

# RADIATION WORKER'S GUIDE



University of California, Riverside  
Environmental Health & Safety

Available at EH&S or on the EH&S website: [www.ehs.ucr.edu](http://www.ehs.ucr.edu)

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## CREDITS

Some text was copied from a document of the same name produced by the Environmental Health & Safety Office at the University of California, San Diego.

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## **I. Introduction**

### **A. Radiation Hazard**

There are two broad categories of radiation.

1. Non-ionizing radiation includes ultra-violet, infrared, radio waves and microwave radiation. Non-ionizing radiation of concern in the workplace is produced by machines.
2. Ionizing radiation includes alphas, betas, protons, x-rays, gamma radiation, and neutrons. Ionizing radiation of concern in the workplace is produced by machines, or present in the form of radioactive materials (unstable atoms that spontaneously decay to a more stable configuration by emitting one or more forms of ionizing radiation).

The main difference between these two basic types of radiation is that a single quanta or particle of ionizing radiation has enough energy to remove orbital electrons from the atoms of the material being irradiated while non-ionizing radiation does not. The process of removing orbital electrons is called ionization. Ionization can cause biological damage in living tissue.

### **B. Resolution**

This manual is only concerned with ionizing radiation. It will provide a broad introduction to the technical and practical considerations associated with the safe use of the most common radiation sources found at UCR. State and University requirements will also be outlined. The goal of this handbook is to provide sufficient information for you to identify and deal effectively with the radiation hazards in the immediate work area, thus providing for your own safety, the safety of those around you and protection of the environment.

## II. Units and Calculations for Measuring Radiation

There are several different units used to describe the quantities, and properties associated with ionizing radiation.

### A. Energy (quantity)

The energy of ionizing radiation is usually given in electron Volts (eV). The electron volt is the energy of an electron that has been accelerated through an electrical potential of one volt.

The eV is a very small amount of energy so KeV (thousand electron volts) and MeV (million electron volts) are used as the units of measurement for the energies associated with the emissions from radioactive materials or machines.

The energy of visible light is about two or three eV.

### B. Activity (quantity)

The total quantity of a radioactive material that is present in a particular sample or source is measured by the total number of disintegrations for a given period of time (activity). The units used to describe activity are:

1. The Curie (Ci): a large unit of activity defined as  $3.7 \times 10^{10}$  disintegrations per second. This means that  $3.7 \times 10^{10}$  atoms change each second. Most radioactive samples at UCR contain quantities of activity that are more appropriately measured in milli-Curies ( $1 \times 10^{-3}$  Curies) or micro-Curies ( $1 \times 10^{-6}$  Curies).
2. The Becquerel (Bq): a very small unit of activity defined as one disintegration per second. More appropriate units for expressing the activity of a sample in Becquerels are mega-Becquerels ( $1 \times 10^6$  Becquerels) and giga-Becquerels ( $1 \times 10^9$  Becquerels)..

### C. Half Life (property)

Half-life is the time required for the activity in a sample to decrease to one-half of its initial activity. Radioactive half-lives range from millionths of a second to billions of years. The mathematical description of the exponential decay of a radioactive isotope is given as follows and can be used to determine the amount of activity remaining in a particular sample after a certain time (t) has elapsed:

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

Where:

$A_0$  = the initial activity of an isotope

$A_t$  = the activity of an isotope after an elapsed time (t)

T = the elapsed time since the initial activity was measured (days, years, etc.)

$\lambda$  = the radioactive decay constant =  $0.693/T_{1/2}$

$T_{1/2}$  = the half-life of the isotope in days, years, etc. available in reference tables

Note: It is important to choose units for  $T_{1/2}$  and t such that  $\lambda$  has no units

### D. Exposure (quantity)

Exposure is the amount of ionization (charge) produced when ionizing radiation produces ionization (removes electrons from atoms) when it passes through any material. The

amount of ionization (charge) produced in air is called exposure. The method used to determine the exposure resulting from an x-ray or gamma field is calculated by measuring the amount of charge produced (ionization) in a measured volume of air.

The units used to measure exposure are the Roentgen.. The Roentgen is defined as the Coulombs/Kilogram only in air for gamma and/or x-ray radiation, with energies of less than three MeV. It is the amount of gamma or x-ray radiation required to produce one statcoulomb of charge ( $2.08 \times 10^9$  ion pairs) in one cubic centimeter of air at standard temperature and pressure (STP).

### **E. Absorbed Dose (quantity)**

Energy is deposited in (absorbed by) any material when it interacts with ionizing radiation. The absorbed dose units are:

1. Rads, where 1 rad = 100 ergs/gram
2. Grays (Gy), where 1 Gray (Gy) = 100 rads

### **F. Quality Factor (quantity)**

Some types of radiation are more efficient at producing biological effects than others (alphas more than betas) and the absorbed dose (rad) is not necessarily related to the biological effect, so a quality factor is used to account for these variations.

The quality factor for betas, gammas and x-rays is 1. The quality factor for alphas is  $\approx 20$  and for neutrons, it can vary from  $\approx 3-50$  depending on the energy of the neutron.

Alphas and neutrons produce more biological damage than betas or gammas for the same absorbed dose.

### **G. Dose Equivalent (quantity)**

Some types of radiation cause different biological damage to living tissue, so the dose equivalent is used to indicate the biological effect. The dose equivalent is determined by multiplying the absorbed dose by the quality factor. The units most commonly used for radiation protection purposes are:

1. Rem, where 1 rem = rad x quality factor
2. Sievert (Sv), where 1 Sievert (Sv) = 100 rems

For practical purposes, the rad is equal to the rem for betas, gammas and x-rays in soft tissue.

### III. Radioactive Decay and Interactions

There are several ways for an unstable atom to become more stable. The most common are: decay by emission of alphas, negative betas (negative electrons), positive betas (positrons or positive electrons), gammas, and/or electron capture. More than one of these processes may occur during a single decay event. Let's look at the various radioactive decay processes more closely.

#### A. Alpha Radiation

These large electrically charged, heavy mass and slow speed particles (helium nuclei) interact strongly with the atoms through which they pass and therefore, have a short range. Alpha radiation does not cause an external radiation hazard because most will not penetrate the dead layer of skin. However, alpha radiation can be a serious internal radiation hazard and precautions must be taken with alpha-emitting radioisotopes, particularly since they tend to accumulate in specific body organs (usually bone) and deliver high local doses.

Alpha decay results in monoenergetic alpha particles, where all the alpha particles emitted by a particular isotope undergoing a particular nuclear transition have the same energy. Alpha emission is common only for elements with a high atomic number (83 or higher) and is usually accompanied by one or more of the other types of radiation.

Common alpha-emitting isotopes are  $^{210}\text{Po}$ ,  $^{226}\text{Ra}$ ,  $^{222}\text{Rn}$ , thorium, and uranium compounds.

Storing alpha emitters in a container with a tight seal and opening it only in a fume hood prevents leakage or other releases. Alpha emitters should be stored in a fume hood, but not near the entrance of the airflow.

#### B. Beta Radiation

Beta particles are moderately charged, light, fast-moving particles (electrons or positrons). The energy released during a specific radioactive decay process that results in beta emission is discrete (one energy). However, the betas emitted have a spectrum of energies (polyenergetic) since each beta emitted is accompanied by an anti-neutrino/ neutrino that shares the total energy released (not of concern since their mass is very small and they don't result in a significant risk). Unless otherwise stated, the beta energy given in reference literature is the maximum or end-point energy. The average beta energy is about one-third of the indicated maximum beta energy.

Some isotopes are pure beta emitters, emitting only betas. Examples are  $^{32}\text{P}$ ,  $^3\text{H}$ ,  $^{14}\text{C}$ ,  $^{35}\text{S}$ , and  $^{45}\text{Ca}$ . Table I gives the physical properties of these pure beta emitters. Other beta emitters may release beta radiation with other types (e.g., gammas, see Appendix I).

High-energy beta emitters require special considerations for shielding that are more involved than the straightforward methods used for gamma emitters..

**TABLE I  
COMMON BETA EMITTERS**

PROPERTIES	H-3	C-14	S-35	Ca-45	P-32
Half-life	12.3y	5730y	87.4d	163d	14.3d
Maximum Beta Energy (MeV)	0.0186	0.156	0.167	0.257	1.71
Average Energy (MeV)	0.006	0.049	0.049	0.077	0.695
Range in air (cm)	0.5	23	24	46	610
Range in water (cm)	0.001	0.03	0.03	0.06	0.8
Fraction transmitted through dead layer of skin (.007 cm)	0.00	0.11	0.16	0.37	0.95
Dose rate to basal cells (rad/hr per uCi/cm <sup>2</sup> ) *	0.00	1.4	1.6	4.0	9.2

\* From Healy, 1971. The dose is from beta particles emitted in all directions equally from contamination on the surface of the skin. Basal cells are considered to be 0.007 cm below the surface.

