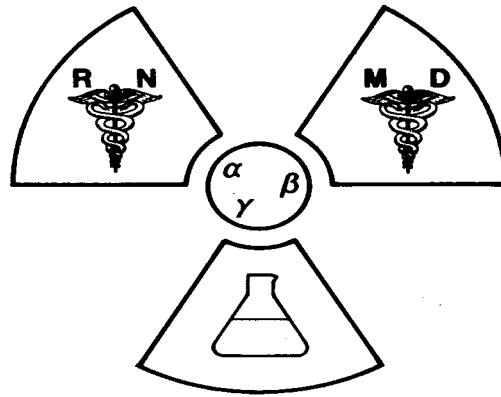




OFFICE OF ENVIRONMENTAL HEALTH AND SAFETY

RADIATION SAFETY TRAINING MANUAL



UNIVERSITY OF CALIFORNIA, SAN FRANCISCO

RADIATION SAFETY TRAINING MANUAL

SEPTEMBER, 1996

This information is being provided in accordance with the following State requirements:

CALIFORNIA RADIATION CONTROL REGULATIONS 17CAC30280(a) (1)

Each user shall inform individuals working in or frequenting any portion of a controlled area as to the presence of sources of radiation; instruct such individuals in safety problems associated therewith and in precautions or procedures to minimize radiation exposure; and instruct such individuals in the provisions of department regulations and licenses applicable for the protection of personnel.

Environmental
eh&s
Health and Safety

RADIATION SAFETY TRAINING MANUAL

TABLE OF CONTENTS

SECTION	DESCRIPTION	PAGE
	INTRODUCTION	1
CHAPTER 1	PROPERTIES OF IONIZING RADIATION	2
A	Structure of the Atom	2
B	Atomic Nomenclature	3
C	Beta Particles	3
D	Radioactive Decay	5
E	Gamma and X-rays	5
F	Other Modes of Decay	7
G	Bremsstrahlung - A Type of X-ray	7
CHAPTER 2	UNITS FOR MEASURING IONIZING RADIATION	8
A	Roentgen: The Unit of Exposure	8
B	Rad: The Unit of Absorbed Dose	8
C	Rem: The Dose Equivalent Unit	9
D	Curie: The Unit of Activity	9
CHAPTER 3	MAXIMUM PERMISSIBLE EXPOSURES	11
A	Guidelines for Radiation Exposure	11
B	Maximum Permissible Dose (MPD)	11
C	How Does the MPD Compare with Other Sources of Radiation Exposure?	13
D	What is the Risk at the MPD?	14
E	Special Safeguards for Pregnant Women	16
CHAPTER 4	BIOLOGICAL EFFECTS OF RADIATION	20
A	Somatic and Genetic Effects	20
B	Increase in Cancer Incidence	21
C	Genetic Damage	21
D	Exposure of Unborn Children	21
CHAPTER 5	SAFETY HAZARDS ASSOCIATED WITH COMMONLY USED RADIONUCLIDES	22
A	Internal Radionuclide Hazards	22
B	External Exposure to Radionuclides	23

CHAPTER 6	PRACTICAL STEPS TO RADIATION SAFETY	29
A	Principles of Radiation Safety	29
B	The Laboratory Radiation Safety Program	32
C	Becoming an Authorized User of Radioactive Material	34
D	Storage of Radioactive Materials	36
E	Handling Radioactive Materials	39
F	Use of Volatile Radionuclides	42
G	Special Precautions for the Use of Radioactive Iodine	42
H	Transportation of Radionuclides	43
I	Posting and Labeling Requirements	45
J	Working with Radioactive Animals	47
CHAPTER 7	MEASUREMENTS OF RADIATION EXPOSURE	48
A	Film Badge and Finger Ring Dosimeters	48
B	Bioassays	52
C	Survey meters	52
D	Wipe Surveys	54
CHAPTER 8	RECORD KEEPING	57
A	UCSF Radioisotope Usage Form	57
B	Radioisotope Inventory	57
C	Wipe Survey Records	58
CHAPTER 9	RADIOACTIVE WASTE DISPOSAL	60
A	Categories of Radioactive Waste	60
B	Radioactive Decay	67
C	Storage Considerations for Radioactive Waste	67
D	Classification	68
E	Documentation	68
F	Scheduling of Radioactive Waste Pick-Ups	71
G	Dose Rate Limits for Radioactive Waste Packages	71
H	Billing	71
CHAPTER 10	EMERGENCY PROCEDURES	72
A	Notification of the Radiation Safety Office	72
B	Management of Radiation Incidents	72
C	Personnel Contamination	73
D	Emergency Telephone Numbers	74
E	Injury and Contamination	74
CHAPTER 11	GLOSSARY	76
CHAPTER 12	SELF-ASSESSMENT QUIZ	86

RADIATION SAFETY TRAINING MANUAL

PREFACE

This Manual has been prepared to help you use radioactive materials at the University of California, San Francisco (UCSF) safely and in accordance with pertinent requirements and regulations. Following established procedures and requirements will ensure that users, visitors to this campus and those who live nearby are at minimal risk from our uses of radioactivity.

Radioactive materials are used in strict accordance with the terms and conditions of a Radioactive Materials License issued to UCSF by the State of California, Department of Health Services, Radiologic Health Branch and in accordance with the California Radiation Control Regulations contained in Title 17 of the California Administrative Code and the Nuclear Regulatory Commission's Code of Federal Regulations 10CFR20. In addition, UCSF must comply with rules and regulations issued by other agencies that relate to the use of radiation. For example, the U.S. Department of Transportation has regulations governing the packaging, shipping, and transport of radioactive materials; the Food and Drug Administration has regulations governing certain aspects of the preparation and use of radiopharmaceuticals.

THIS WRITTEN GUIDE *DOES NOT REPLACE* THE REQUIREMENT THAT THE SUPERVISOR, OR AN APPROPRIATE ALTERNATE, PROVIDE *PRACTICAL, HANDS-ON* TRAINING IN THE CORRECT STORAGE, USE, DISPOSAL AND TRANSPORTATION OF RADIOACTIVE MATERIAL.

RADIATION SAFETY TRAINING MANUAL

INTRODUCTION

We use radioactivity in experimental and diagnostic situations at the University of California, San Francisco (UCSF) because there is no better way to get the information we seek. Yet working with radioactivity does pose some risk. A great deal is known about the risks associated with radiation as compared with other environmental hazards in the work place and, unlike some hazardous materials, radiation is relatively easy to measure and protect ourselves against.

Exposure to ionizing radiation is a real, although a relatively minor, hazard. It will remain minor for ourselves and our colleagues if we are careful. Regulations and common sense dictate that radionuclide users be familiar with the:

1. Properties of ionizing radiation.
2. Biological effects of ionizing radiation.
3. Measurement of ionizing radiation.
4. Safe procedures for storage, use and disposal of radionuclides.
5. Survey and monitoring procedures.

The first goal of this training manual is to provide enough information about the radionuclides we use, their properties and their containment so that our involvement with radionuclides can be as risk-free as possible. The second goal is to establish standards of behavior such that visitors to this campus and those who live nearby can be assured they are at minimal risk.

CHAPTER 1

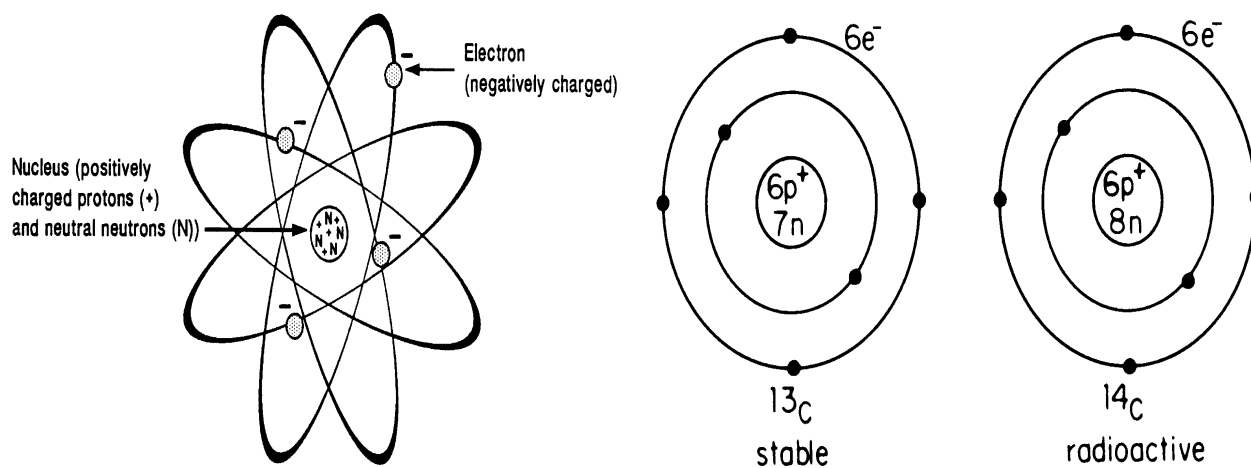
PROPERTIES OF IONIZING RADIATION

To better understand radiation safety procedures, a general understanding of the physical properties of ionizing radiation is useful. For a more complete description of the interaction of ionizing radiation with matter, a radiation safety textbook should be read. Consult the Radiation Safety Officer (RSO), or your Department Safety Advisor (DSA), for additional reading material.

A. STRUCTURE OF THE ATOM

The building blocks of atomic and nuclear structure are the electron, proton, and neutron. In its simplest form the atom has a dense core (nucleus) with electrons traveling in specific orbits or energy levels about the nucleus (See Figure 1.1).

Figure 1.1 Structure of the Atom



1. NUCLEUS

- Protons - positive charge.
- Neutrons - uncharged.
- The mass of the neutron and proton is as follows (1 proton = 1.00727 amu; 1 neutron = 1.00866 amu). 1 amu = 1/12 of the mass of the carbon nucleus with 6 protons and 6 neutrons.

2. ELECTRONS

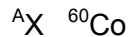
- Mass equals 0.00055 amu (approximately 1/2000 of the mass of a proton).
- Negatively charged.
- Atom is electrically neutral if total electron charge equals total proton charge.

- d. Electrons are bound to the positively charged nucleus by electrostatic attraction.

B. ATOMIC NOMENCLATURE

The following terms are commonly used in radiation physics:

- X = Chemical symbol
- A = Mass number (proton number + neutron number)
- Z = Atomic number (proton number)
- N = Neutron number (A minus Z)



With the exception of ${}^{209}\text{Bi}$, all nuclei with atomic numbers greater than 82 are unstable. Many nuclei with atomic numbers less than 82 also are unstable. Unstable nuclei undergo transformations which release energy. Each transformation of a parent nucleus is called a disintegration. The disintegration rate is proportional to the number of radioactive atoms and the **half-life**. **The half-life is the time required for half of the radioactive atoms to disintegrate.** Each radionuclide is unique in terms of the type and energy of the ionizing radiation it emits, and in the duration of its half-life.

At the University of California, San Francisco (UCSF), many different radionuclides are used. Below, the classes of decay events that we most commonly encounter are identified.

C. BETA PARTICLES

1. NEGATIVE BETA PARTICLES

Commonly used radionuclides at UCSF (${}^3\text{H}$, ${}^{14}\text{C}$, ${}^{32}\text{P}$, ${}^{35}\text{S}$ and ${}^{45}\text{Ca}$) emit beta particles. In beta decay, a neutron is converted to a proton and an electron, and the electron is promptly ejected from the nucleus. An electron emitted from the nucleus of an atom is called a beta particle. Although the correct name for a negatively charged beta-particle is a negatron, the term is so unfamiliar that we will reserve the term "beta-particle" for a negatively charged beta-particle, and the term "positron" to denote a positively charged one.

Electrons emitted during beta decay have a continuous energy distribution ranging from zero to a maximum which is characteristic of a particular radioisotope. The maximum energy of a particular beta decay is defined as E_{max} ; the mean energy (E_{mean}) is approximately $E_{\text{max}}/3$. The shape of the beta energy spectrum and the values for E_{max} are characteristic. Modern liquid scintillation counters allow the identification of radionuclides by detecting and measuring the energies of the emitted beta particles.

Beta-particles have a finite range in air and other materials (Figure 1.2) linearly related to the E_{mean} . As a rule of thumb, the range of beta particles in air is about 12 feet per MeV. For example, ${}^{32}\text{P}$ has an E_{max} of 1.7 MeV or a maximum range in air of 12×1.7 or approximately 20 feet. The mean range would be approximately 7 feet.

