the receipt of radioisotopes. **Included for each entry in the records must be the name of the radioisotope received (^{32}P , etc.), the quantity received (in mCi or μCi), and the date it was received (not the ordering date!).** Additionally, when quantities of radioisotope are withdrawn from a storage vial and used in an experiment, this needs to be noted in the lab's records (in the *use log*). The green copies of the radioactive waste forms must be maintained and kept with the radiation safety records.

3. Semiannual Isotope Inventory Reports

Prior to sending completed Semiannual Isotope Inventory Reports (*previously this was done quarterly*) to EH&S, copies must be made and kept with the radiation safety records. Inventory records must be maintained because they provide information on the approximate quantities of radioisotopes present in the lab; *it is a legal requirement that such information be known.*

M. Acquisition and transfer of radioisotopes

In order to acquire radioisotopes, a Responsible Principal Investigator (RPI) must have a valid RUA, the radioisotopes requested must be authorized by the RUA, and the amounts requested must be within the limits prescribed by the RUA.

Each purchase requisition for a radioisotope must contain the following information:

- a) Name of the radioisotope (e.g., ^3H , ^{32}P)
- b) Quantity of radioisotope in units of radioactivity (mCi, μCi)
- c) Chemical form
- d) Name of RPI and RUA number

All radioisotope shipments are delivered to the UC Irvine Receiving Department, from which they are picked up by EH&S. At the UC Irvine Health Physics Laboratory, the following assessments are performed:

- a) Visual inspection of integrity of packaging
- b) Test exterior of the packaging for contamination
- c) External radiation measurement to ensure proper hazard labeling
- d) Test exteriors of inner containers (usually vials) for contamination

If the radioisotope shipment passes these assessments, it is logged into the EH&S radioisotope inventory records, and the lab of the appropriate RPI is notified that a package has arrived so that it can be picked up. **In some cases, it will be necessary for the individual picking up the package to bring recent contamination monitoring records with him/her.** This will be mentioned when the laboratory is notified that a radioactive shipment has arrived.

If the shipment does not pass inspection, the RPI will be contacted and a decision will be made (by the RPI and EH&S) whether the shipment must be replaced by the vendor, depending upon the severity of the situation (degree of contamination).

The EH&S Office must be notified in advance in cases in which special handling will be needed for shipments that have very short half-lives.

No radioisotope may be transferred from one RPI to another RPI on campus unless the recipient RPI is authorized by his/her RUA to receive the radioisotope in the quantity/chemical form/physical form to be transferred. A "Transfer of Radioactive Materials" form related to the transfer must be completed and sent to the EH&S Office.

N. Transfer of Radioisotopes Off-Campus

All transfers of radioisotopes off-campus must have the prior approval of the UC Irvine Radiation Safety Officer and the Radiation Safety Officer of the recipient institution. All shipments must be routed through EH&S to ensure compliance with government regulations. EH&S will arrange for all packaging and shipping.



XI. EMERGENCY PROCEDURES

Emergency procedures, which vary somewhat depending upon several factors (injuries, degree of emergency, etc.), are discussed briefly below:

A. Personnel Contamination with Serious Injury

Administer first aid immediately! In all conceivable accidents at UC Irvine in which serious injuries are involved (severe bleeding, heart attack, etc.), the risk to the life of the injured person would far outweigh the risk to the rescuer caused by exposure to radiation. Call the campus police (☎ dial x911 from a campus phone, or 949-824-5222 from a cell phone ☎), and the EH&S Office (☎ 949-824-6904 or 949-824-6098 ☎), as soon as possible.

B. Personnel Contamination with No Injury

If you know or suspect that you have been contaminated with radioactivity, do not panic. Considering the quantities of radioisotopes used in most labs on campus, you should suffer no health consequences as a result of being contaminated.

Remove all items of clothing which may be contaminated. Wash contaminated skin areas with *cold water and a non-abrasive soap*. The use of hot water and abrasive soap may increase the absorption of the radioactivity into the skin!! Don't worry about contaminating the sink or shower. These can be decontaminated later.

Notify the EH&S Office as soon as possible.

C. Laboratory Contamination Incidents

Isolate the contamination to prevent its spread. If only a small amount of radioisotope is spilled, clean it up with absorbent paper towels (dispose of them as radioactive waste). Verify by Geiger counter survey and wipe test that the area is decontaminated.

If a sufficient quantity of radioisotope is spilled such that there is a high radiation exposure rate in the vicinity of the spill, or if other hazards or problems are involved, notify the EH&S Office (949-824-6904, 949-824-6098) immediately, and trained personnel will come and either advise lab personnel regarding the proper decontamination procedure, or actually perform the decontamination.

D. Radiation Exposure Incidents

If you know or suspect that you have been exposed to a high level of radiation, or you think that you have accidentally inhaled or ingested a radioactive substance, notify the EH&S Office as soon as possible!

☎ Note: When accidents occur after-hours or on weekends, call the campus police (949-824-5222, or 911 in a serious emergency), who will in turn call appropriate EH&S personnel at their homes. ☎

E. EH&S Emergency Response

The EH&S Office has a trained and well-equipped team which is available 24 hours per day, 7 days per week, to respond to serious emergencies on campus. These emergencies could include major spills of hazardous materials (including radioisotopes) in laboratories, earthquakes, explosions, releases of hazardous materials to the environment, etc. More information on the EH&S Emergency Response Team can be obtained by contacting the EH&S Office. **Should you become aware of a**

serious emergency on campus, call the UC Irvine Police (x911, or 949-824-5222 from a cell phone) or the EH&S Office (949-824-6200).



XII. MOST COMMON CAUSES OF RADIATION ACCIDENTS

1. Necessary safety precautions ignored or forgotten.
2. Inattentiveness (chatting, thinking about other matters), or fatigue.
3. Overconfidence; feeling of complacency.
4. Failure to follow procedures as described by the principal investigator (taking inappropriate shortcuts).
5. Failure to perform dry runs (without using radioisotopes) prior to actual use of radioisotopes.
6. Failure to label all containers/items which contain radioactive substances.
7. Failure to clean up contamination as soon as the incident occurs.
8. Failure to properly train new personnel.
9. Carelessness, or an unreasonable fear of radiation.
10. **Failure to anticipate possible accidents before they occur, and to take steps up-front in order to avoid them.**

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If you ever have any radiation safety questions or concerns, please call the Radiation Safety Division of EH&S at 949-824-6904 or 949-824-6098.