Beta radiation will penetrate varying thicknesses based on the type of material and the energy of the beta radiation. The greater the energy of the beta, the greater the penetration through air or other materials will be. Beta emitters with energies less than 200 KeV, such as <sup>3</sup>H (tritium), <sup>35</sup>S, and <sup>14</sup>C, have limited ranges in tissue and air and are not considered an external radiation hazard. An exception is the case of skin contamination (examples of typical exposures are given on the bottom line of Table I) where it can be seen that the dose rate to the basal cells of the skin range from 1.4-9.2 rad/hr, for 1 uCi/cm<sup>2</sup> of skin contaminated with isotopes other than tritium.

Higher energy betas can result in significant external radiation exposure hazard since they can travel long distances in air and penetrate considerable distances in tissue. A beta particle will travel approximately 12 ft per MeV in air. Therefore, high-energy betas, such as those from <sup>32</sup>P and <sup>90</sup>Sr can travel considerable distances in air (about twenty-six ft).

All beta emitters can cause internal exposure, so precautions must be taken to prevent the intake of radioisotopes (orally, via air, wounds, or by transport directly through the skin).

#### 1. Negative Betas, electrons ( $\beta^-$ )

In addition to producing exposure directly by ionization, all charged particles, including beta particles, lose energy in an absorbing material by excitation and radiation, a process called bremsstrahlung, German for "braking radiation". This process occurs when a charged particle slows down as it passes through an absorber and in the process produces an x-ray, or bremsstrahlung radiation, more penetrating than the original beta radiation since it is a photon. The fraction of the total beta energy that results in the production of bremsstrahlung radiation is proportional to both the atomic number of the absorber and the energy of the beta, or other charged particle. To reduce the production of bremsstrahlung radiation, high-energy particle emitters (<sup>32</sup>P) must be shielded with a material that has a low-atomic number (lucite or plastic) about one cm thick for <sup>32</sup>P. If excessive bremsstrahlung radiation passes through the low atomic-number shield, lead must be added on the outside of the plastic (away from the source)

to reduce it. In most cases, the amount of lead required to reduce the bremsstrahlung produced by the  $^{32}\text{P}$  betas is about 0.3 mm. The bremsstrahlung radiation produced as a result of  $^{32}\text{P}$  betas is characterized in Table II.

**TABLE II**  
**Characterization of the Bremsstrahlung from  $^{32}\text{P}$**

<b>Absorber</b>	<b>Fraction of Energy Converted into Bremsstrahlung</b>	<b>Average Energy of Bremsstrahlung Radiation</b>
Lucite	0.36%	~0.2 MeV
Lead	5.0%	~0.2 MeV

## 2. Positive Betas, positrons ( $\beta^+$ )

When a positron enters an absorber, it slows down like a regular electron, but eventually interacts with an orbital electron in the absorbing material. When this interaction occurs, the orbital electron and positron annihilate one another to produce two gamma rays, each with energy of 0.511 MeV. This annihilation radiation is more penetrating than the original positron radiation but can be reduced by using lead shielding in the same way as for the bremsstrahlung radiation discussed above.

## C. Gamma and X-Ray Radiation

Gamma rays are electromagnetic radiation (photons) that originates in the nucleus of an atom. X-rays are electromagnetic radiations that are identical to gamma radiation except that they originate in the electron cloud surrounding the nucleus. Gamma radiation is emitted in discrete (monoenergetic), packets of energy known as photons. X-rays can have discrete energies or a whole spectrum of energies (polyenergetic) if produced by the process of bremsstrahlung. The specific properties of gamma and x-ray photons are determined by their energy, which is proportional to the frequency ( $E=h\nu$ ) where  $\nu$  is the frequency and  $h$  is Planck's constant.

Photons interact with matter primarily by three processes: photoelectric effect, Compton effect and pair production. A lengthy explanation of these processes will not be presented here, but note that all three processes transfer energy to electrons and that these electrons can have sufficient energy to ionize or excite other atoms in the absorber, interactions that permit detection of gammas and x-rays.

Gamma and/or x-ray emissions seldom occur alone, and are usually accompanied by other types of radiation. Common gamma emitters on campus include  $^{125}\text{I}$ ,  $^{131}\text{I}$ ,  $^{22}\text{Na}$ ,  $^{86}\text{Rb}$ , and  $^{51}\text{Cr}$ . X-rays are produced by some radioisotopes, but are usually machine-produced. Information in Appendix I can be used as a basis for designing the shielding necessary for protection when working with some of the more common gamma emitters.

## D. Electron Capture

In this transformation, one of the electrons is captured by the nucleus and unites with a proton to form a neutron. Excess energy is released in the form of a mono-energetic gamma ray, a mono-energetic neutrino (not of concern since the mass is very small and it doesn't result in a significant risk), and characteristic x-rays as an electron from an outer orbital falls into the energy level occupied by the electron which had been captured (see Gamma and X-Ray Radiation above).

## **E. Other Types of Radiation**

There are many other types of radiation, but most are not encountered in the typical laboratory setting. The following may be of some interest.

### **1. Protons**

Protons are positively charged particles with considerable mass (hydrogen nuclei). These particles are usually produced by special machines (accelerators) and have high energies. They have a relatively short range in matter because of their fairly large mass, but direct exposure to a proton beam could result in a significant radiation dose.

### **2. Neutrons**

Neutrons are uncharged particles with a mass approximately equal to that of a proton. These particles are generally produced by reactors, or machines, but can also result when particles (protons) strike a target or other material (concrete shielding). Since neutrons have no charge, they can penetrate easily through certain materials, particularly those without hydrogen. Good shielding materials include water and plastics. Due to the way in which neutrons interact with tissue, a small neutron exposure can result in a significant dose equivalent.

## IV. Biological Effects and Risks

The biological effects and risks associated with exposure to ionizing radiation have been studied more thoroughly than those from any other hazardous agent found in the laboratory environment.

### A. Sources of Information

The information that we have concerning the biological effects of radiation comes from several different sources. These include the WWII atomic bomb survivors (the largest group), medical patients, accident victims, and animal studies. They yield information primarily about radiogenic cancers.

### B. Modes of Exposure

There are two basic types of radiation exposure.

1. Acute exposure is an exposure to a large amount of radiation in a short period of time.
2. Chronic exposure is a long-term exposure to low levels of radiation such as received from background radiation during the course of one's lifetime.

Acute and chronic exposures can result from either external radiation sources or internally deposited radionuclides. In general, the effects of acute exposures are much greater than those resulting from chronic exposures to the same quantity.

### C. Types of Biological Effects

Ionizing radiation may cause three general types of biological effects.

#### 1. Somatic effects

Experienced only by the irradiated individual, prompt or delayed depending on how long after the exposure they become visible. Effects include damage to body tissues and organs that can impair their ability to function normally. The symptoms exhibited during the early stages of the Chernobyl accident were prompt somatic effects (nausea, vomiting, reduced blood count). Delayed somatic effects can occur 20 to 30 years after the exposure and include an increase in the probability of the development of various types of cancers.

#### 2. Genetic effects

Apparent in the offspring of irradiated individuals. Radiation can alter genes and produce mutations that may eventually result in anomalies in offspring. These mutations are generally recessive and several generations may pass before the effects become apparent, if at all.

#### 3. Fetal effects

Result from the exposure to a fetus or embryo, more sensitive to radiation than an adult. Sensitivity is greatest during the first three months after conception, when a woman may not be aware that she is pregnant. The main concerns during this early stage of pregnancy are related to developmental abnormalities of the fetus. As the pregnancy progresses, the sensitivity of the fetus to radiation decreases. The main concern related to exposure later in the pregnancy is an increased risk of leukemia during the first 10 years of the child's life.

## D. Dose Response Curves

Dose response curves are graphical representations of the changes in biological effects with changes in dose. Dose response curves can be used to estimate the biological effect related to a particular radiation dose.