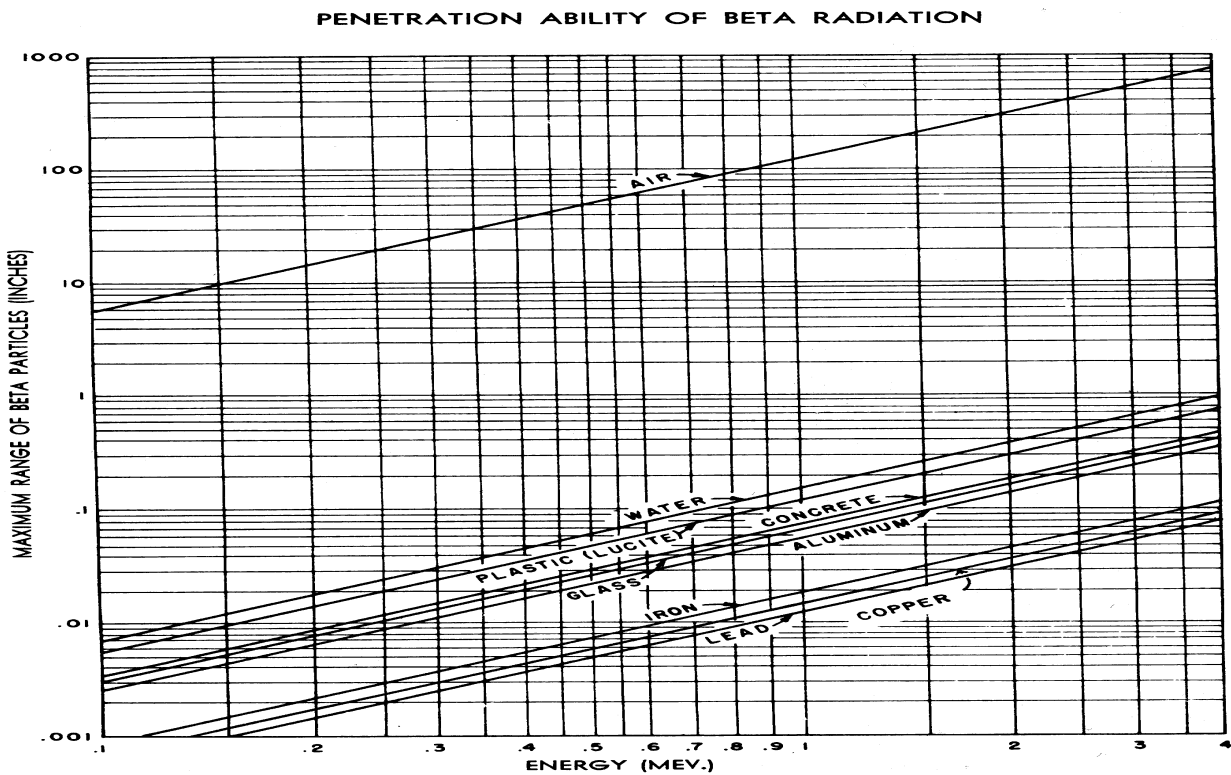
2. POSITIVE BETA PARTICLES

Some nuclei decay by beta+ (positron) emission. This decay results from a proton converting to a neutron and an electron having a positive charge (positron). The result of this type of decay is the loss of a positive charge in the nucleus of the atom. The most commonly used positron emitters at UCSF are ^{22}Na , ^{65}Zn , ^{68}Ga , and ^{114}In .

A positron is an example of anti-matter. When matter and anti-matter collide, they annihilate each other, converting their mass directly into electromagnetic energy in the form of x-rays.

The positron's spectral response is similar to that of negatively charged beta-particles. When shielding positron emitters, however, they should be treated as photon-emitters, since their annihilation can result in the generation of 0.51 MeV photons.

Figure 1.2 Penetration Ability of Beta-Particles



D. RADIOACTIVE DECAY

Radioactive decay is the disintegration of the nucleus of an unstable nuclide by spontaneous emission of charged particles and/or photons. The decay rate (i.e. the number of nuclear disintegrations per second) of a radionuclide decreases as an exponential function. The activity of the sample is the curie (Ci). (See Chapter 2.)

The half-life (T_{phy}) is the time required for a radioactive substance to lose 50% of its activity by decay. Each radionuclide has a unique half-life (a physical property that cannot be modified). Figure 1.3 presents two graphs showing the exponential decay of radioactive gold. The half-lives of some beta-emitters and gamma-emitters are given in Chapter 5.

Clinicians and researchers must be aware of the biological half-life of a radionuclide in a biological system. The biological half-life (T_{bio}) is the time required for the body to eliminate one-half of an administered dosage of any substance by the regular processes of elimination. This time is approximately the same for both stable and radioactive isotopes of a particular element.

The effective half-life (T_{eff}) is the time required for a radioactive element in an animal body to be diminished by 50% as a result of the combined action of radioactive decay and biological elimination. T_{eff} is computed as follows:

$$T_{\text{effective}} = T_{\text{phy}} \times T_{\text{bio}} / (T_{\text{phy}} + T_{\text{bio}})$$

The biological half-life for carbon is about 10-40 days, calcium about 10^4 days, sulfur about 100-1600 days and for phosphate about 20-1200 days.

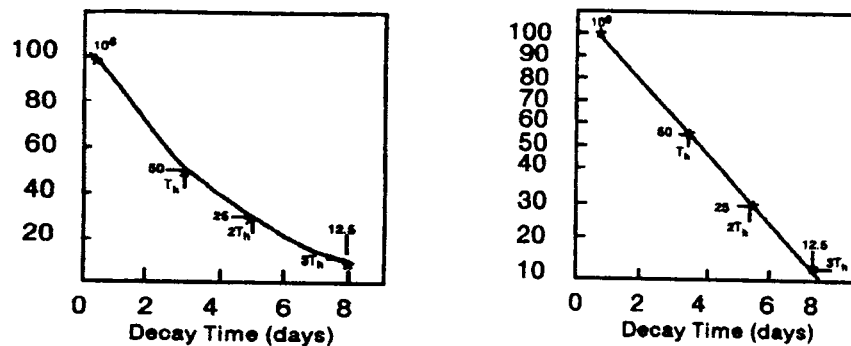


FIGURE 1.3 Graphs showing the exponential decay of a source of 10^8 atoms of an ^{198}Au radionuclide with a half-life of 2.70 days. The graph on the left is a linear plot while the one on the right is a semi-logarithmic one.

E. GAMMA AND X-RAYS

Gamma rays and x-rays are types of electromagnetic radiation with about the same wave length. Other types of electromagnetic radiation are radio waves, visible light, and ultraviolet irradiation. Gamma rays and x-rays are very much more energetic (have very much shorter wave lengths) than the other forms mentioned. Sometimes these rays behave like waves and have an energy proportional to their frequency. At other times they are best considered as discrete bundles of energy called photons. Gamma rays and x-rays occupy the same region within the electromagnetic spectrum. They are distinguishable by their origins - gamma-rays result from nuclear transitions (inside the nucleus) and x-rays from the interaction of electrons (outside the nucleus). Gamma rays have discrete wave lengths while x-rays cover a wide band of wave lengths.

Some of the radionuclides used at UCSF emit gamma-rays and/or x-rays. Because of their short wave length, these photons can pass through matter. As they pass through matter, they may be attenuated by their interaction with bound electrons in the matter (photoelectric effect), with "free" electrons in the matter (Compton effect), or with the transfer of their energy to the creation of a positive and negative electron pair (pair production). The importance of each of these effects depends on the atomic number (Z) of the absorbing material and the energy of the photon.

Gamma and x-ray photons with energies between 30 KeV and 30 MeV interact in soft tissue predominantly by Compton scattering. This means a partial energy transfer by the incoming photon through interaction with an orbital electron. The weakened photon continues on until it undergoes another Compton interaction. The Compton electron produces secondary ionizations by ejecting other electrons from their respective orbits. These electrons may have an energy that is higher than chemical bonds and by their interaction may alter chemical structures. The primary cause, approximately 80%, of biological damage is the result of the energetic charged particles produced secondarily by the x-ray or gamma-ray, not the original photon.

The intensity of electromagnetic radiation varies with the distance from the source according to the Inverse Square Law. This means that the intensity is inversely proportional to the square of the distance. $I_1 \times (D_1)^2 = I_2 \times (D_2)^2$ where: I = Intensity, D = Distance.

Example: At 1 foot a beam of gamma-rays has 1000 photons crossing a 1 cm square in one second. At 2 feet the beam will consist of $1000/2^2 = 250$ photons/cm²/sec.

The rate at which the intensity (number of photons) decreases also depends on the density of the absorber. Lead, for example, is a more effective absorber of photons than air. If a certain thickness of an absorber reduces the intensity by 50%, twice that thickness reduces it to 25%, three times to 12.5% and so on; then the thickness of that absorber which reduces the intensity by 50% is called the *half value layer* (HVL). This is an exponential process; that is, as the thickness of the absorber is increased the intensity of the electromagnetic radiation decreases, but statistically never reaches zero. Note the contrast with beta particles. Beta particles can be completely shielded because of their finite path length.

F. OTHER MODES OF DECAY

There are other modes of radioactive decay besides beta, positron, and gamma decay which include alpha decay, internal conversion, electron capture, and neutron emission. Alpha decay is briefly discussed below. A textbook can be consulted to review the other modes.

An alpha particle is composed of two neutrons and two protons, and is identical to a helium nucleus. Alpha particles are emitted by many heavy radionuclides when they decay. Three familiar alpha-emitting elements are radium, uranium, and plutonium. Alpha energies range from about 4 MeV to 8 MeV. However, the range of alpha particles is very short - a 5 MeV alpha has a range of 0.034 mm in tissue and will not penetrate the skin. Although external exposure is of negligible concern, internal exposure is of very great concern. The concern is due to the very high linear energy transfer of alpha particles. Thus, extreme precautions must be taken to prevent entry inside the body by inhalation, ingestion, or skin puncture.

G. BREMSSTRAHLUNG - A TYPE OF X-RAY

Energetic beta-particles, like those emitted by ^{32}P , are quickly decelerated when passing through matter. The energy lost to deceleration is emitted in the form of x-rays called "Bremsstrahlung" which translates as "braking radiation". Bremsstrahlung is of concern when shielding beta emitters.

The intensity of bremsstrahlung increases with the increase in energy of the electrons or the mass of the absorbing media. Thus, it is common to use light materials, such as lucite or plastic, to shield beta particles. The shield should consist of a light material (for absorption of the beta radiation) followed by a dense material (such as lead) to absorb the bremsstrahlung.

The bremsstrahlung from a 1 curie source of ^{32}P solution in a glass container is approximately 10 mrad/hr at 1 foot. Approximately 1 cm of lucite is sufficient to shield ^{32}P .

CHAPTER 2

UNITS FOR MEASURING IONIZING RADIATION

When conducting a survey of the laboratory for radioactive contamination, you note that the instrument reads in mR/hr (milliroentgen/hour). This is a radiation exposure rate measurement. The laboratory has another instrument which reads in counts per minute (cpm). While opening a radioactive vial, you notice that the label describes the contents in microcuries. This is a unit of radioactivity. When reviewing film badge and finger ring records, you note that the results are given in millirems. This is a measure of radiation dose. These units, commonly used at the University of California, San Francisco (UCSF), are discussed below.

A. ROENTGEN: THE UNIT OF EXPOSURE

The roentgen (R) was adopted in 1928 as a unit of exposure to medium-energy x-radiation. It is the approximate exposure to one gram of radium located one yard away for one hour (i.e. one gram of radium produces an exposure rate at one yard of approximately one R/hour). Specifically, the roentgen is the quantity of x- or gamma rays that produce 2.58×10^{-4} coulombs/kg of air at standard conditions of temperature and pressure. In measuring the roentgen, a known volume of air is irradiated, and the ions produced (electrical charge) are collected and measured. The choice of air as a standard substance was for convenience. Since air and water have an effective atomic number that is nearly the same as that of tissue, absorption of x-ray energy per gram of soft tissue, water and air is within about 12% of being the same.

However, the roentgen has limitations. By definition it is limited to x- and gamma-rays, and medium of air, and does not include other types of radiation. Further, the definition of the roentgen holds only for lower energy radiations (up to 3 MeV).

B. RAD: THE UNIT OF ABSORBED DOSE

The rad is the unit of absorbed dose and is a measure of the energy deposition per unit mass by all types of ionizing radiation. Chemical and biologic changes in tissue exposed to ionizing radiation depend upon the energy deposited in the tissue rather than the amount of ionization which the radiation produces in air. The rad, an acronym for **R**adiation **A**bsorbed **D**ose, is not limited to x- or gamma rays and is not limited to the medium of air.