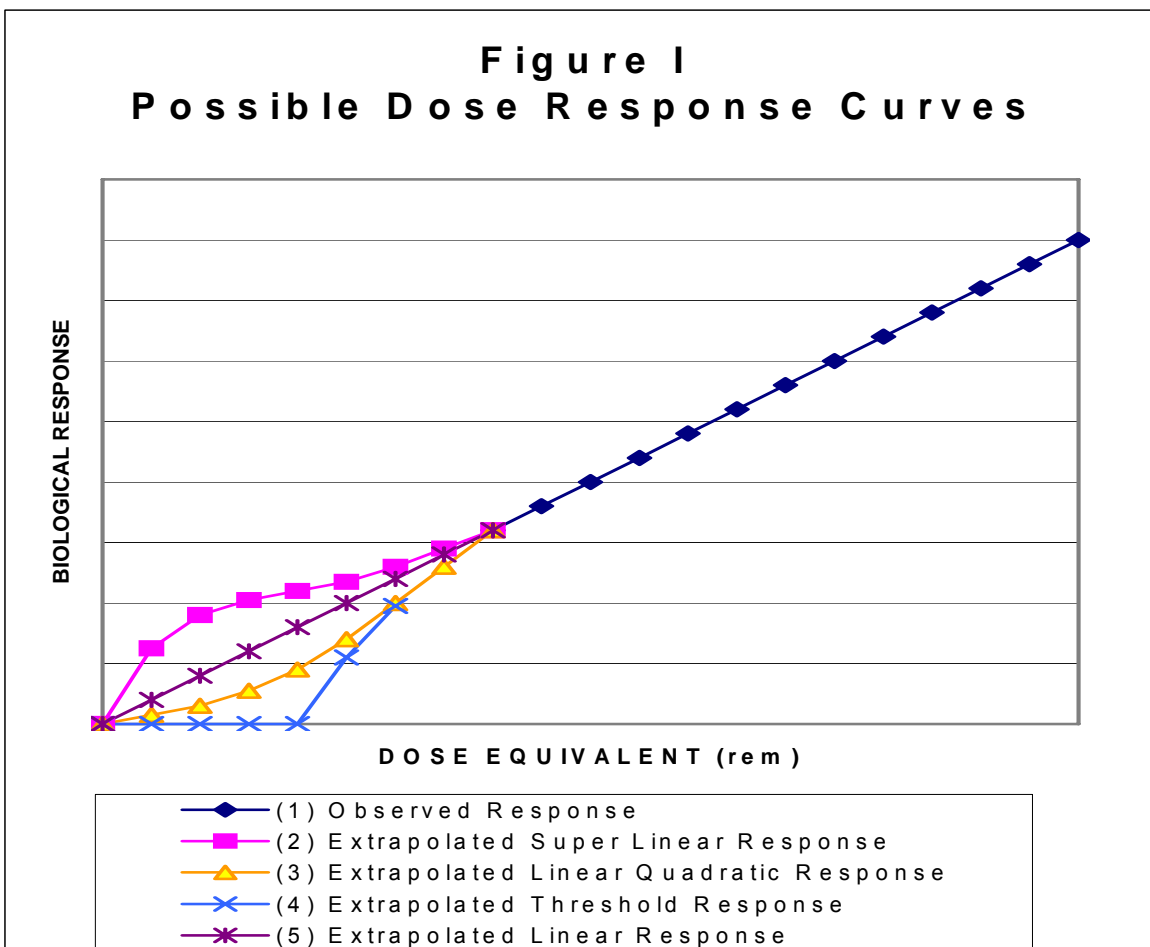
Radiation is like most substances that cause cancer since the effects are apparent at high doses, but not at low doses. The estimate of the risk of cancer from the low exposures likely at a university or medical center is extrapolated from the obvious effects observed at high doses. For radiation protection purposes, these estimates are made using a linear response model (Figure I, Curve 1) that extrapolates the biological response from high doses where effects are actually observed to estimate the effects at low doses (Figure I, Curve 5).

Most studies are unable to measure the effect of radiation to dose equivalents of less than 100 rem, primarily because of

1. The small number of individuals actually exposed
2. The effects are small compared to the normal differences of cancer incidence from year-to-year and place-to-place
3. Radiation-induced effects can't be distinguished from those that occur normally

To obtain a meaningful estimate of the risk from low-level radiation exposure, very large groups of people (many millions) would be needed.

Many "experts" believe that there is a degree of risk, no matter how small the dose (Figure I, Curves 2, 3 & 5). Others believe that the risk drops to zero at low doses (Figure I, Curve 4), often referred to as the threshold effect. A few believe that even small doses can result in a significant risk (Figure I, Curve 2). For radiation protection purposes, the Nuclear Regulatory Commission (NRC) endorses the linear response model (Figure I, curve 5) that assumes effects decrease linearly as the dose decreases. Estimated risks using the linear model are listed in Table III.



**TABLE III**  
**Estimated Risks Associated With Low-Level Radiation Exposure**  
Based on the Linear Non-Threshold Model\*

Biological Effects	Natural Occurrence	Radiation Related/rem First generation	Radiation Related/rem Equilibrium
Cancer Cases	3,000 per 10,000	Low, not estimated	Low, not estimated
Fetal Effects	373 to 473 per 10,000	0.24 to 0.53 per 10,000	1.2 to 2.1 per 10,000

\* Per National Research Council, BEIR V, Health Effects of Exposure to Low Levels of Ionizing Radiation.

## V. As Low As Reasonably Achievable (ALARA) Program

The ALARA concept is a vital part of the radiation safety program at UCR. It's a philosophy achieved through both administrative and engineering controls that seeks to keep workers' radiation doses as low as practical.

### A. Administrative Controls

#### 1. Guidance and Regulatory Agencies

Several scientific groups provide information and recommendations concerning radiation safety: the National Council on Radiation Protection (NCRP), the International Commission on Radiation Protection (ICRP), the International Atomic Energy Agency (IAEA), and the American National Standards Institute (ANSI). These groups provide only recommendations without the force of law and don't enforce or establish radiation safety policy. The agencies responsible for developing and enforcing radiation policy are the Environmental Protection Agency (EPA), the Nuclear Regulatory Commission (NRC), the State of California Department of Health Services, and the Department of Transportation (DOT).

#### 2. UCR License

Radioactive materials and radiation producing machines are used in many laboratories at UCR. This work is authorized by a broadscope radioactive materials license granted by the State of California Department of Health Services, Radiological Health Branch. Projects involving the use of radioactive materials or radiation-producing machines are reviewed and approved by the UCR Radiation Safety Committee before work is started. Therefore, each Principal Investigator (PI) wishing to use radioactive materials must request authorization from the Radiation Safety Committee whose function it is to safeguard radiological health at the institution. When a request is approved, an authorization for radiation use is issued that specifies what radioisotopes or machines can be used, where they may be used, how much activity may be used, and what special radiation safety precautions must be followed.

The Radiation Safety Officer (RSO) is responsible for managing the radioactive materials license and the overall radiation safety program by using the resources of the campus Environmental Health and Safety Department (EH&S), Radiation Safety Section. The RSO communicates the requirements of the license to the PI through the "Radiation Safety Manual", the Radiation Use Authorization, lab postings, training sessions and personal communications. The "Radiation Safety Manual" is a presentation of the organization and requirements of the radiation safety program at UCR, and contains practical information about the use of radioisotopes and radiation-producing machines at the facility. PIs are required to become familiar with the Radiation Safety Manual to enforce its requirements in their labs or facilities.

#### 3. Dose Limits for Radiation Workers

If the acceptable limits are not exceeded, there should be no evidence of harm to the worker or his/her offspring. Current dose limits for radiation workers are listed in part a) of Table IV. The risk from radiation exposure may be greater for young people so the dose limits for those under 18 years are 10% of those listed in part a) of Table IV. Individuals under 18 years of age should avoid laboratories that use radioisotopes or radiation producing machines.

**TABLE IV  
Dose Limits for Radiation Workers**

Radiation exposure shall be "As Low As Reasonably Achievable" (ALARA), but in no case exceed the limits specified below when exposures from external and internal sources are added together:

a) For workers with "occupational" exposure:

Exposure Area	Limit
Whole body	5 rem/year
Lens of eye	15 rem/year
Skin of the whole body or extremities (hands and forearms, feet and ankles)	50 rem/year
Individual organ, other than the lens of eye	50 rem/year
Embryo/ fetus of a "declared pregnant woman" (has notified EH&S Radiation Safety, in writing)	0.5 rem during pregnancy

b) For minors (<18 years of age) working in areas where radiation is used: 10% of that allowed for adult workers

c) Members of the General Public (workers with "non-occupational" exposure or students under the age of 18 involved in educational activities):

Time Period	Limit
Long term:	100 mrem/year
Short term:	2 mrem/hour

"Occupational" exposures at UCR should not exceed 1/10 of the above limits without prior approval by the UCR Radiation Safety Committee.

#### 4. Expected Doses from Background Radiation

Each one of us is exposed to radiation every day of our lives. This radiation comes from:

- a) Naturally occurring radioactive materials that are in the food we eat, the building materials in our homes and workplaces, the air we breathe
- b) Radiation that reaches us from outer space (cosmic radiation)
- c) Man-made sources: medical treatments, radioactive sources used in consumer items (luminous dials and smoke detectors), and cigarettes.

The average radiation dose equivalent received by all workers at UCR is less than the dose received from natural and man-made background radiation and, therefore, the attendant risks should be low.

## 5. Expected Doses at UCR

The annual whole body exposure that you are most likely to receive while working at UCR is only a small percentage of the dose limits listed in Table IV. Even though the expected dose will most likely be small, it is prudent and your responsibility to do what you can to keep your annual dose ALARA.

## 6. Special Concerns in Case of Pregnancy

According to the International Commission on Radiation Protection, special efforts should be taken to reduce the radiation exposure of an embryo or fetus to the lowest practical level during the entire period of gestation. In addition, the National Council on Radiation Protection has recommended that the occupational radiation dose to the fetus should not exceed 0.5 rem (500 mrem) during the 9-month gestation period.

EH&S Radiation Safety is required to take reasonable steps to ensure that radiation exposure rates are kept as low as reasonably achievable in work areas. However, it is your responsibility to decide whether the exposure you are receiving is sufficiently low to protect your unborn child. You should contact EH&S Radiation Safety to determine whether radiation exposure levels in your work area is high enough to cause a dose equivalent of 0.5 rem (500 mrem) or more during the 9 months of pregnancy.

If you are pregnant now, or are considering becoming pregnant, contact EH&S Radiation Safety for more information on radiation risks. It is important to do this promptly since the unborn child is most sensitive to radiation during the first 3 months of pregnancy.

A copy of the U.S. NRC Regulatory Guide 8.13, Instructions Concerning Prenatal Radiation Exposure, is available upon request from EH&S Radiation Safety.

## B. Engineering/ Practical Controls

It's possible to maintain exposures ALARA and satisfy regulatory requirements by following certain basic techniques.

### 1. Control of External Radiation Exposure

External radiation exposure is primarily a problem related to high-energy beta/ gamma emitters and x-ray sources. There are several methods to reduce the exposure from external radiation sources, some may be more appropriate in your particular situation than others.

#### a) Time

Reduce the amount of time you spend in close proximity to a radioactive source by working quickly and efficiently, without working so fast that you will compromise your results or cause spills. If possible, take time to plan your work and perform dry runs. This will make you more familiar with the required experimental procedures and lower the time required to work with the radioactive source. Don't hang around radioactive sources.

Exposure (mR) = exposure rate (mR/hr) x exposure time (time in hours)

#### b) Distance

Whenever possible, increase the distance between you and the source of radiation. The intensity of radiation exposure decreases with the square of the distance from the source according to the relationship:

$$I_1 \times D_1^2 = I_2 \times D_2^2$$

Where:

$I_1$  = the intensity at an initial distance

$I_2$  = the intensity at a new distance

$D_1$  = the initial distance

$D_2$  = the new distance

Therefore, if you double your distance from a source of radiation the exposure rate will be decreased to one-fourth of the initial value.

### c) Shielding

Check your work area using an appropriate survey meter to determine if shielding is required.

Beta emitters:

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

Gamma Emitters:

Attenuation refers to the reduction in the intensity of radiation (e.g., gammas and x-rays) as they pass through an absorbing material. For monoenergetic (single energy) photons (e.g., x-rays, & gamma rays) the relationship is as follows:

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

Where:

$I_0$  = the intensity of radiation with no absorbing material.

$I_x$  = the intensity of radiation after passing through an absorber with thickness

$x$  = absorber thickness.

$\mu$  = Attenuation Coefficient =  $0.693/x_{1/2}$ . Values can be found in reference tables.

$x_{1/2}$  = Half value layer = Thickness of absorber that will reduce radiation intensity to one half of its original value. Values can be found in reference tables.

Note: The units for  $\mu$  and  $x$  must be chosen such that  $\mu x$  has no units.

The higher the photon energy, the more shielding (absorbing) material needed to reduce the exposure rate.. The amount of absorbing material needed to reduce the intensity of photons to one-tenth of their original value is called the tenth-value layer. Photons with energy less than about 10 KeV are attenuated mostly in the skin of the body, presenting an external radiation hazard only to the skin. Higher energy photons can penetrate into and through the body. Therefore, photons of high energy are considered an external radiation hazard to the whole body. The external radiation hazard of gamma and x-ray emitters can be eliminated with lead foil for low energy x-rays and gamma radiation or lead bricks for high energy x-rays and gamma radiation. Gamma and x-ray emitters can result in an internal hazard if ingested, so precautions must be taken.

When using gamma emitters, shielding is required if your meter indicates an exposure rate greater than 2 mR/hr. Adequate shielding for low energy gamma emitters, such as  $^{125}\text{I}$ , can be provided by thin sheets of lead foil. Medium energy gamma emitters, such as  $^{57}\text{Co}$ , often require about one-fourth inch (6.4 mm) of lead and high-energy gamma emitters such as  $^{60}\text{Co}$ ,  $^{22}\text{Na}$ ,  $^{54}\text{Mn}$ ,  $^{51}\text{Cr}$ , and  $^{131}\text{I}$  may require several inches of lead to effectively reduce the radiation. Use the HVL values from Appendix II to determine the actual amount of lead shielding needed for your particular application.

When planning shielding, make sure to shield the source in such a way as to protect those individuals who may be on the other side of adjoining walls or lab benches, occupied areas above and below the work area, your feet and legs. Notify EH&S Radiation Safety if you need assistance to measure exposure rates, determine shielding requirements, or require additional information.

### **C. Control of Internal Radiation Contamination**

Internal deposition of radioactive materials within the body may cause high doses to body organs. This is most significant when a radioisotope has a long residence time (effective half-life) in the body and/or selectively accumulates in specific body organ(s).

When attempting to control internal radiation exposure, it is helpful to know that there are four primary routes of entry into the body: inhalation, ingestion, absorption through the skin, and injection via cuts, abrasions, etc. Methods to prevent internal radiation exposure seek to prevent the entrance of radioactive materials into the body via any of these routes.

#### **1. Inhalation**

Radioactive materials that are volatile or in a particulate form (dust) enter the body through inhalation. Specific examples include radioiodines, some forms of tritium and fine particulates such as labeled microspheres.

The most effective and straightforward means of eliminating the potential hazards related to inhalation is to perform all work with volatile compounds or fine particulates in a fume hood (Laboratory Chemical Hood) or glove box. To work properly, a fume hood must allow unobstructed airflow through the hood face and into the exhaust system. Clutter in the hood and excessive face velocities (the optimal face velocity is about 100 linear feet per minute), can greatly reduce overall hood efficiency. Effectiveness can be increased by moving the radioactive source further into the fume hood, checking that the fume hood sash is not open past the indicated maximum, that the air flow indicator (if any) is working properly, and by verifying that the fume hood air velocity has been checked within the last year. If a fume hood needs to be checked or if there are questions, call EH&S Radiation Safety. If your fume hood malfunctions, stop work and notify Physical Plant and/or EH&S. Don't put your head into the fume hood during work.

#### **2. Ingestion**

Ingestion of radioisotopes is most likely to occur when radioactive materials are transferred from a source to the hands and then to the mouth.

#### **3. Absorption**

Absorption is an especially important route of entry into the body for radioactive iodine and some forms of tritium. Aseptic techniques and common-sense lab practices can prevent most internal intakes of radioisotopes by ingestion and absorption. Some

important lab practices are listed below which will reduce the chance of internal exposure due to ingestion and absorption:

#### Important Work rules

1. Food and drink must not be stored or consumed in a laboratory.
2. Cosmetics must not be applied while working in laboratory areas.
3. Smoking is not allowed in laboratory areas.
4. Wear proper personnel protective equipment (PPE) at all times when working with radioactive materials/ machines. This usually includes a lab coat or apron, gloves (2 pairs when working with iodine, or high concentrations of other isotopes), safety glasses, and shoes. Additional PPE may be required for some operations (respirator).
5. Use required engineering controls (hoods, glove boxes, remote pipettors, etc.).
6. Perform radiation surveys of your work area and promptly decontaminate "hot spots".
7. Monitor your clothing and body for radioactive contamination frequently and at the end of each workday.
8. Wash your hands thoroughly with soap and water after working with radioisotopes, and before leaving the laboratory.