The rad is specifically defined as the deposition of 100 ergs per gram of absorbing material. As a general rule, the absorbed dose in soft tissue from 1 R of intermediate energy x- or gamma rays is about 1 rad. The rad is being replaced by the Gray (Gy), which is defined as an absorbed energy 100 times greater than a rad (1 Gy = 100 rad = 1 joule/kg). This Manual has retained the older units of rad, rem, curie.

C. REM: THE DOSE EQUIVALENT UNIT

The rem, an acronym for **R**oentgen **E**quivalent **M**an, was developed in response to evidence that biologic effects per rad of various radiations are often different. The dose equivalent (DE) is defined as the absorbed dose (rads) multiplied by a quality factor (QF), a term that expresses the differences in biologic effectiveness of various types of radiation as compared to x-rays. The QF is a function of the linear energy transfer (LET) of the radiation. The QF for x-rays, gamma-rays, and beta particles with a maximum energy of greater than 30 KeV is 1.0. This category represents a majority of radioactive materials used at UCSF. For information, the QF for neutrons and protons with energies less than 10 MeV is 10 (30 for irradiation of the eyes); for alpha particles from natural radionuclides the QF is 10.

The new unit for dose equivalent is the Sievert (Sv), which is related as $1 \text{ Sv} = 100 \text{ rem}$.

TO SIMPLIFY THIS MANUAL AND TO MAKE CALCULATIONS EASIER, THE TERMS ROENTGEN, RAD, AND REM ARE CONSIDERED INTERCHANGEABLE.

D. CURIE: THE UNIT OF ACTIVITY

When an excited nucleus emits characteristic neutrons, alpha, beta (positive or negative) particles, and/or gamma rays, the nuclei are said to be radioactive. (Radioactive materials used at UCSF primarily emit beta particles and gamma rays.) Each transformation of a parent nucleus is called a disintegration. Cobalt-60, often used in radiation teletherapy, emits a beta particle followed immediately by two gamma rays. These three radiations are emitted per disintegration.

An important unit in the practical application of radioactivity is the number of disintegrations per unit time (typically seconds or minutes). The quantity of any radionuclide in which the number of disintegrations per second is 3.7×10^{10} is one curie (Ci).

$$1 \text{ Ci} = 3.7 \times 10^{10} \text{ disintegrations per second (dps)}$$

A millicurie is one-thousandth of a curie and microcurie is one-thousandth of a millicurie.

The curie is being replaced by the becquerel (Bq) unit defined as: 1 dps. Thus

$$\begin{aligned} 1 \text{ Ci} &= 3.7 \times 10^{10} \text{ Bq} \\ 1 \text{ Bq} &= 2.7 \times 10^{-11} \text{ curies.} \end{aligned}$$

Units of conversion are found in the Glossary.

Many UCSF survey meters read in counts per minute (cpm) or counts per second (cps). If the counting efficiency (counts per unit time/disintegrations per unit time) is known for the radioactive material being measured, then the activity of the material can be estimated. The efficiency will vary for each isotope and instrument type.

Assume that the efficiency of a survey meter for measuring ^{35}S is 1%. Assume that 1,000 cpm are measured with the meter. Then, dpm would be computed as $1,000/0.01$

or 100,000 dpm. The activity would be computed as $100,000 \text{ dpm}/60 \text{ sec/min} = 1,667 \text{ Bq}$ or 0.045 microcuries.

CHAPTER 3

MAXIMUM PERMISSIBLE EXPOSURES

A. GUIDELINES FOR RADIATION EXPOSURE

For investigators working with radioactive materials in University of California, San Francisco (UCSF) laboratories, the risk, if any, to low levels of radiation exposure is small. Nevertheless, the risk is real and can only be kept small if the policies and procedures of UCSF, along with the regulations of the State and Federal governments, are carefully followed. UCSF policies and government regulations are based, in part, on three radiation protection principles:

1. Occupational exposure should only take place when the benefit to society warrants the risk. There is little doubt that medically-related research falls into this category.
2. Exposure to workers should be **As Low As is Reasonably Achievable (ALARA)**. This has been characterized as the "optimization" of radiation protection by the International Commission on Radiological Protection.
3. A "maximum allowable individual dose" must be established to set an upper limit on the risk to individual workers.

UCSF is fully committed to the principle of ALARA. The Radiation Safety Manual spells out this commitment and the ALARA program for the campus. Each authorized user should familiarize themselves with this material. This chapter is devoted to a description of permissible doses.

B. MAXIMUM PERMISSIBLE DOSE

The maximum permissible doses allowed by state and federal regulations have been set based on current knowledge. Scientific committees composed of the world's leading authorities in radiation science and biology are established to periodically appraise the literature and recommend changes in dose limits, if indicated.

The dose limits consider that damage caused by radiation exposure is dependent upon several factors:

1. The age of the person exposed.
2. The absorbed dose.
3. The body part exposed.

The occupational radiation dose limits first divide people into two groups: those 18 years and over, and those under 18 years of age. The latter group is limited to the same doses as the general population (i.e. non-radiation workers). Table 3.1 presents a synopsis of the dose limits contained in the Code of Federal Regulations (10CFR20). (The limits are the same throughout the country.)

Review Table 3.1 Note that the hands have a limit 10 times higher than the whole body radiation dose. Radiosensitive tissues, such as the blood forming cells, and the gonads, have the lowest maximum permissible dose.

The regulations limit radiation exposure to members of the public (i.e. those who are not occupational radiation workers) to limits that are one-fiftieth of the occupational values. These lower limits apply to visitors, custodial help, delivery persons, or administrative personnel.

UCSF's commitment to ALARA has resulted in the administrative imposition of even lower limits than those required by regulation. In essence, UCSF is committed to keeping the radiation doses to occupationally exposed workers at levels 25% or more below the State limits. For example, the limit for whole body exposure is 5 rems/year. This is roughly 400 millirems per month. UCSF is committed to keeping whole body exposures below 100 millirems per month. Based on years of monitoring the exposures of UCSF laboratory workers, radiation exposures rarely exceed the detectable limits of the film badge (approximately 10 millirem/month). In fact over 90% of personnel receive less than 100 millirem in one year.

TABLE 3.1

Summary of Recommendations^a (After Report No. 91, NCRP, 1987a)

A. Occupational exposures (annual) ^b			
1. Effective dose equivalent limit (Stochastic effects)	50 mSv		(5 rem)
2. Dose equivalent limits for tissues and organs (Nonstochastic effects)			
a. Lens of eye	150 mSv		(15 rem)
b. All others (e.g., red bone marrow, breast, lung, gonads, skin and extremities)	500 mSv		(50 rem)
3. Guidance: Cumulative exposure	10 mSv x age		(1 rem x age in years)
B. Public exposures (annual)			
1. Effective dose equivalent limit, continuous or frequent exposure ^b	1 mSv		(0.1 rem)
2. Effective dose equivalent limit infrequent exposure ^b	5 mSv		(0.5 rem)

^a Excluding medical exposures.

^b Sum of external and internal exposures.

C. HOW DOES THE MAXIMUM PERMISSIBLE DOSE COMPARE WITH OTHER SOURCES OF RADIATION EXPOSURE?

We are continuously irradiated by external ionizing radiation from cosmic and terrestrial sources, and from naturally occurring radioisotopes within our body (i.e. potassium-40 and carbon-14). For example, a person 70 years old will have received, on average, a 9 rem whole body dose from these sources alone. The internal radiation exposure accounts for approximately 20 millirem per year. The cosmic exposure varies by elevation but ranges from about 30 to 120 millirem per year. The terrestrial exposure also varies with mineral deposits and other geological considerations but generally varies from 20 to 120 millirem per year. The external background radiation in San Francisco is approximately 80 millirem/year, or about one-fiftieth of the allowable limit for radiation workers - 80% of the limit for the general public. On the open ocean, the annual dose is approximately 55 mrem/yr and in Denver about 150 mrem/yr (almost twice the level in San Francisco). The average individual in the United States accumulates a dose of 1 rem from natural sources every 12 years. The dose from natural radiation is higher in some states, such as Colorado, Wyoming and South Dakota, primarily because of increased cosmic and terrestrial irradiation. The average individual may receive 1 rem every 8 years or less. However, there are other areas in the world where natural background radiation levels are very much higher. For example, a dose of 1 rem may be received in some areas on the beach at Guarapari, Brazil, in only about 9 days, and some people in Kerala, India get a dose of 1 rem every 5 months.

In addition to natural background radiation, many people receive additional radiation exposure for medical reasons. Medical exposures are intentional and clearly have defined benefits for the individual. For purposes of comparison, the average surface skin dose from one radiographic (P/A view) chest x-ray is 0.027 rem. The estimated average surface skin dose per abdominal x-ray is 0.62 rem. Table 3.2 and Figure 3.1 list annual dose contributions from some of these sources.

TABLE 3.2
Annual GSD in the U. S. population circa 1980-82

Source	Contributions to GSD (mSv) ^a
Natural Sources	
Radon	0.1
Other	0.9
Occupational	~0.006
Nuclear fuel cycle	<0.0005
Consumer products	
Tobacco	_____
Other	~0.05
Miscellaneous environmental sources	<0.001
Medical	
Diagnostic x rays	0.2-0.3
Nuclear medicine	0.02
Rounded total	~1.3

^a 1 mSv = 100mrem.

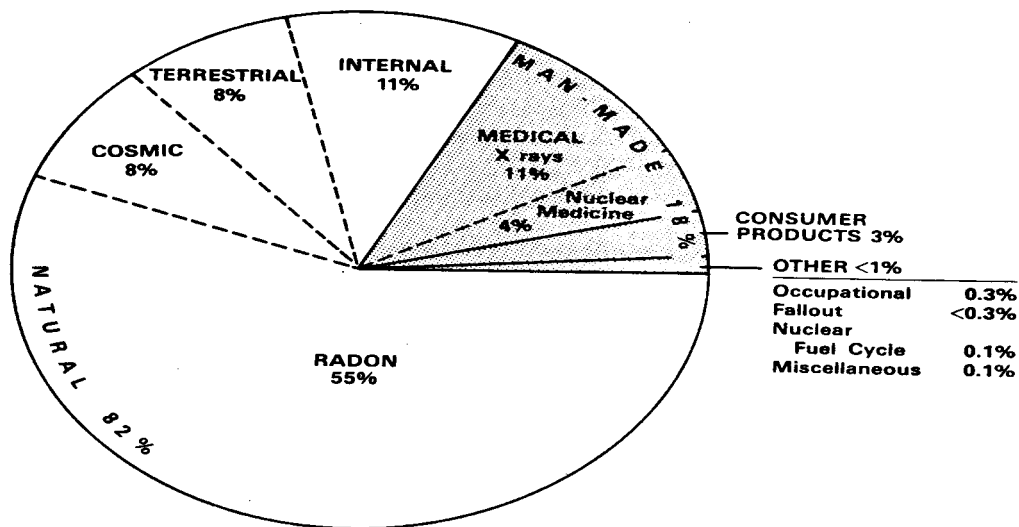


Figure 3.1 The percentage contribution of various radiation sources to the total average effective dose equivalent in the U. S. population.

Radiation can also be received from natural sources such as rock or brick structures, from consumer products (such as smoke detectors containing radioactive materials), and from air travel. The possible annual dose from working 8 hours a day near a granite wall at the red cap stand in Grand Central Station, New York City, is 0.2 rem, and the average annual dose in the United States from consumer products and air travel is 0.0026 rem.

D. WHAT IS THE RISK AT THE MAXIMUM PERMISSIBLE DOSE?

Death due to radiation exposure requires high exposures. In measuring radiation effect, the concept of the lethal dose 50 (LD_{50}) has been borrowed from pharmacology. The LD_{50} is defined as the dose of any agent or material that causes a mortality of 50% in the experimental group. The LD_{100} produces a mortality of 100%. For acute whole body human radiation exposure, the $LD_{50/60}$ is in the range of 300 to 350 rads. This means 50% mortality within 60 days.

There are variations in the population due to age, sex, degree of health, and sensitivity to radiation exposure. Briefly stated, the young and the old appear to be more radiosensitive than the middle-aged individual. The female appears to have a greater degree of tolerance to radiation than does the male.

The effects from chronic or protracted exposure are less than from acute exposure. Exposure to the sun offers some parallels to radiation exposure. Whole body exposure to the direct sun for several hours can result in a severe sun burn. However, as more of the body is protected (using sun screens, clothing, shade, etc.) the length of exposure can be increased without the effect of sunburn. For example, one can stay out for a few minutes each day (eventually accumulating a total exposure of several hours) and have a very different effect than by receiving an acute dose within several hours. Radiation exposure may also work this way, although experts do not fully agree.

The chief risk to radionuclide users comes from intermittent exposures to very low doses not from an acute exposure to a very high dose. The risks to low doses of radiation are not fully known and so the best principle to follow is ALARA - the minimum exposure that can be reasonably achieved.

One risk is cancer. The figures for cancer mortality are given in Table 3.3. If the average figure of 300 excess cancers per million people per rad is used, and a scenario of 20 years of exposure at the State limit is assumed, the result would be a total of 6,000 extra cancers per million workers, or a 0.8% increase in extra cases over a thirty year period. If the American Cancer Society's figures that 25% of Americans will contract cancer are used, the maximally exposed worker would increase his/her chances of getting cancer from 25% to 25.8%. Of course, there are only a few thousand UCSF radiation workers, and the average UCSF worker receives an occupational dose of less than 100 mrem/year as opposed to the 5,000 mrem/yr used in this example. The cancer risk from a radiation dose received at this rate may well be zero.

TABLE 3.3

Excess Mortality Estimates - Lifetime Risks per 100,000 Exposed Persons
(extracted from Table 4-2 of *BEIR V*)

	Males	Females
Normal Expectation of Cancer Mortality	20,910	17,710
Continuous Exposure to 1 rem/year from age 18 to 65	2,880	3,070

However, these statistical arguments are not very comforting if we, or one of our friends or relatives, develop cancer. The way to avoid even this small risk of a radiation induced-cancer is to stay well below the maximum allowable level by following established policies and procedures.

In 1980, approximately 1.3 million workers were employed in occupations in which they were potentially exposed to radiation. About half of these workers received no measurable occupational dose. In that year, the average worker exposed to a measurable amount of external radiation received an occupational dose equivalent of 0.2 rem to the whole body, based on the readings of individual dosimeters worn on the surface of the body. We estimate (assuming a linear non-threshold model) the increased risk of premature death due to radiation-induced cancer for such a dose is ~2-5 in 100,000 and that the increased risk of serious hereditary effects is about one-third smaller. To put these estimated risks in perspective with other occupational hazards, they are comparable to the observed risk of job-related accidental death in the safest industries, wholesale and retail trades, for which the annual accidental death rate averaged about 5 per 100,000 from 1980 to 1984. The U.S. average for all industries was 11 per 100,000 in 1984 and 1985.

E. SPECIAL SAFEGUARDS FOR PREGNANT WOMEN

A number of studies have indicated that the embryo/fetus is more sensitive to radiation exposure than the adult, particularly during the first three months after conception. This

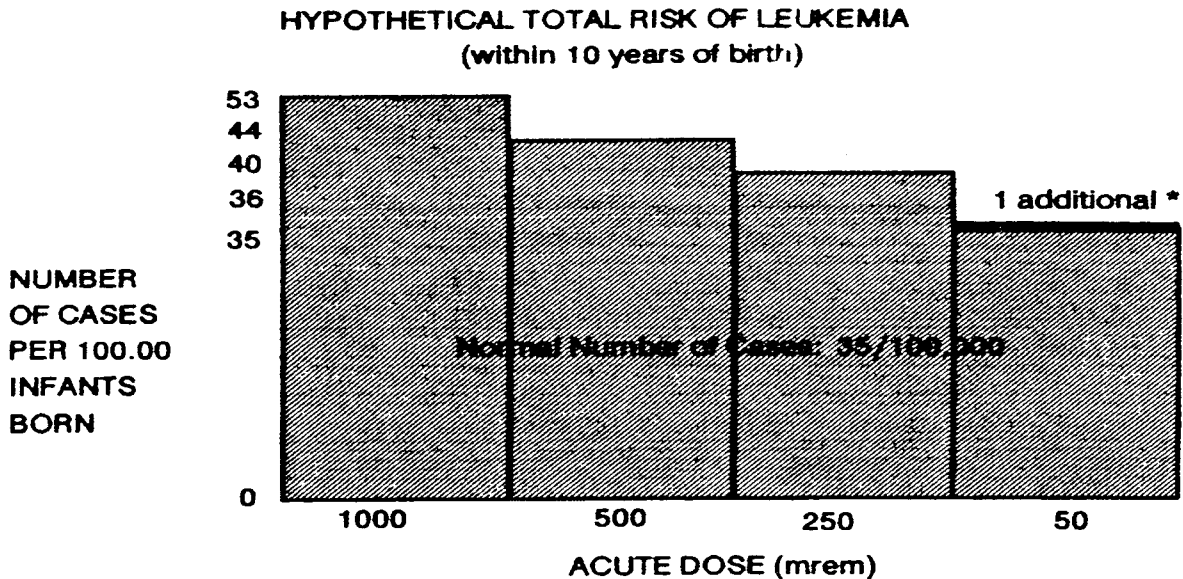
is also a period when a woman may not be aware she is pregnant. Women who are pregnant or who are considering pregnancy should be aware of the special needs of their situation. Supervisors and co-workers of fertile women should be aware of the risks to the fetus to avoid creating a situation that might put the embryo/fetus at risk. The National Council on Radiation Protection and Measurements has made two recommendations: a) the maximum dose to the fetus from occupational exposure should not exceed 0.5 rem, and, b) radionuclide workers must know about prenatal exposure risks arising from ionizing radiation. In particular they must know why pregnant women have a lower maximum permissible dose.

The Appendix of the UCSF Radiation Safety Manual contains a reprint of the U.S. Nuclear Regulatory Commission (NRC), Regulatory Guide 8.13, Instruction Concerning Prenatal Radiation Exposure. In addition, this section contains the UCSF pregnant personnel policy. Each authorized user should read and become familiar with this material.

The prediction that an unborn child would be more sensitive to radiation than an adult is supported by observations for relatively large doses. The National Academy of Sciences noted that doses of 25-50 rems to a pregnant human may cause growth disturbances in offspring. Such doses substantially exceed, of course, the maximum permissible occupational exposure limits.

Concern about prenatal exposure (i.e., exposure of a child while in its mother's uterus) at the permissible occupational levels is primarily based on the possibility that cancer (especially leukemia) may develop during the first 10 years of the child's life. According to a report by the National Academy of Sciences, the incidence of leukemia among children from birth to 10 years of age in the United States could rise from 3.7 to 5.6 cases per 10,000 children exposed to 1 rem in utero, an increase of 50%. See Figure 3.2

FIGURE 3.2



* One additional case in 10 years per 100,00 infants born.

The Academy also estimated that an equal number of other types of cancers could result from this level of radiation. Although other scientific studies have shown a much smaller effect from radiation, women employees should be aware of any possible risk so that they can take steps they think appropriate to protect their offspring. Efforts should be made to keep the radiation exposure of an embryo/fetus the lowest practicable level during the entire period of pregnancy.

The employer should take practicable steps to minimize the radiation exposure of a potential mother. The advice of the Radiation Safety Office can be obtained to determine if radiation levels in working areas are high enough that a baby could receive 0.5 rem or more before birth.

The following facts should be noted in making a decision about continuing to work with ionizing radiation:

1. If you are planning on becoming pregnant or think you may be pregnant, discuss the matter with your supervisor or Principal Investigator so that appropriate appraisal of the potential radiation exposure may be made.
2. In most cases of occupational exposure, the actual dose received by the unborn baby is less than the dose received by the mother because some of the dose is absorbed by the mother's body.
3. At the present occupational exposure limit, the actual risk to the unborn baby is quite small, even though experts disagree about the exact level of risk.

4. There is no need to be concerned about a loss of your ability to bear children. The radiation dose required to produce such effects is many times larger than the State dose limits for adults.
5. Even if you work in an area where you receive only 0.5 rem per three-month period, in nine months you could receive 1.5 rem and the unborn baby could receive more than 0.5 rem, the full-term limit suggested by the NCRP. Therefore, if you decide to restrict your unborn baby's exposure as recommended by the NCRP, be aware that the 0.5 rem limit to the unborn baby applies to the full nine-month pregnancy.

To put the risk due to radiation in perspective, a table of the effects of various risk factors on the outcome of pregnancy is included (Table 3.4).

TABLE 3.4**Effect and Frequency of Certain Maternal Factors on Pregnancy Outcome**

Maternal Factor	Pregnancy Outcome	Rate of Occurrence
German Measles	Defects of heart, lens of the eye skeletal muscles, inner ear, teeth	2 in 3
Cigarette Smoking:	In general, babies weigh 5-9 oz less than average babies:	
Less than 1 pack/day	Infant death	1 in 5
Pack or more per day	Infant death	1 in 3
Alcohol Consumption:		
2 drinks/day	Babies weigh 2-6 oz less than average	1 in 15 to 20
2-4 drinks/day	Signs of fetal alcohol syndrome	1 in 10
4 or more drinks/day	(growth deficiency, brain dysfunction	1 in 5
Chronically alcoholic	characteristic facial signs)	1 in 3 to 1 in 2
Maternal Age		
20 years	Down's syndrome (mental and physical growth retardation)	1 in 2300
35-39 years		1 in 64
40-44 years		1 in 39
Aspirin (salicylates)	Clubfoot	1 in 13
High Altitude:		
Mean Altitude		
263 ft	Low birth weight (higher risk);	1 in 15
5000 ft	babies weigh less than 5.5 lb	1 in 10
10,500 ft		1 in 4
Radiation		
Childhood cancer:		
1 rem	Childhood leukemia deaths before the age of 12 yr	1 in 3333
1 rem	Deaths from other childhood cancers before the age of 10	1 in 3571
Bomb exposure at 4-13 weeks gestation:		
From 15 to greater than 100 rads (Hiroshima)	Small head size with severe mental retardation at exposures greater than 25 rads	1 in 4

CHAPTER 4

BIOLOGICAL EFFECTS OF RADIATION

The fact that ionizing radiation produces biological damage has been known for many years. The first case of human injury was reported in the literature just a few months following Roentgen's original paper in 1895 announcing the discovery of x-rays. The first case of radiation induced cancer was reported seven years later. Early human evidence of the harmful effects of ionizing radiation, as a result of high exposures, became available in the 1920s and 30s through the experience of radiologists, miners exposed to airborne activity, and workers in the radium industry. However, the long term biological significance of smaller, repeated doses of radiation was not widely appreciated until later. Most of our knowledge of these effects has accumulated since World War II.

A. SOMATIC AND GENETIC EFFECTS

Biological effects can be conveniently subdivided into two groups:

1. Genetic effects which occur in the reproductive cells and may be inherited.
2. Somatic effects which arise from damage to all cells in the body and are observable in the individual affected.

Genetic effects are essentially long term in nature since they are manifested in offspring. In discussing somatic effects, it is convenient to further subdivide them into early (or acute) effects and late (or chronic) effects. The terms acute and chronic are also used to describe the period during which the radiation exposure is carried out. An acute exposure takes place within seconds, minutes or hours and the early (or acute) effects may be seen within minutes, hours or up to a few weeks later. A chronic exposure may extend over weeks, months or years, it may not be continuous and the late (chronic) effects may be produced during or after the irradiation.

Somatic effects may also be categorized as non-stochastic or stochastic. In some irradiations, the biological response increases in severity as the dose increases. Skin, for example, may only show a slight reddening (erythema) at low doses, but will exhibit severe gross tissue damage at high doses. Such a response is termed non-stochastic and usually exhibits a threshold dose below which the response is not observed. Other irradiations produce a response such as leukemia where the severity is independent of dose, the disease is either contracted or it is not. The probability of inducing the response does depend upon the dose. Such a response is termed stochastic.

Studies in both early and late effects of ionizing radiation are of great importance in the establishment of guidelines for minimizing the risk inherent in the use of ionizing radiation. The first radiation protection standards were devised to protect workers from acute radiation effects. The present standards recommended by the International Commission on Radiological Protection (ICRP) are largely based on the incidence of late stochastic effects, such as cancer, for radiation workers and on genetic effects for the general public.

B. INCREASE IN CANCER INCIDENCE

While the relationship between acute effects and radiation levels is well known, the situation for late effects, both *somatic* and *genetic*, is more obscure. The difficulty arises in part because the effects are so small. Since so many of the population (16-25%) die of cancer, small effects due to low levels of chronic radiation exposure are impossible to measure. As a consequence, data must be extrapolated from cancer incidence rates in individuals who received extremely high exposures, such as the victims of nuclear weapons, accidents, or experimental medical procedures. An additional problem in making an accurate assessment is the factor of age at the time of exposure. The time of onset can be delayed for 30 years or more after the exposure (latent period). To estimate the possible risks to us as users of radiation, information is needed about the properties of radionuclides, the measurement of radiation exposure, and the other topics presented in this Manual.