If you have reason to suspect that you have had an intake of radioactive material, notify EH&S Radiation Safety immediately.

#### 4. Injection

Radioisotopes can be injected into the body by a contaminated sharp instrument or through a pre-existing cut or abrasion that simply allows a route for contamination to enter the body. Sharp instruments should always be handled with care and immediately disposed of in an appropriately labeled "Sharps" container to prevent accidental injection. Prevent intake through pre-existing cuts by covering them with bandages and following the same rules for absorption.

## VI. Personnel Monitoring

Measuring the amount of exposure received by personnel can take many forms; following are some of the more common methods.

### A. Film Badges and TLD's

If you work with gamma or high energy beta emitters, you will usually be issued a personnel monitor (film badge or TLD) to measure radiation exposure. Film badges and TLD's are used to record your exposure to external sources of radiation. A film badge contains a small piece of film and several different types of filters. These filters help to identify the type and energy of radiation producing the exposure; therefore, the film must be inserted into the holder properly.

### B. Extremity Monitoring

If you work with certain radiation-producing machines or millicurie quantities of high-energy beta or gamma emitters, you may be issued a finger ring, or similar device, to measure hand exposure. Be sure to wear the monitor with the detector facing the inside of the hand.

### C. Specialized Monitors

Individuals working in certain areas or under special circumstances (pregnant females or those working around accelerators) may require specialized monitoring. Details of this special monitoring can be arranged through EH&S Radiation Safety.

### D. Monitor Usage and Reports

Personnel radiation monitors are exchanged weekly, monthly or quarterly depending on the potential for exposure in the particular work area. The exposure recorded by each radiation monitor is reported to the user.

You can do several things to improve the accuracy of your radiation exposure record. Proper Personnel Monitor Use includes the following.

1. Wear dosimeter any time you work with or are near radioactive materials or radiation-producing machines.
2. Wear your film badge on the collar or belt. If you wear a leaded apron during work, wear the badge on the outside of the apron on or near the collar. Ring dosimeters should be worn with the sensitive element facing the most likely source of radiation, usually toward the inside of the hand.
3. Return dosimeters to EH&S Radiation Safety each time a new one is issued.
4. Do not take your dosimeter home. Store it in a cool, dry place away from radiation sources.
5. Notify EH&S Radiation Safety if you accidentally expose your dosimeter to radiation other than on the job.
6. Do not wear your dosimeter when you receive medical treatment involving radiation and/or radiopharmaceuticals.
7. When you terminate your work assignment involving radiation at UCR, please return your dosimeter(s) to the "dosimeter contact person" for your group, or to EH&S Radiation Safety on the last day of your employment.

## **E. Bioassay Program**

A bioassay is a procedure used to determine the activity of radioisotopes contained in the body. A bioassay for radioactive iodine would involve placing a calibrated scintillation detector on the neck directly over the thyroid gland and measuring the activity.. Bioassays for other types of radioisotopes involve a urinalysis where a urine sample is counted in the lab using an appropriate procedure or submitted to EH&S Radiation Safety for analysis by a method that will determine the amount of radioactive material present.

## VII. Radiation Measuring Devices

One of the ways to avoid widespread contamination in your laboratory or on you is to monitor with a properly calibrated radiation survey meter. There are many types of survey meters available. Each type of survey meter has limitations, both in its operation and the type(s) of radiation that it can most effectively detect. You, in consultation with EH&S Radiation Safety, can determine what type of survey meter is needed for your particular situation. The most common types of instruments are discussed below.

### A. Ionization Chambers

Ionization chambers are used primarily to determine the exposure rate from gamma and x-ray emitters and are particularly useful when measuring machine-produced x-rays. Ion chambers are expensive, but portable and most models are easy to use.

In general, ion chambers are not used to monitor for beta contamination.

Ionization chambers usually measure exposure in milliroentgens or exposure rate in milliroentgens per hour. They should be calibrated every year.

### B. Geiger Muller detectors

GM detectors are the most commonly used on campus. They are easy to use, portable, relatively inexpensive, and good for many types of lab surveys. GM's are most efficient for detecting high-energy beta emitters, such as  $^{32}\text{P}$ , but can also be used to measure low energy beta emitters, such as  $^{14}\text{C}$  and  $^{35}\text{S}$ , if they have a thin end-window (about  $7 \text{ mg/cm}^2$ ).

In addition to a meter, many GM survey meters have an audible output that produces a click for each photon or particle detected. This feature is very useful when doing a survey since the meter response is sometimes quite slow. GM survey meters should be calibrated every year.

Even thin window GM's cannot be used to monitor for tritium ( $^3\text{H}$ ) since the beta particles emitted from tritium don't have sufficient energy to penetrate even the thin end-window of the detector. GM detectors can be used to detect gamma and x-ray radiation from radioisotopes or x-ray machines, but the efficiency is much less than that for beta emitters.

G-M counters usually measure counts per minute, so are often calibrated with an electronic pulser, but they can also be calibrated using a radiation source to measure mR/hr for specific x-ray/gamma energies.

### C. Scintillation Detectors

Scintillation detectors are used primarily to detect gamma radiation. They are much more sensitive to gamma and x-ray radiation than GM detectors, but cost more, are more fragile, and can be more complicated to use. Some portable survey meters can use either a GM detector or a scintillation detector.

If the detector crystal is covered with a metal case, the detector may not be sensitive to low energy gamma and x-ray radiation, therefore, special detector crystals are available for low energy gamma emitters such as  $^{125}\text{I}$ .

Scintillation detectors typically measure counts per minute and may have an audio output like GM detectors. Scintillation detectors should be calibrated every year.

#### **D. Liquid Scintillation Counters**

LSC's are common on campus. They are not portable, and are used primarily for counting laboratory samples. Some sample preparation effort and supplies (counting vials, and liquid scintillation cocktail) are required but these counters are sensitive to low energy beta emitters, and provide one of the few methods that can detect tritium and other very low energy beta emitters. In addition, LSC's can be used to detect most types of radiation, but must be calibrated specifically for each isotope measured.

LSC's typically have good counting efficiency and can be set up to measure in counts per minute, per second, etc. LSC's can be used to count the wipes taken periodically as part of a laboratory survey program. If used for lab surveys LSC's should be calibrated annually.

## VIII. Using Your Radiation Survey Meter

Radiation survey meters must be used properly to function as an effective tool for detecting radioactive contamination or measuring radiation exposure. An audio output is useful when doing surveys since the audio is instantaneous and the meter may respond slowly.

### A. Monitoring

When monitoring for low energy beta emitters with a GM survey meter, the detector must be passed slowly across and very close to the surface that is being monitored. Failure to do this could result in missed contamination. If the detector is covered with plastic, etc., to reduce the possibility of contamination, the sensitivity for low energy beta emitters will be greatly reduced. Remember, you will not be able to monitor for tritium with a portable GM detector.

### B. GM Efficiency

It is impossible for your survey meter to detect every disintegration that is emitted from a radioactive source. Your instrument will indicate some units, counts per minute (cpm) while the source emits disintegrations per minute (dpm). The response of your meter in cpm is typically only a small fraction of the actual dpm. The ratio of cpm to dpm is called the efficiency of the instrument for that particular isotope or type of radiation.

Detector Efficiency =  $\text{cpm} / \text{dpm}$

The intrinsic efficiency of the different types of detectors for the different types and energies of radiation can vary greatly and is also dependent on the geometry (distance of the source from the detector and source configuration).

1. The efficiency for low energy beta emitters is quite low, only about 1 to 6%.
2. The efficiency for high-energy beta emitters is high, about 50%.
3. For gamma emitters, the efficiency is less than 0.1%.

The distance of the source from the detector can influence these factors greatly.

## IX. Special Topics

### A. Lab Surveys

Radioactive contamination levels should be maintained As Low As Reasonably Achievable and must not exceed the levels specified in Table V, unless special authorization is granted by the RSC. Compliance with these levels can be determined by the use of an appropriate survey meter or area wipe.

An area will be decontaminated and resurveyed if the contamination levels exceed those specified in Table V.

**TABLE V**  
**Limits for Removable Surface Contamination\***

TYPE OF SURFACE	Type of Radioactive Material**		
	ALPHA EMITTERS (dpm/100cm <sup>2</sup> )	BETA, X-RAY, OR GAMMA EMITTERS (dpm/100cm <sup>2</sup> )	LOW-RISK BETA, X-RAY, OR GAMMA EMITTERS (dpm/100cm <sup>2</sup> )
Uncontrolled Areas	22	220	2,200
Controlled Areas	220	2,200	22,000
Personal clothing worn outside controlled areas	22	220	2,200
Protective clothing worn only in controlled areas	220	2,200	22,000
Skin	220	220	220

\* As adapted from Table II from Reg. Guide 8.23, Jan '81. Averaging is acceptable over inanimate areas of up to 300 cm<sup>2</sup>, or for floors, walls, ceiling, 100 cm<sup>2</sup>. Averaging is also acceptable over 100 cm<sup>2</sup> for skin or, for the hands, over the whole area of the hand, nominally 300 cm<sup>2</sup>.