C. GENETIC DAMAGE

Genetic effects occur when there is radiation damage to the germ cells carried by the parents, due to radiation exposure of either parent. These effects may show up as birth or other defects in the children of the exposed parents or in succeeding generations. From animal studies it is estimated that the risk of producing serious genetic effects is about *one-third* the risk of producing cancer. However, it is difficult to apply animal data to humans. Damage to germ cells should not be confused with damage to the cells of an embryo/fetus from in utero irradiation.

D. EXPOSURE OF UNBORN CHILDREN

While the risks of cancer or genetic damage are barely significant for a prudent worker, the unborn child is at a higher risk. The more rapidly dividing cells of the embryo/fetus are more sensitive to the effects of radiation than slowly dividing cells such as brain or bone cells. Cells in the unborn child are dividing very rapidly. Furthermore, the child has its whole life ahead during which delayed effects might occur.

Women who work with radioactivity and are considering pregnancy should carefully read the material presented in Chapter 3, Section E of this manual. Supervisors and co-workers of fertile women should also be familiar with this material to be sure that situations that might put the embryo/fetus at risk are avoided.

CHAPTER 5

SAFETY HAZARDS ASSOCIATED WITH COMMONLY USED RADIONUCLIDES

Working with radioactive materials involves some potential risks. Therefore, precautionary measures must be taken to ensure the safety of personnel working with such materials as well as the public. The following summarizes the procedures and methods used in protection against internal or external radiation hazards.

The hazard from radionuclides can be divided into internal and external exposures. The severity of the hazard depends on a number of factors including the energy of the radionuclide, the type of radiation emission (e.g. beta or gamma radiation), the activity, and the chemical form.

A. INTERNAL RADIONUCLIDE HAZARDS

The possibility of a radioisotope inadvertently entering the body exists. Once this occurs, the protection techniques are somewhat limited; so emphasis has to be placed on preventing radionuclides from entering the body. The possible pathways into the body are inhalation, ingestion, absorption, and puncture.

1. INHALATION

Airborne radioactive materials can enter the body through inhalation. In biomedical applications, this is not a major problem since most isotopes are used as bound chemicals. However, the use of HTO (tritiated water), ^{35}S in some labeling reactions, and Na^{125}I can create potential problems. Adequate protection can be obtained by performing operations involving potential airborne radioactivity in approved fume hoods. These hoods are designed to maintain a negative air flow and have a face velocity of at least 100 linear feet per minute. The air from these hoods is vented to the outside. The evaluation by the Radiation Safety Office of the procedure ensures that the air flow is sufficient to keep environmental concentrations well within acceptable limits. Some sterile hoods are not suitable for use with volatile radioisotopes because they operate under a positive pressure.

2. INGESTION

Ingestion is possible when unsealed sources of radioactive materials are used. Ingestion can arise from direct consumption of a radionuclide (!), by placing contaminated fingers in or close to the mouth, or from the consumption of contaminated food. Food can be contaminated by coming in contact with the radionuclides or with other contaminated items such as plates, utensils, or even hands. This potential can be eliminated by following the guidelines listed below.

- a. Do not store food or beverages where radioactive materials or contaminated items are stored or used.
- b. Do not eat, drink, smoke, or apply cosmetics in areas where radioactive materials are used.

- c. Wear disposable gloves when handling radioisotopes or contaminated articles.
- d. Label all containers used for radioisotopes or contaminated items.
- e. Segregate and clearly label radioactive or non-radioactive waste.

Table 5.1 gives the Annual Limit of Intake (ALI) of radionuclides that an individual may ingest without exceeding a body dose of 5000 mrem/yr, a bone surface dose of 50 rem/yr, and a thyroid dose of 15 rem/yr. As a simple rule of thumb; the more energetic the particle, the less that can be ingested. Finally, iodide uptake is clearly the major hazard which is why bioassays are required of users of ^{131}I and ^{125}I .

3. ABSORPTION

Disposable gloves should be worn because some radionuclides can be absorbed through the skin.

4. PUNCTURE

Radionuclides can also enter the body via punctures in the skin so it is important that sharp objects which could be contaminated with radionuclides be handled with utmost care. Any wounds received while working with radioisotopes should be checked for possible contamination immediately.

B. EXTERNAL EXPOSURE TO RADIONUCLIDES

1. RADIONUCLIDES ON THE SKIN

A matter of interest to users of radioactive materials is having contamination on the skin. Approximately 50% of the ionizing radiations will be captured by the body. Low energy beta-emitters, such as ^3H , have such a short path length that they do not penetrate dead skin. Thus, unless the skin is cut or abraded there is no direct risk from skin irradiation by ^3H . Slightly higher energy emitters such as ^{14}C , ^{35}S , and ^{45}Ca pose a slight risk since only 10-40% can cross the dead layer of skin.

In Table 5.2 the properties of the common beta-emitters are listed. The estimated dose in mrad/hr is calculated for a situation in which one uCi of radionuclide is deposited on one square cm of skin. Note that these calculations only give the radiation dose to which the basal cells are subjected. High energy emitters can damage internal organs. How long would it take to reach the yearly limit if the radionuclide remained on the skin?

The yearly limits allowed by the State are:

	<u>Rems/year</u>
Whole body	5
Hands, forearms, feet, ankles	50

TABLE 5.1

Annual Limits of Intakes (ALI) 10CFR20 App B

Radionuclide	Form	Target Organ	ALI uCi Ingestion
³ H	Water	Total Body	80,000
	5- ³ H-CdR	Hematopoietic, Stem Cell Nuclei & Spermatogonia	
¹⁴ C	All other DNA & RNA & RNA Precursors	Hematopoietic, Stem Cell Nuclei & Spermatogonia	2000
	Soluble	Total Body	
	Inorganic		
	DNA Precursors RNA Precursors		
²² Na	Soluble	Total Body	400
³² P	Soluble incl	Total Body	600
	DNA Precursors		
³⁵ S	Soluble	Total Body	10,000
³⁶ Cl	Soluble	Total Body	2000
⁴⁵ Ca	Soluble	Bone surfaces	30,000
⁵¹ Cr	Soluble	Total Body	40,000
⁸⁶ Rb	Soluble	Total Body	500
⁹⁹ Tc	Soluble	Total Body	4000
¹¹¹ In	Soluble	Total Body	4000
¹²⁵ I	Soluble	Thyroid	40

If the radionuclide were on the extremities, the limit could be reached in about 24 hours; if on skin of the remainder of the body, 6 hours. If the contamination is detected, as it should be, the radionuclide should be removed as soon as possible. The danger comes from inadvertent contamination. High energy radionuclides should be readily detected by lab monitors. Wearing disposable gloves coupled with careful surveillance procedures after experiments will avoid skin contamination.

2. EXTERNAL SOURCE OF BETA-EMITTERS

The risk to external exposure from low energy beta-emitters is small when they are handled away from the body. Beta-particles have a finite range in air. Thus, when at least two feet separates the user from ^{14}C , ^{35}S , and ^{45}Ca , there is no exposure. If these radionuclides are contained in a vial, very little radiation will escape through the walls.

Higher energy beta-particles such as ^{32}P are a different case. They have a range of 20 feet in air. The dose rate from a 1 mCi source of ^{32}P at 1 cm is 200 rad/hr. As illustrated in Table 5.2, ^{32}P will penetrate about 1 cm through biological tissue. The major risk from external exposure is to the eye, a radiosensitive organ for which the maximum permissible dosage is 15 rem/yr. If the 1 mCi source were held 1 cm from the eye, the maximum dose would be reached in 4.5 min. Use of a lucite shield (1 cm thick) will practically eliminate the exposure hazard.

3. EXTERNAL SOURCE OF GAMMA-EMITTERS

The exposure rate for gamma emitters can be calculated for each radionuclide using the Specific Gamma Ray Constant which has units of R/hr per mCi at 1 cm. Data for three of the most commonly used gamma-emitters are given in Table 5.3, and for a much wider range of emitters in Table 5.4.

Consider two examples:

- a. ^{125}I has a Gamma Constant of 0.7 (Table 5.3) which means a 1 mCi source would produce 0.7 R/hr at 1 cm, a 2 mCi source, 1.4 R/hr at 1 cm, and a 1 mCi source would produce 0.007 R/hr at 10 cm.
- b. A 1 mCi ^{60}Co source will produce an exposure of 13.2 R/hr at 1 cm and 0.132 R/hr at 10 cm, in the absence of shielding.

The best safety rule to apply when using gamma-emitters is to maximize distance, minimize the time of exposure, and use shielding, as possible. Fortunately, the hands are the body part that most often come near to an unprotected gamma-emitter source, and the hands are relatively radiation-resistant.

TABLE 5.2

	Properties of Some Commonly Used Beta-Emitters					
	³ H	¹⁴ C	³⁵ S	⁴⁵ Ca	³² P	⁹⁰ Sr
Half Life	12.3y	5730y	88d	165d	14.3d	28.1y
Maximum beta E (Mev)	0.018	0.154	0.167	0.254	1.71	2.24
Average beta E (Mev)	0.006	0.050	0.049	0.077	0.70	0.93
Range In Air (ft)	0.02	1	1	2	20	29
Range in Unit Density Material (cm)	0.00052	0.029	0.032	0.06	0.8	1.1
Half value layer (cm) unit density material	—	0.0022	0.0025	0.0048	0.10	0.14
Dose Rate/100 beta/cm ² -sec (mrad/hr)	—	64	60	43	12	11
Fraction transmitted through dead layer of skin (0.007cm)	—	0.11	0.16	0.37	0.95	0.97
Dose rate to basal cells of epidermis from 1 uCi/cm ² mrad/hr	—	2600	3600	5900	4300	3900

TABLE 5.3

	<u>Properties of Some Beta-Gamma Emitters</u>		
	¹²⁵ I	¹³¹ I	⁶⁰ Co
Half Life	60d	8.1d	5.25y
Maximum Beta Energy (Mev)		0.61	0.31
Average Beta Energy (Mev)	0.022	0.188	0.093
Gamma Energies (Mev)	0.035(7%) 0.027-0.032(136%)	0.364(80%) 0.638(8%)	1.17(100%) 1.33(100%)
Gamma Half Value Layer			
Lead (cm)	0.0037	0.3	1.1
H ₂ O (cm)	2.3	5.8	11.0
Dose Rate/100 photons/cm ² -sec (mrad/hr)	0.020	0.065	0.45
Specific Gamma Ray Constant (R/hr per mCi at 1 cm)	0.7	2.2	13.2

4. RADIATION EXPOSURE FROM STORED RADIONUCLIDES

University of California, San Francisco (UCSF) policy limits the exposure rate to 2 mrem/hour at 1 foot from stored radioactive materials or radioactive waste. Adherence to this limit ensures that no authorized user who regularly works close to stored isotopes or waste can exceed permissible dose limits. For example, 2000 working hr/yr divided into the limit of 5000 mrem/yr equals 2.5 mrem/hr whole body dose.

These examples have been chosen to illustrate that it is possible to imagine situations in which maximum permissible doses can be reached in UCSF labs. The next section details procedures that, if followed, will prevent such levels of exposure, even when accidents happen.

TABLE 5.4

NUCLIDE	Gamma** Factor	Physical Half-Life	Shielding Factors (cm Lead)	
			1/2-value	10th-value
Americium-241***	1.30	458 y	<.001	0.003
Barium-133	4.4	10.4 y	<.1	0.5
Cadmium-109	1.58	453 d	0.001	0.004
Carbon-11	5.9	20.3	0.55	1.6
Cesium-137	3.4	30.0 y	0.80	2.4
Chromium-51	0.18	27.7 d	0.2	0.7
Cobalt-57	0.94	270 d	0.01	0.05
Cobalt-60	13.2	5.26 y	1.5	4.5
Gallium-67	0.80	78.1 h	<.1	0.5
Gold-198	2.3	2.69 d	0.33	1.1
Indium-111	3.19	2.81 d	--	0.2
Indium-113m	1.68	99.4 m	0.2	0.9
Iodine-123	1.77	13 hr	0.04	0.2
Iodine-125	0.7	60.2 d	0.002	0.006
Iodine-131	2.2	8.06 d	0.3	1.1
Iron-59	6.2	45 d	1.5	4.5
Krypton-81m	1.46	13 s	--	0.1
Mercury-203	1.48	46.5 d	0.10	0.4
Molybdenum-99	1.69	66.7 h	0.65	2.55
Potassium-42	1.36	12.4 h	1.7	5.2
Potassium-43	5.3	22.4 h	0.5	1.8
Radium-226***	8.25	1600 y	1.4	4.6
Rubidium-86	0.5	18.6 d	1.4	4.1
Scandium-47	0.53	3.40 d	0.05	0.17
Selenium-75	2.0	120 d	0.1	0.5
Sodium-22	12.0	2.60 y	0.9	3.6
Sodium-24	18.3	15.0 h	1.8	5.7
Strontium-85	5.94	65.1 d	0.1	1.1
Tantalum-182	6.8	115.0 d	1.2	4.0
Technetium-99m	0.7	6.03 h	0.02	0.08
Thallium-201	0.31	74 h	0.025	0.09
Tin-113	0.96	115 d	0.001	0.004
Xenon-133	1.07	5.31 d	0.003	0.015
Zinc-65	3.1	243 d	1.4	4.1

*Many of these nuclides also emit beta particles or conversion electrons which may contribute additional dose.

**Gamma factor is in R-cm²/mCi-hr

***Also emits alpha particles.

CHAPTER 6

PRACTICAL STEPS TO RADIATION SAFETY

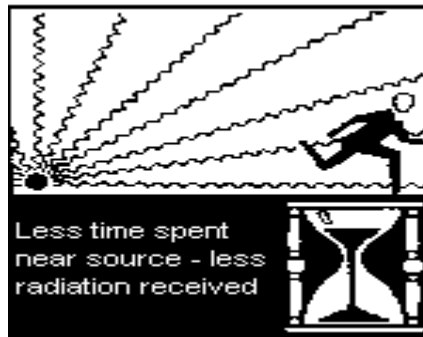
The hazards of ionizing radiation and how they can be estimated have been previously discussed. In this section the principles that form the foundation for good laboratory practice when using radioactive materials are reviewed. These principles are applied to specific situations in the work place (such as storage and use of radioisotopes, ventilation requirements, transportation and waste disposal). In addition, information is provided about the radionuclides that you are likely to use, their properties and methods of containment, and the standards of behavior that you will be expected to meet.

A. PRINCIPLES OF RADIATION SAFETY

The three basic principles used to protect against external radiation are to decrease the time of exposure (See Figure 6.1), increase the distance from the radiation source (See Figure 6.2), and increase shielding between the source and detector (See Figure 6.3).

1. TIME

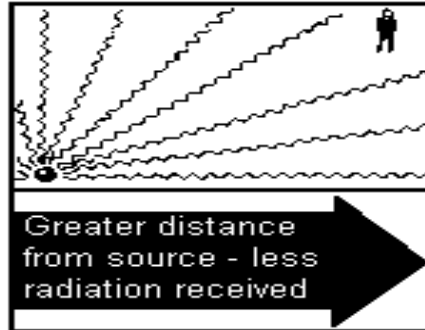
Figure 6.1 Variation of Exposure With Time



The energy imparted to tissues from external sources is proportional to the number of radioactive decay events, the energy of the emissions, and the length of exposure time. Laboratory personnel can minimize their radiation exposure by simply reducing the amount of time that they are involved in the direct use of radioactive materials. One way that this can be accomplished is by practicing a procedure using non-radioactive material. For example, if an iodination is planned with ^{125}I , the procedure for separating free from bound radionuclides should be practiced with non-radioactive material until it becomes routine.

2. DISTANCE

Figure 6.2 Variation of Exposure With Distance
(Inverse Square Law)



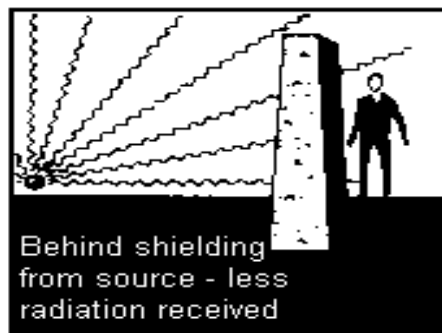
Since radiation exposure is reduced by the square of the distance from the source, very intense radioactive sources should be handled with tongs or placed into devices that will allow manipulation of the material while still providing as much distance from the source as possible.

For example, if a 10 mCi ^{59}Fe source were used, the exposure rate would be 62 Roentgen/hour at 1 cm. (See Table 5.4 to obtain the gamma factor for ^{59}Fe .) To reduce the exposure rate to a more acceptable level, the distance from the source would have to be increased, the source would have to be shielded, or a combination of the two would have to be used. If the principle of increasing distance is used, at what distance would the exposure rate be reduced to 2 mR/hr? The inverse square law states that the intensity will be reduced by the square of the distance from the source.

In this case, the intensity at 1 cm is 62,000 mR/hr. The desired intensity is 2 mR/hour. Thus, the required distance is computed as the square root of $62,000/2$ or approximately 176 cm.

3. SHIELDING

Figure 6.3 Shielding Affect on Radiation



For low energy beta-emitters, (e.g., ^3H , ^{14}C , ^{35}S , and ^{45}Ca), the walls of commonly used containers will

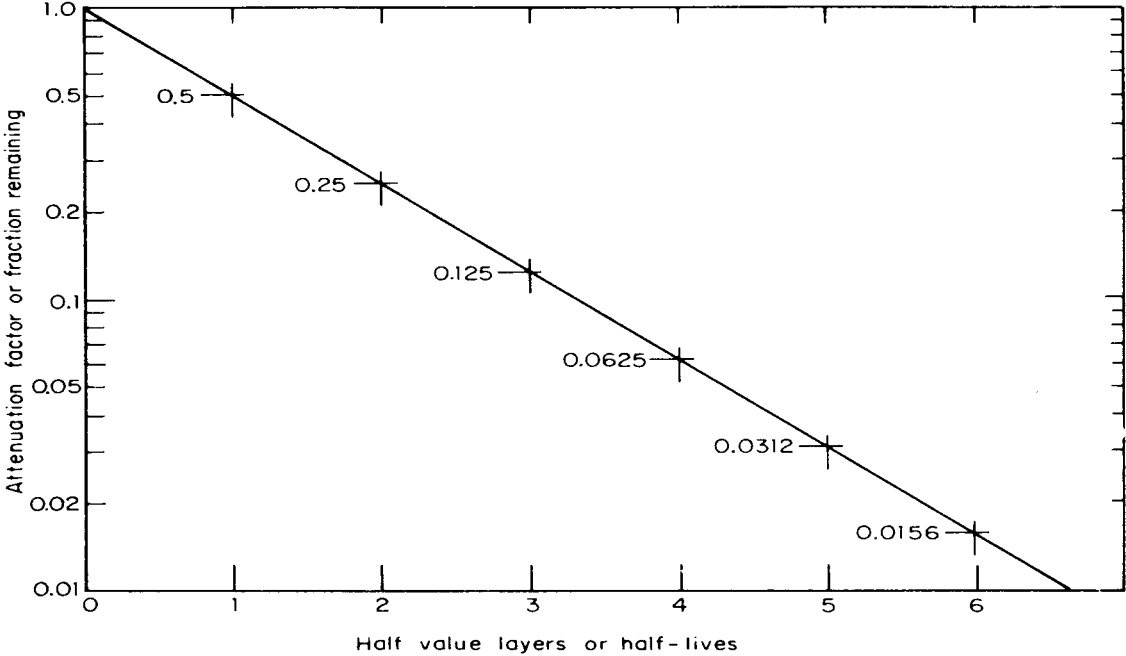
completely shield the beta-particles. But ^{32}P is so energetic that additional shielding is necessary for protection. Nominally 1 cm of Plexiglas or weight equivalent material is sufficient to stop all of the beta-particles. However, a problem occurs if the shielding for ^{32}P is made of a heavy material such as lead or steel. In this case bremsstrahlung will be produced.

Gamma-emitters are shielded with high atomic number materials such as lead. The half value layer (HVL), discussed previously, is the thickness of a material required to reduce the radiation intensity by 50%. Each additional half-value layer will reduce the beam intensity by another 50%. (See Table 6.1 and Figure 6.4)

TABLE 6.1

HVL	Beam Intensity
0	100%
1	50%
2	25%
3	12.5%
4	6.25%
5	3.125%

Figure 6.4 Half Value Layer vs Radiation Exposure



A summary of shielding needs and methods for different radioisotopes is given in Table 6.2. A useful rule of thumb is that a shielding thickness seven times the half-value layer reduces the intensity by two orders of magnitude, and ten times by three.

B. THE LABORATORY RADIATION SAFETY PROGRAM

Each Principal Investigator (PI) is responsible for ensuring that radioactive materials are used in their laboratory in conformance with University of California, San Francisco (UCSF) policies and procedures and applicable regulations. The Laboratory Supervisor is generally responsible for implementing the laboratory's Radiation Safety Program.

The purpose of the program is to ensure that the laboratory is kept free of radioactive contamination, that radiation exposures to laboratory workers and others who may visit the laboratory are kept to an absolute minimum, and that required records (such as radioisotope usage, storage, disposal, and monitoring) are properly maintained.

The Radiation Safety Office audits the laboratory's Radiation Safety Program on a periodic basis (generally every three months). Deficiencies are reported in writing to the PI. Repeated and/or serious problems may be referred to the Radiation Safety Committee (RSC).

**TABLE 6.2
BASIC SHIELDING NEEDS AND METHODS**

BETA EMITTERS - OPTIMUM VISIBILITY AND SHIELDING NEEDS ARE MET WITH THE USE OF LUCITE "L" BLOCKS (REMEMBER ALL SHIELDS SHOULD BE MARKED WITH THE RADIATION SYMBOL TO PREVENT ACCIDENTAL EXPOSURE). CAUTION: DO NOT USE DENSE MATERIALS SUCH AS LEAD TO SHIELD BETA EMITTERS. USE OF SUCH MATERIALS MAY CAUSE BREMSSTRAHLUNG (X-RAY) EXPOSURE.

ISOTOPE	MINIMUM CM THICKNESS OF LUCITE TO STOP ALL PARTICLES
³ H	None needed
¹⁴ C	None needed except for close work (< 2 feet use 0.1)
³⁵ S	None needed except for close work (< 2 feet use 0.1)
⁴⁵ Ca	0.1
³² P	0.8
⁹⁰ Sr	1.0

GAMMA EMITTERS - LEAD GLASS GIVES BEST VISIBILITY, BUT LEAD SHEET OR BRICKS PROVIDE BETTER ATTENUATION. LEAD "L" BLOCKS WITH LEAD GLASS IN THE 45% ANGLE TOP PLATE ARE A GOOD COMPROMISE WHEN VISIBILITY IS THE PRIME CONCERN. ANY LEAD GLASS OR OTHER SHIELDING (SUCH AS STEEL) USED SHOULD HAVE EQUIVALENCY TO THE LEAD VALUE SPECIFIED. GENERALLY SPEAKING, 10 TIMES THE HALF VALUE LAYER IS ADEQUATE FOR MOST ISOTOPES, AS THIS WILL REDUCE THE EXPOSURE BY THREE ORDERS OF MAGNITUDE.

ISOTOPE	HALF VALUE LAYER (Pb)	MATERIAL	DENSITY
	(cm)		(gm/cc)
²² Na	1.00		
²⁴ Na	1.60		
⁵¹ Cr	0.20		
⁵⁴ Mn	0.95		
⁵⁵ Fe	0.03	Water	1.00
⁵⁷ Co	0.02	Concrete	2.30
⁵⁹ Fe	1.03	Regular glass	2.80
⁶⁰ Co	1.20	Lead glass	4.2-6.0
⁶⁵ Zn	1.00	Iron	7.86
⁸² Br	1.00	Lead	11.35
⁸⁵ Sr	0.53		
^{99m} Tc	0.10		
¹¹¹ In	0.10		
¹¹³ Sn	0.07		
^{113m} In	1.78		
¹²³ I	0.05		
¹²⁵ I	0.01		
¹³¹ I	0.30		
¹³³ Xe	0.03		
¹³⁷ Cs	0.65		
¹⁵³ Gd	0.06		
¹⁸² Ta	1.30		
¹⁹² Ir	0.70		
¹⁹⁸ Au	0.30		
²⁰¹ Tl	0.03		
²²⁶ Ra	1.66		

UCSF is committed to following established radiation safety policies and procedures. Failure to follow these procedures can result in the suspension or revocation of your "authorized user" status.