\*\* Beta or x-ray emitter values are applicable for all beta or x-ray emitters other than those considered low risk. Low-risk nuclides include C-14, H-3, Tc-99m, and others whose beta energies are <0.2 MeV maximum, whose gamma or x-ray emission is <0.1 R/h at 1 meter per curie, and whose permissible concentration in air (see 10 CFR Part 20, Appendix B, Table I) is >10<sup>-6</sup> uCi/ml.

#### 1. Survey Methods

A survey method must be chosen to measure the exposure to individuals in the area or the amount of removable contamination as required under the circumstances. In the research lab setting, removable contamination is usually of most concern. Survey instruments such as ion chambers, GM detectors, or scintillation detectors can be used to measure exposure if they are properly calibrated for the type of radiation being

measured. Area wipes or smears that are counted by a proper counting system are best for measuring removable contamination.

a) Area Wipe or Smear

A method used to determine the amount of radioactive contamination that can be removed from a surface by rubbing with a wipe or smear.

In most large object cases, wipes should be taken with a piece of absorbent material (filter paper), dry or moistened with an appropriate solvent, from an area not less than 100 cm<sup>2</sup>

For small objects, wipe as much of the total surface area as possible.

Specific areas to check are cracks and corners in floors and counter tops, the area around container closures, and inside shipping containers. This method of contamination detection is particularly useful since it is an effective way to detect low energy radiations (C-14 and H-3), or difficult areas (high background) that are hard to monitor by other methods. Once a wipe is taken, the removable contamination can be measured using an appropriate detection system, usually the regular sample counting equipment in the laboratory (liquid scintillation, gamma counter, GM detector, etc.) is adequate if proper techniques are used. The allowable amount of removable contamination, as determined by a wipe, depends on factors such as the type of radiation and where it is found. (See Table V.)

b) Records

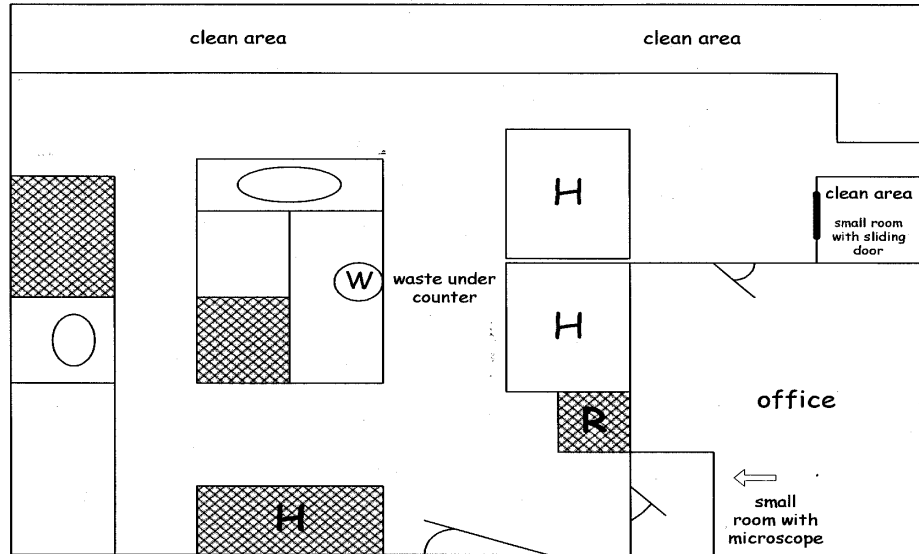
A record of all survey results need to be maintained, including negative results. The records should include the following information and can be maintained in a form similar to that shown in Figures II and III (copies available on the EH&S web site).

- (1) Location, date of survey and description of survey equipment used (type, model/serial #, last calibration date)
- (2) Name of person conducting the survey
- (3) Drawing of area surveyed, identifying relevant features such as active storage areas, active waste areas, etc
- (4) Measured exposure rates, keyed to location on the drawing
- (5) Detected contamination levels, keyed to locations on the drawing
- (6) Corrective action taken in case of contamination or excessive exposure rates, and the reduced contamination levels or exposure rates after corrective action

If contamination is encountered, draw a line through the box and record contamination level in the top half. After decontamination, record the new level in the bottom half.






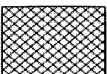
**FIGURE II**  
**Typical Lab Plan**

Pl: \_\_\_\_\_  
Bldg: \_\_\_\_\_  
Rm#: \_\_\_\_\_



**Survey Locations**

	Description
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
14	
15	
16	

-  Refrigerator
-  Radioactive Waste Area
-  Hood
-  Sink
-  Door
-  Radioactive Use Area



## **B. Decontamination Techniques**

During the course of work, laboratory surfaces, equipment, clothing, may become contaminated in spite of precautions. Such contamination does not necessarily present a serious hazard, provided it is detected promptly and not allowed to spread or be ingested. A general Emergency Plan is given. In most cases, a surface or material may be cleaned using ordinary methods (soap, water, brush). However, there may arise cases when these methods are not satisfactory either because the surface or material is porous or because of the high level of contamination. In such cases the levels listed in Table V are considered to be safe for small area or spot contamination. If these levels can't be attained, or if the contamination is extensive, call EH&S Radiation Safety for assistance.

During a Decontamination Procedure it is important to:

1. Keep unnecessary personnel away from the area
2. Wear appropriate protective clothing (gloves, lab coats, etc.)
3. Confine the spread of contamination and isolate the site
4. Do a pre clean-up survey to determine the extent of contamination, level of exposure and when possible, the isotopes and chemical forms present
5. Carefully remove all loose or easily removable contamination, followed by washing with soap, detergent, or special solvents
6. Place all cleaning materials (absorbent materials, gloves, etc.) in a radioactive waste container
7. Do a post clean-up survey to demonstrate that the radiation levels in the area are suitable for the intended use
8. Dispose of waste properly

## **C. Radioactive Spills (Emergency Response)**

Spills of radioactive materials can occur at any time. If you have any doubt about your ability to clean up a spill involving radioactive materials, call EH&S Radiation Safety for assistance at extension 2-5529 or Dial 9-1-1 (campus phone) and ask for EH&S Radiation Safety. If you have determined that the spill can be managed by individuals in your lab, there are several steps you can take to ensure a timely and thorough clean-up of the contamination:

Emergency Response Procedure Outline:

1. Notify everyone in the area that a spill of radioactive material has occurred
2. Assess the overall situation
3. Isolate the effected area and try to prevent further spread of the spilled material with paper towels or other absorbent materials, but only if this can be done with minimal risk of spreading the contamination or contaminating yourself
4. Assemble clean-up materials that include paper towels, plastic bags, gloves, lab coats, radiation survey meter, and cleaning solution (soapy water works well in most cases)
5. Determine the extent of the contamination and mark the boundaries with tape, rope, etc.
6. Starting from the least contaminated areas, work inward toward the most contaminated area of the spill. Clean each area as you proceed
7. Periodically check the cleaned area with either your survey meter or by taking wipes and counting them in an appropriate counter (liquid scintillation counter). Clean until all

removable contamination is removed. Be aware that widespread contamination can cause high background levels that can make it difficult to localize areas of contamination

8. If irremovable contamination remains greater than 100 dpm/100 cm<sup>2</sup>, notify EH&S Radiation Safety
9. For personnel contamination, rinse and wash the contaminated area immediately with plenty of water and mild soap. In some instances, several washings may be required. If the contamination can't be reduced to background levels, call EH&S Radiation Safety for further assistance. Do not use harsh detergents or stiff brushes to remove contamination from skin
10. If a radioactive spill is accompanied by fire or explosion call 9-1-1 (campus phone) and report the specific conditions

#### **D. Radioactive Waste Management**

The radioactive waste program at UCR requires your cooperation for the large amounts of waste generated to be handled in a safe, cost-effective, and responsible manner. Our waste management program is based on regulations related to waste disposal and the resources available at the University to optimize disposal options.

Specific requirements related to radioactive waste management include:

1. All radioactive waste must be transferred to EH&S for disposal. This means that no radioactive material can be placed with the regular trash or poured down the drain.
2. For waste pick-up, contact EH&S Integrated Waste Management at ext. 2-5518 or on the EH&S web site at [www.ehs.ucr.edu](http://www.ehs.ucr.edu)
3. Segregate waste according to half-life and in the following general categories:
  - a) Dry Solids - All dry, solid waste must be placed in properly labeled containers provided or approved by EH&S (absolutely no liquids allowed)
  - b) Sharps - All Sharps must be placed in an approved, properly labeled Sharps container. Sharps include needles, syringes, pipette tips, broken glass, etc
  - c) Liquids - Liquid waste includes the primary radioactive liquid and at least the first rinse. Aqueous and organic waste must be collected separately and must be placed in properly labeled containers approved or provided by EH&S. All liquid waste containers must be compatible with their contents and stored in secondary containers large enough to contain five times the volume of the primary container
  - d) Animal/Medical Waste - All animal/medical waste must be double-bagged, labeled, and stored in a cold room or frozen if held for more than 48 hours before pickup
  - e) Filled Scintillation Vials - Filled vials are picked up only in flats. Segregate glass and plastic vials into separate flats
  - f) Scintillation Cocktails - If vials are emptied, collect the scintillation cocktails, separate from other liquids, in properly labeled containers approved or supplied by EH&S
  - g) Miscellaneous (high specific activity, stock vials, gels, etc.) – Contact EH&S Integrated Waste Mgt. Ext. 2-5518 or EH&S Radiation Safety, Ext. 2-5529 for specific instructions
4. Label Information must be complete before pick-up by EH&S
5. Minimize the amount of radioactive waste generated during the course of your work by:
  - a) Using the smallest animals possible
  - b) Using short-lived radioisotopes whenever possible

- c) Disposing only contaminated items or portions (cut out spots from coats, paper towels, etc.)
- 6. A responsible individual must be present in the lab at the time of the pick-up
- 7. If you need containers or other supplies, contact EH&S Integrated Waste Mgt. at [www.ehs.ucr.edu](http://www.ehs.ucr.edu)

## X. Rules of Thumb

### A. Alphas and Betas

1. It requires an alpha particle of at least 7.5 MeV or a beta particle of at least 70KeV to penetrate the dead layer of skin 0.07 mm thick.
2. The range of beta particles in air is about 12 feet per MeV.
3. The bremsstrahlung x-rays from 10 mCi <sup>32</sup>P of aqueous solution in a glass bottle causes an exposure rate of about 0.1 to 0.2 mR/hr at 1 foot.
4. For a point source of beta radiation that can travel at least 1 foot in air, the beta skin dose can be determined by multiplying the activity, in mCi, by 300. The result is the beta skin dose at 1 foot from the source in mR/hr.
5. For <sup>32</sup>P, 8,300 cpm is approximately equal to 1 mR/hr beta skin exposure when using a Ludlum Model 3 with a pancake probe, which has been calibrated with an electronic pulser.

### B. Photons (Gamma and X-ray)

1. For a point source gamma emitter with an energy between 0.07 and 3 MeV:

The exposure rate (mR/hr) at 1 foot = 6 CEn

Where:

C = The activity of the source in millicuries

E = The gamma energy in MeV

n = The number of gammas per disintegration.

This information is available from Appendix I and various sources that include ICRP publications. Contact EH&S Radiation Safety if there are questions.

If more than one gamma is emitted per disintegration, this equation becomes:

$$\text{mR/hr at 1 foot} = 6C \sum_i E_i n_i$$

2. The energy of a photon is equal to Planck's constant times its frequency ( $E=h\nu$ ).

$$\text{Planck's constant (h)} = 6.63 \times 10^{-27} \text{ erg-sec}$$

$\nu$  = the frequency in Hz (1/sec).

3. The energy of a photon in KeV = 1.24/ $\lambda$

Where:

$\lambda$  = the wavelength in nm

1nm =  $10^{-9}$ m

## XI. Appendices

### A. Data for Some Common Radioactive Isotopes

Element	Atomic#(Z)	Mass#(A)	Half	Radiation	(MeV)	Major Gammas** MeV (% abundance)	$\Gamma^*$
Americium	95	241	5.57 a	$\alpha\gamma$	E =5.6	0.026(2.4), 0.060(35.7)	
Bromine	35	82	35.7 h	$\beta^-, \gamma$	0.142	0.55(66), 0.62(41), 0.70(27), 0.78(83), 0.83(25), 1.04(29), 1.32(26), 1.48(17)	14.6
Cadmium	48	109	1.3 a	ec	0.023		
Calcium	20	45	164 d	$\beta^-$	0.077		
w/Sc 47		47	4.7 d	$\beta^-, \gamma$	0.553	0.49(5), 0.82(5), 1.31(74)	5.95
Californium	98	252	432.2 a	$\alpha, \gamma$	E =6.0		
Carbon	6	11	20.4 m	$\beta^+$	0.380		6.2
		14	5570 a	$\beta^-$	0.050		
Cesium	55	134	2.3 a	$\beta^-\gamma$	0.116	0.57(23), 0.61(98), 0.80(99)	8.6
w/Ba-137m		137	30 a	$\beta^-\gamma$	0.242	0.662(85)	3.0
Chlorine	17	36 38	3.0E <sup>5</sup> a 37.3 m	$\beta^-\beta^+$ $\beta^-, \gamma$	0.279 0.150	1.60(38), 2.17(47)	8.64
Chromium	24	51	27.8 d	ec, $\gamma$	0.005	0.32(9)	0.1
Cobalt	27	57	270 d	ec, $\gamma$	0.007	0.014(9), 0.12(87), 0.14(11)	0.9
		58	72 d	ec, $\beta^+\gamma$	0.035	0.51(30), 0.81(99), 0.87(1.4)	5.4
		60	5.2 a	$\beta^-, \gamma$	0.093	1.17(100), 1.33(100)	12.9
Copper	29	64	12.8 h	ec, $\beta^-, \beta^+, \gamma$	0.130	0.51(38)	1.1
Gallium	31	72	14.3 h	$\beta^-, \gamma$	0.375	0.60(8), 0.63(27), 0.84(96), 0.89(10), 1.05(7), 1.47(4), 1.60(5), 1.86(5), 2.2(26), 2.5(20)	14.7
Gold	79	198	2.69 d	$\beta^-, \gamma$	0.328	0.41(95), 0.68(1)	2.27
		199	3.15 d	$\beta^-, \gamma$	0.13	0.16(37), 0.21(8)	0.42
Hydrogen	1	3	12.26 a	$\beta^-$	0.006		
Iodine	53	125 129 131	60 d 1.6E <sup>7</sup> a 8.1 d	ec, $\gamma$ $\beta^-$ $\beta^-, \gamma$	0.022 0.049 0.188	0.135(7) 0.04(7.5) 0.08(3), 0.28(5), 0.36(82), 0.64(7), 0.72(2)	1.7  2.20
Iron	26	55	2.94 a	ec	0.006		

Element	Atomic#(Z)	Mass#(A)	Half	Radiation	(MeV)	Major Gammas** MeV (% abundance)	$\Gamma^*$
		59	45 d	$\beta^-, \gamma$	0.118	0.14(1), 0.19(3), 1.1(56), 1.3(44)	6.8
Krypton	36	85	10.3 a	$\beta^-, \gamma$	0.224	0.15(74), 0.31(13)	0.02
Mercury	80	197	2.7 d	ec, $\gamma$	0.07	0.08(18), 0.19(2)	0.4
		203	47.9 d	$\beta^-, \gamma$	0.10	0.28(77)	1.2
Molybdenum	42	99	66 h	$\beta^-, \gamma$	0.400	0.04(2), 0.18(7), 0.74(12), 0.78(4)	1.29
Nickel	28	56	6.4 d	ec	0.007		
		63	125 y	$\beta^-$	0.018		
Phosphorus	15	32	14.3 d	$\beta^-$	0.70		
		33	25.4 d	$\beta^-$	0.077		
Plutonium	94	239	2.4E <sup>4</sup> a	$\alpha, \gamma$	E =5.2	0.00007(99.9)	
Potassium	19	40	1.3E <sup>9</sup> a	ec, $\beta^-$	0.59	1.46(10.7)	
		42	12.4	$\beta^-$	1.43	1.53(17.9)	
Rubidium	37	86	18.6 d	$\beta^-, \gamma$	0.68	1.078(8.8)	0.49
Scandium	21	46	85 d	$\beta^-, \gamma$	0.12	0.89(100), 1.12(100)	11.0
		47	3.4 d	$\beta^-, \gamma$	0.146	0.16(73)	0.48
Selenium	34	75	127 d	ec, $\gamma$	0.011	0.07(1.1), 0.1(3.5), 0.12(17.7), 0.14(6.1), 0.20(1.5), 0.26(59.4), 0.28(2.5), 0.30(1.3), 0.40(11.3)	1.84
Silver	47	111	7.5 d	$\beta^-, \gamma$	0.34	0.25(1), 0.34(6)	0.17
Sodium	11	22	2.6 a	$\beta^+, \gamma$	0.193	0.51(180), 1.28(100)	11.9
		24	15 h	$\beta^-, \gamma$	0.56	1.37(100), 2.75(100)	18.7
Strontium	38	85	65 d	ec, $\gamma$	0.004	0.51(100)	6.5
w/Y-90		89	54 d	$\beta^-$	0.56		
		90	28 a	$\beta^-$	0.20+ 0.93		
Sulfur	16	35	87 d	$\beta^-$	0.049		
Tellurium	52	121	17 d	ec, $\gamma$	0.027	0.58(18), 0.57(80)	3.4
Thallium	81	204	4.1 a	ec, $\beta^-$	0.234		
Tin w/In-113m	50	113	115 d	ec, $\gamma$	0.025	0.26(2) + In-113m rad	3.5
Tungsten	74	185	74 d	$\beta^-$	0.130		