A description of the responsibilities and roles of the RSC, PIs, and authorized users may be found in Chapter 3 of the UCSF Radiation Safety Manual. Copies of the forms mentioned in this manual may be obtained from your Laboratory Supervisor or from the Radiation Safety Office.

C. BECOMING AN AUTHORIZED USER OF RADIOACTIVE MATERIAL

You may be reading this Manual to prepare for the written examination given by the Radiation Safety Office. To use radioactive materials at UCSF, you must first obtain a training number which is issued after you pass a written examination on the contents of the Radiation Safety Manual and this Manual.

Next, you must submit to the Radiation Safety Office, for review by the Radiation Safety Staff, a completed Radioisotope Training and Experience Record (Supplement A Form, see Figure 6.5). The form requests information about your scholastic training regarding the use of radioactive materials, your experience in using radioisotopes, and verification that you are familiar with, and have available for reference, the Radiation Safety Manual.

The Supplement A Form is attached to a Radiation Use Authorization (RUA) Application or RUA Modification Request (See Figure 6.6) . The application form asks for specific information such as the radioisotopes that will be used, the amounts, the exact locations of use, the procedures to be followed, and the radiation detection instrumentation available. The application must be signed by the PI in whose laboratory you will be working. The RUA Modification form is for requesting changes or additions to the RUA. For example, the Supplement A Form would be used if you are simply requesting to be added as an authorized user to an existing RUA.

The Radiation Safety Staff reviews this information. If you are found lacking in training and experience to perform the procedures specified in the application, you may be required to receive appropriate training prior to using radioactive materials. If the application is approved and you pass the written examination, you will be named as an "authorized user" working under the designated PI.

You must also receive refresher training every two years in order to keep current with changes in UCSF radiation safety policies and procedures. The Radiation Safety Office will assist you in meeting this requirement.

Figure 6.5 Supplement A Form

SUPPLEMENT A FORM

A: LABORATORY INFORMATION

P.I.	RUA #	P.I./SUPERVISOR SIGNATURE	RSO
DELETION: _____		STUDENT _____	

B: PERSONNEL INFORMATION

Name: _____ Phone: _____
 Job Title _____ Campus Mailing Address: _____

C: TRAINING - Scholastic training in the use of radioactive materials

Institution	Subject	Date	Hours

D: EXPERIENCE IN THE USE OF RADIOISOTOPES

ISOTOPE	³ H	¹⁴ C	³² P	³⁵ S	¹²⁵ I		
ACTIVITY (mCi)							
YEARS OF USE							

E: DOSIMETRY

Is your laboratory currently issued Film Badges? **Yes** ___ **No** ___ Finger Rings? **Yes** ___ **No** ___
 If YES, and you intend to use radioisotopes other than ³H, ¹⁴C, ³⁵S complete and enclose a UCSF DOSIMETRY CARD.

F: USER

I have read, am familiar with and have available for reference, the "UCSF Radiation Safety Manual".
 Signature: _____ Date: _____

G: FOR EH&S USE ONLY

Training #: _____ Date: _____

FB: _____ FR: _____ BA: _____ Code: _____

Data: _____ File: _____

Conditions _____

Figure 6.6

RUA Modification Form

UCSF - RUA MODIFICATION REQUEST

LABORATORY INFORMATION

RUA #: _____ Principal Investigator: _____
 Laboratory Supervisor: _____

A: CHANGE IN OPERATION, FORM, AMOUNT OF POSSESSION, AMOUNT OF PURCHASE OR AMOUNT USED IN EXPERIMENT

1.) Isotope						
2.) Add/Delete						
3.) Purchase - mCi						
4.) Experiment - mCi						
5.) Possession - mCi						
6.) Form						
7.) Operations						

If radioisotope is volatile, identify fume hood that will be used: _____

Justification: _____

B: CHANGES IN LOCATION: (State Campus, Building, and Room)
 Include Diagram of Location

Campus	Building	Room	Add/Delete

FACILITIES AND SHIELDING: Please check the laboratory facilities and shielding available for use in areas being added.

Pb Bricks _____ Pb or Metal Sheets/Foil _____ Plexiglass/Lucite _____ Glove Box _____
 Open Bench Only _____ Chemical Fume Hood _____ Refrigerator/Freezer _____
 Cold Room (state isotopes used) _____ Shielded Waste Storage Area _____
 P.I. SIGNATURE: _____ DATE: _____

FOR EH&S USE ONLY

Received: _____ Approved: _____ Date: _____
 Comments: _____

PI retains Pink Copy EH&S-White and Yellow Copies

D. STORAGE OF RADIOACTIVE MATERIALS

1. Food or drink cannot be stored in areas where radioactive materials are stored or used.
2. Radioactive materials must be stored in areas under the control of the user at all times. If a storage area is located outside of the laboratory, or the laboratory is left unattended, it must be locked to prevent unauthorized removal of the material.
3. Radioactive materials should be stored in a container, shielded if necessary, to limit the radiation exposure to 2 mrem/hour at a distance of 1 ft from the container. Arrange heavy shielding so that it will not fall in the event of an earthquake. Containers should be unbreakable and placed in trays lined with absorbent materials to contain possible spills.
4. Containers must be labeled and areas properly posted, as required.

(See Posting and Labeling Requirements, Section I).

5. Explosion-proof refrigerators and freezers are preferred for storage. Store the radioisotopes or labeled compounds on lower shelves, if possible. In the event of a spill, this will decrease the areas of contamination.
6. Volatile radioactive materials should be stored in an approved fume hood.

E. HANDLING RADIOACTIVE MATERIALS

1. PURCHASING AND RECEIVING RADIOACTIVE MATERIALS

Radioactive materials may only be transferred to a UCSF PI who holds a valid RUA authorizing possession of such materials (See Figure 6.7). All packages shipped to UCSF are received by the Radiation Safety Office to check for damage (e.g. crushed or wet), external and internal contamination, and appropriate authorization for the amount and type of radioisotope.

Each vial is individually assigned a unique number that is also written on the "Radioisotope Usage Form." Prior to delivery to the lab, a check is made to verify that the lab's possession limit will not be exceeded. If it appears that the limit will be exceeded, the Laboratory Supervisor is notified. In most cases, aged inventories of radioactive materials simply need to be disposed.

Each laboratory must designate a radioactive package receiving area (not on the floor) and post it with a "PLEASE PLACE DELIVERIES HERE" sign. All radioactive packages will be delivered to this area which must be kept clear of other items and maintained in a neat manner.

Radioactive packages will only be delivered to authorized users, preferably the Laboratory Supervisor. If no authorized user is available, an "Attempt to Deliver" notice will be left in the laboratory.

- a. When receiving packages, wear disposable gloves, a lab coat, and appropriate personnel dosimetry (i.e. film badge and/or finger ring).
- b. Open the package, verify that the contents agree with the "UCSF Radioisotope Usage Form," and then sign the form.
- c. Carefully inspect each package for possible breakage of seals, lids, or containers, loss of liquid, or change in color of absorbing material. If contamination, leakage, or shortages are observed, notify the Radiation Safety Office and the vendor's Customer Service Department immediately.
- d. Promptly place radioactive materials in designated storage areas (all volatile radioactive materials should be immediately stored in an approved radioactive fume hood). Note that radioactive solutions inadvertently stored upside down may gradually leak and cause contamination.
- e. Check the radiation levels of unshielded containers. If necessary, place containers behind shielding to reduce exposure. (Pertinent for high energy beta and gamma emitters.)
- f. Deface radioactive labels before placing shipping boxes in the trash.

2. PREPARING THE WORK AREA

Check the following points before starting a procedure:

- a. Locate work areas away from heavy traffic or doorways. Clear an adequate area of the bench top of unnecessary items. When volatile radioactive materials are to be handled, the work area must be set up in an approved fume hood.
- b. Use plastic-backed, absorbent pads in trays or pans to cover work areas. Small, easily-spilled containers need a stable work surface to prevent spillage -- use trays or shallow pans, if necessary.
- c. Change bench coverings frequently to avoid producing contaminated dust problems from dried spills. It is recommended that small pads be used in the work area to minimize the volume of waste.
- d. Keep containers and contaminated materials well to the rear of the work area.
- e. Provide adequate shielding, radiation exposure rate should be less than 2 mR/hr at 30 cm from shields; survey periodically using an appropriate method. Make sure that a bench will support the required shielding and that the shield is secured so that it will not fall. Heavy lead brick shielding is not required for ^{125}I . Thin (1/16-1/8 in) sheeting or leaded plastic shields are adequate. Lucite is preferred for shielding high-energy beta sources (lead shields may cause bremsstrahlung (x-rays) exposure).
- f. Food, drinks, smoking materials, food or drink containers, eating utensils or cosmetics cannot be present in areas where radioactive materials are used or may be used. All food or beverage consumption must be in areas approved by the Radiation Safety Office. Refrigerators shall not be used jointly for foods and radioactive materials.

3. PRECAUTIONS DURING THE EXPERIMENT

- a. Wear appropriate protective clothing such as waterproof gloves and a lab coat when handling unsealed radionuclides. Change gloves frequently, especially after moving from working in a contaminated area to a clean one. Wear two pairs of gloves during iodination procedures. There appears to be some passage of vapors through the glove. Safety glasses or goggles can reduce eye exposure from high energy beta-particles as can leaded eyeglasses for low energy photons. These are not a substitute for use of shields.

- b. Film badges and/or finger rings must be worn, if assigned, to monitor exposure.
- c. Handle gamma and energetic beta-emitting sources and stock bottles using tongs or forceps. Crucible tongs, with rubber tubing on tips to increase gripping effectiveness, are usually satisfactory (and inexpensive).
- d. Use remote or hand-controlled pipettes. Mouth pipetting is expressly forbidden.
- e. Cover containers (vials, etc.) which hold volatile and air-reactive radioactive materials, such as radioiodide, borotritides, tritiated water, labeled methyl halides, etc. If possible use covered tubes when centrifuging radioactivity. Also cover tubes with foil, wrap or parafilm when vortex mixing is done. Be sure to wrap wastes containing radioiodine prior to disposal.
- f. Use appropriate containment, e.g., approved fume hoods or glove boxes (see Section F below).
- g. Maintain good personal hygiene. Keep fingernails short and clean. Do not work with radioactive materials if there is a break in the skin below the wrist or if open cuts may be contaminated. Wash hands thoroughly before handling any object which goes to the mouth, nose, or eyes.
- h. Have a small waste container (bag or can) in the work area for disposal of waste. After the procedure, the waste should be placed in a metal waste can that has a foot-operated lid, is lined with a plastic bag, and is marked with a "Caution - Radioactive Materials" label.
- i. Make sure that a functioning survey meter is available at the work area when working with millicurie levels of radionuclides, especially ^{125}I and ^{32}P . Always check the batteries and verify that the meter is within the calibration period.
- j. Survey glassware and apparatus used for experiments with radioactive materials and decontaminate prior to releasing the items to general dishwashing services or releasing them for general usage.
- k. Be informed; know the mechanical, chemical and radiation hazards of the materials and operations which are to be performed. Frequently it is useful to try a "cold-run" to see if an experiment is feasible.

F. USE OF VOLATILE RADIONUCLIDES

An Office of Environmental Health and Safety (EH&S)-approved fume hood (properly functioning) must be used for operations that create a possibility of airborne radioactivity, such as iodination procedures or procedures using dispersible solids or volatile liquids like tritiated water. Hazardous or high activity (more than 1 mCi) materials should be handled in a fume hood. Some procedures may require further containment such as a glove box or glove bag. The Radiation Safety Office will assist in determining the necessity for such devices. In general, all precautions mentioned previously apply to using radioactive materials in a fume hood.

1. An absorbent surface covering is important since the work area of many hoods is porous. A good practice is to paint the hood with a latex paint that can be readily stripped, if decontamination is necessary.
2. A malfunctioning hood must not to be used. EH&S measures the face velocity and verifies that a hood meets the standard (an average of 100 linear feet per minute with no individual measurement falling below 70 feet per minute).
3. Unnecessary items should be removed from the hood to prevent their contamination and to maintain the air flow efficiency of the hood. Cover stationary objects not to be used.