Element	Atomic#(Z)	Mass#(A)	Half	Radiation	(MeV)	Major Gammas** MeV (% abundance)	$\Gamma^*$
Vanadium	23	48	16 d	ec, $\beta^+$ , $\gamma$	0.14	0.511(100), 0.95(10), 0.98(100), 1.31(97), 2.24(3)	10.0
Xenon	54	133	5.27 d	$\beta^-$ , $\gamma$	0.110	0.081(37)	0.44
Yttrium	39	90	64.6 d	$\beta^-$	0.93		
		91	58 d	$\beta^-$ , $\gamma$	0.585	1.21(0.3)	0.21
Zinc	30	65	245 d	ec, $\beta^-$ , $\gamma$	0.010	0.51(3.4), 1.12(49)	2.9

\* Exposure rate (R/hr) for a 1mCi source at a distance of 1 cm. Divide by 900 for the exposure rate at 1 ft.

\*\* Most prominent gammas and X-Rays (greater than 1% abundance) listed by energy in MeV and approximate percent abundance.

### B. Half Value Layer Data for Photons

Energy (MeV)	Lead (cm)	Iron (cm)	Aluminum (cm)	Water (cm)	Air (m)	Concrete (cm)
0.3	0.160	0.845	2.457	5.823	5.133	2.76
0.5	0.396	1.062	2.936	7.532	6.243	3.39
1.0	0.816	1.471	4.225	9.760	8.451	4.65
1.5	1.174	1.833	5.058	12.157	10.343	5.72
2.0	1.358	2.074	6.187	13.860	12.375	6.66

**C. Small and Large Factors for SI Units**

PREFIX	SYMBOL	MULTIPLICATION FACTOR
exa	E	$10^{18}$
peta	P	$10^{15}$
tera	T	$10^{12}$
giga	g	$10^9$
mega	M	$10^6$
kilo	k	$10^3$
hecto	h	$10^2$
deka	da	$10^1$
deci	d	$10^{-1}$
centi	c	$10^{-2}$
milli	m	$10^{-3}$
micro	$\mu$	$10^{-6}$
nano	n	$10^{-9}$
pico	p	$10^{-12}$
femto	f	$10^{-15}$
atto	a	$10^{-18}$

**D. Common Conversion Factors**

1 Ampere (A)	= 1 Coulomb per second = $6.25 \times 10^{18}$ electrons per second
1 Becquerel (Bq)	= 1 dps
1 Calorie (Cal)	= $4.184 \times 10^7$ ergs
1 Curie(Ci)	= $3.7 \times 10^{10}$ disintegrations per second = $3.7 \times 10^{10}$ Bq
1 millicurie (mCi)	= $3.70 \times 10^7$ disintegrations per second
1 microcurie (uCi)	= $3.70 \times 10^4$ disintegrations per second
1 nanocurie (nano-Ci)	= 37 disintegrations per second
1 day	= 1,440 minutes = 86,400 seconds
1 electron Volt (eV)	= $1.602 \times 10^{-12}$ ergs
1 million electron Volts (MeV)	= $1.602 \times 10^{-6}$ ergs
1 esu	= 1 statcoulomb
1 electrostatic unit of charge (esu)	= $2.083 \times 10^9$ electrons
1 erg	= $6.24 \times 10^5$ MeV
1 gram	= $5.60999 \times 10^{26}$ MeV = $6.0242 \times 10^{23}$ amu
1 Gray (Gy)	= 100 rad
1 rad	= 100 ergs absorbed per gram of any absorber = $6.24 \times 10^7$ MeV absorbed per gram
1 Roentgen (R) produces ionization	= 1 esu of charge per 0.001293 gm dry air = 1 esu of charge per $\text{cm}^3$ air (STP) = 1 statcoulomb/cc of air (STP) = $2.083 \times 10^9$ ion pairs per $\text{cm}^3$ air (STP)
1 Seivert (Sv)	= 100 rem
W (mean energy expended)	= 34 electron Volts per ion pair in air
Photon energy in KeV	= $12.4 \times 10^{-10}$ /photon wavelength in meters

**E. Useful Constants**

(J.W.M. DuMond and E.R. Cohen, Least Squares Adjustment of the Atomic Constants, 1952. Rev. Mod. Phys. 25, 691, 1953.)

Avogadro's Number (N)	=	$6.025 \times 10^{23}$ molecules per gram-mole
Planck's Constant (h)	=	$6.625 \times 10^{-27}$ erg-seconds
Velocity of light ©	=	$2.998 \times 10^{10}$ cm per second
Electron charge (e)	=	$4.803 \times 10^{-10}$ esu
	=	$1.6 \times 10^{-19}$ coulomb
One Mass Unit (amu)	=	$1.6598 \times 10^{-24}$ grams
Energy Equivalent to one Atomic Mass Unit	=	$1.492 \times 10^{-3}$ ergs
	=	931.16 MeV
Electron Rest Mass ( $m_e$ )	=	$9.108 \times 10^{-28}$ gm
	=	0.000549 amu
	=	0.51098 MeV
Proton Rest Mass ( $M_p$ )	=	$1.6724 \times 10^{-24}$ gm
	=	1.00759 amu
	=	938.23 MeV
Neutron Rest Mass ( $M_n$ )	=	$1.6747 \times 10^{-24}$ gm
	=	1.00898 amu
	=	939.53 MeV

## XII. References

1. "Radiation Safety Handbook". University of California-Irvine.
2. "Radiation Protection Manual". Stanford University.
3. "Technical Information for Radiation Safeguards". University of California-Los Angeles.
4. *Instruction Concerning Prenatal Radiation Exposure. U.S. NRC Regulatory Guide 8.13, Revision 3, June 1999.*
5. *Instruction Concerning Risks From Occupational Radiation Exposure. U.S. NRC Regulatory Guide 8.29, Revision 1, February 1996.*
6. Cember, Herman. *Introduction to Health Physics*. 2nd ed., Pergamon Press, New York, NY. 1993.
7. Shapiro, Jacob. *Radiation Protection - A Guide for Scientists and Physicians*. 2nd ed., Harvard University Press, Cambridge, MA. 1981.
8. Healy, *Surface Contamination: Decision Levels*. Los Alamos Scientific Laboratory, Los Alamos, New Mexico. LA-4558-MS. 1971.
9. Hall, Eric. *Radiobiology for the Radiologist*. Harper and Row, New York, NY. 1978.
10. Pizzarello, Donald and Richard Witcofski. *Basic Radiation Biology*. Lea and Febizer, Philadelphia, PA. 1967.
11. *Health Effects of Exposure to Low Levels of Ionizing Radiation*. National Research Council, BEIR V. 1990.
12. Upton, Arthur. *The Biological Effects of Low-Level Ionizing Radiation*. Scientific American, Volume 246, Number 2, February, 1982.
13. *Radiological Health Handbook*. Public Health Service, FDA, Bureau of Radiological Health, Revised Edition, Rockville, MD. 1970.
14. *A Handbook of Radioactivity Measurement Procedures*. Number 58, National Council on Radiation Protection and Measurements, NCRP, Washington, DC. 1978.
15. Brodsky, Allen. *Handbook of Radiation Measurement and Protection*. Volume 1, CRC Press, West Palm Beach, FL. 1978.
16. "Radiation Safety Manual". University of California-San Diego.