G. SPECIAL PRECAUTIONS FOR THE USE OF RADIOACTIVE IODINE

Handling radioiodine presents a hazard to personnel. I_2 , I^- , HI and HOI^- are highly reactive and are readily absorbed through the skin and through vinyl gloves. Significant thyroid burdens of radioiodine have been observed when inappropriate handling techniques have been employed. The following precautions should be observed to minimize personal exposures:

1. NaI should be kept at an alkaline pH (above 7.8 and below 11.0). Avoid acidic solutions which result in volatile iodine. Store NaI at room temperature. Studies have shown that freezing results in instability of the compound and volatilization.
2. Always work in a fume hood approved for iodinations and currently certified. If any malfunction is suspected, call EH&S at 476-1300.
3. Wear two pairs of gloves. Volatile iodine compounds can penetrate each layer of gloves within 10 minutes, so gloves should be changed at least every 10 minutes.
4. Place disposable pipettes, syringes, gloves, etc., in properly labeled plastic jars with large screw cap lids as quickly as possible to minimize release of volatile iodine; store the jars in a fume hood until waste pick-up. Liquid waste containers must also be sealed and stored in a fume hood. Use of activated carbon granules in the jar will reduce the emission of volatiles.
5. Significant extremity exposures can occur if vials or containers of radioiodine are handled directly. The levels of exposure as a function of distance are clear from the following example:

^{125}I 600 mR/mCi-hr @ 1 cm
0.24 mR/mCi-hr @ 50 cm

^{131}I 2.5 R/mCi-hr @ 1 cm
1.0 mR/mCi-hr @ 50 cm

6. Finger rings must be worn by all personnel working with 5 mCi or more of a radioiodine.

H. TRANSPORTATION OF RADIONUCLIDES

1. When transporting between stations within a laboratory, carry radioisotopes in a container that will contain inadvertent spills.
2. Always enclose radioisotopes in liquid-tight, unbreakable carrying cases or containers (with enough absorbent to easily absorb the liquid in case of a spill), before transporting through corridors or between buildings. Adequate shielding should be provided so that the radiation exposure at 1 foot is less than 2 mrem/hr.
3. When radioactive material is transferred from one department, laboratory, or project to another within the campus, inform the Radiation Safety Office. The Radiation Safety Office can verify that the receiving laboratory has a valid RUA authorizing the type and quantity of radioactive material to be transferred. They can also check the amount to be transferred against the amount on hand to verify that the receiving laboratory's possession limit will not be exceeded.

A Transfer of Radioactive Material Form must be completed (See Figure 6.8 and Figure 6.9.). One copy of the form is filed in the transferring laboratory's Radiation Safety Logbook, one copy in the receiving laboratory's logbook, and one copy is sent to the Radiation Safety Office.

If radioactive material is to be transferred to a non-UCSF location, notify the Radiation Safety Office. Regulations require that a copy of the recipient's Radioactive Material License be obtained to verify that they have authorization to receive the material to be transferred. Special packaging and transport requirements may also be required depending on the type, quantity, and amount of radioactive material.

Radioactive material that is received in proper Department of Transportation (DOT) packaging, checked as appropriate, and resealed in the same manner as the original package, may be transferred to other UCSF sites. A copy of the manifest must accompany the shipment. If packages are split, a new manifest must be provided and the transfer effected in a proper DOT package. A Transfer of Radioactive Material Form must be completed for each transfer and the Radiation Safety Office informed.

Figure 6.8 **Transfer of Radioactive Material Form**

UNIVERSITY OF CALIFORNIA	RADIATION SAFETY OFFICE
TRANSFER OF RADIOACTIVE MATERIAL	
Use this form for transfer of radioactive material from one P.I. to another within UCSF.	
DATE _____	

CAMPUS: Parnassus SFGH Laurel Heights Mission Center Building
 Other: _____

Radioisotope	Activity mCi	From		To	
		P.I.	RUA #	P.I.	RUA #

Transferred By: _____ Received By: _____
 (signature) (signature)
 White Copy: to EH&S, Box 0942 Pink Copy: to Receiving Lab Yellow Copy: to Lab File

Figure 6.9 Transfer of Radioactive Material Form

Radiation Safety Officer UNIVERSITY OF CALIFORNIA, SAN FRANCISCO Environmental Health and Safety San Francisco, California 94143	Environmental Health and Safety Tel. (415) 476-1300
TRANSFER OF RADIOACTIVE MATERIAL	
Date: _____ No. _____	
Radioisotope: _____ Quantity: _____ mCi Supplier: _____	
Chemical Form: _____ EXEMPT label WHITE I YELLOW II YELLOW III	
Calibration of Lot: _____ mCi/cc. at _____ time on _____ date	
Amount Transferred: _____ mCi at _____ time on _____ date	
Verified by: _____	
Inner Container: _____ no. of vials _____ no. of ampules _____ no. of other (state kind)	
Outer Package: _____ type _____ surface mR/hr _____ mR/hr at 3 ft	
Check one: Water Ice <input type="checkbox"/> Dry Ice <input type="checkbox"/> Refrigerate on arrival <input type="checkbox"/> None <input type="checkbox"/>	
Contaminated Animal: _____ species Live <input type="checkbox"/> Dead <input type="checkbox"/> carcass parts _____	
TRANSFERRED FROM: _____ Institution/Bldg./Room Radioactive _____ Material License No. _____ Expiration Date: _____ Principal Investigator: _____ AUTHORIZED RELEASE Date: _____ Time: _____ Signature: _____ Printed Name & Title: _____ Telephone No. () _____ - _____ Courier Signature: _____ (if applicable)	TRANSFERRED TO: _____ Institution/Bldg./Room Radioactive _____ Material License No. _____ Expiration Date: _____ Principal Investigator: _____ AUTHORIZED RECEIPT Date: _____ Time: _____ Signature: _____ Printed Name & Title: _____ Telephone No. () _____ - _____ Ultimate Recipient Signature: _____ (if applicable)
Completed WHITE COPY Suspense GREEN COPY CANARY COPY Completed PINK COPY Completed GOLDENROD COPY Send to RSO. Address at top of form. Held by RSO at point of origin. Pulled by Courier after Signature. Institution. Retained by Ultimate Recipient in Receiving Retained by Receiving RSO	

I. POSTING AND LABELING REQUIREMENTS

1. POSTING

- a. Areas in which radioisotopes are used or stored must be conspicuously posted with the CAUTION RADIOACTIVE MATERIAL sign. This includes, but is not limited to, rooms, storage cabinets, safes,

refrigerators, incubators, and fume hoods. (See Figure 6.10 for sample radiation safety labels.)

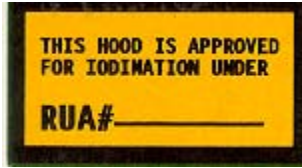
- b. Areas in which the exposure rate exceeds 5 mrem/hr must be posted with the CAUTION RADIATION AREA sign.
- c. Areas in which the exposure rate exceeds 100 mrem/hr must be posted with CAUTION HIGH RADIATION AREA sign.
- d. Areas within a lab that are never to be used for storage or use of radioactive materials should be *clearly* marked.

2. LABELING

- a. Any container in which radioactive material is transported, stored, or used must bear a CAUTION RADIOACTIVE MATERIAL label.
- b. Whenever a container is removed from the working area or when containers are used for storage, the label must ***state the type, quantity, and amount of radioactive material in the container, the date of the measurement of the quantities, and to whom it belongs.***
- c. Special items used with radioisotope procedures which could be contaminated should be labeled (e.g. pipettes, tweezers, ice buckets).
- d. Radioactive work areas should be neatly covered with vinyl-backed absorbent paper. Tape (marked with the radioactive symbol) should clearly delineate the work area.

Figure 6.10

Radiation Safety Labels



J. WORKING WITH RADIOACTIVE ANIMALS

The spillage precautions, shielding precautions, required clothing, and dosimetry are the same when working with radioactive animals as for any experiment using radionuclides. However, particular attention needs to be paid to the collection and disposal of radioactive excreta, and to the disposal of radioactive carcasses (See Chapter 9, Categories of Radioactive Waste).

The Special Precautions/Instructions for procedures involving animals housed in the Animal Care Facility (ACF) are specified on Supplement B Form of the laboratory's RUA application. This form specifies the responsibilities of ACF and the responsibilities of the PIs. A copy of the form can be found in Figure 6.11 below and the requirements for your laboratory are available for review in the laboratory's Radiation Safety Log Book.

Figure 6.11 Supplement B Form

UCSF Radioisotope Application Form	
SUPPLEMENT B	
<u>ANIMAL INVOLVEMENT IN THE ANIMAL CARE FACILITY</u>	
PI _____	Phone _____ Dept _____ Date _____
RUA # _____	Housing dates - start _____ finish _____
Species _____	# _____ Animals per cage _____
Isotope(s) _____	Dose (mCi) per animal _____
	Excretory Route (urine) (feces) (respiration)
Animal exposure rate - Contact _____	(mrem/hr) 1 Meter (mrem/hr)
<u>Special Precautions/Instructions</u>	
<u>ACF Responsibilities</u>	<u>Investigators Responsibilities</u>
1) Identify available housing and primary enclosures. (Room) _____	1) Radiation Safety Committee Approval.
2) Post protocol at animal room.	2) Ascertain whether sufficient housing needs, i.e. metabolic cages are available.
3) Clean cage during study. (yes)(no)	3) Protective clothing to be worn. (lab coats)(face mask)
4) Protective clothing to be worn. (uniforms)(labcoats)(face mask)(disposable outers)(head cover)(shoe cover)(boots)(rubber gloves)(disposable gloves)(glasses)	(disposable outers)(head cover)(shoe cover)(boots)(rubber gloves)(disposable gloves)(glasses)
5) Personnel radiation monitor.	4) Personnel radiation monitor.
a. body badge (yes)(no)	a. body badge (yes)(no)
b. finger badge (yes)(no)	b. finger tape (yes)(no)
6) Provide feed and water to animals. (yes)(no)	5) Provide feed and water to animals. (yes)(no)
7) Remove excreta.	6) Remove excreta.
a. urine (yes)(no)	a. urine (yes)(no)
b. feces (yes)(no)	b. feces (yes)(no)
c. bedding (yes)(no)	c. bedding (yes)(no)
8) Additional requirements. _____ _____ _____ _____ _____	7) Label cages and remove label after decontamination.
	8) Decontaminate cage and etc. (yes)(no)
	9) Area and cage monitoring. (yes)(no)
	10) Inform husbandry Area Supervisor when cage and accessories are decontaminated and can be returned to general use.
cc: ACF Area Supervisor (Bob Fish)(Pete Lindquist)	

CHAPTER 7

MEASUREMENTS OF RADIATION EXPOSURE

Several methods are used to determine radiation exposure. Individual exposure is estimated through personnel monitoring devices such as film badges or finger rings. Internal exposure to radioisotopes from ingestion, inhalation, absorption, or puncture is estimated from bioassay procedures that analyze samples of blood, urine, or tissue or monitor the organ of interest, such as the thyroid gland.

Radiation exposure rates from sources such as stored radioisotopes, radioactive waste, or work areas can be directly measured by using the appropriate survey meter. Finally, radioactivity contamination is measured by analyzing wipe samples in a liquid scintillation counter or well counter.

Each of these methods is considered below.

A. FILM BADGE AND FINGER RING DOSIMETERS

Chapter 3 discussed the occupational dose limits set by regulations and the more stringent limits set by the University of California, San Francisco (UCSF) in adhering to the As Low As is Reasonably Achievable (ALARA) precept. Records from analysis of personal dosimeters are used to verify compliance with these requirements.

Dosimeters are issued by the Radiation Safety Office to those individuals who are authorized to work with sources of ionizing radiation which dosimeters can measure. The most common radiation dosimeters used at UCSF are film badges and finger rings. Film badges have an error range of approximately 20% and finger rings approximately 5%. These dosimeters allow assessment of beta, gamma, and x-ray exposure. Dose assessment for exposure to ^3H , ^{14}C and ^{35}S is performed by urinalysis since the film badges and finger rings are not sufficiently sensitive to these low beta energies.

The following practices pertain to wearing radiation dosimeters. Some are required by regulation and others are common sense.

1. Film badges should be worn at the collar outside of protective clothing, such as a lead apron worn by x-ray personnel. Other acceptable locations are the trunk of the body or shirt pocket. Finger rings should be worn on the same finger when doing procedures and on the hand that is favored. The finger ring should be worn under the glove on the index finger with the detector (located under the label on the top of the ring) pointed towards the palm.
2. The radiation dosimeter is to be worn whenever there is a possibility of being exposed to ionizing radiation in the work place. It should never leave the campus or be worn at other institutions. Store the dosimeter in a radiation-free location when it is not being worn. It should not be subjected to high temperatures or high humidity. Radiation dosimeters are not to be worn when receiving medical radiation exposure for diagnosis or therapy.

3. Loaning your assigned dosimeter to anyone else to wear is illegal. Never use your assigned dosimeter to monitor an area. Radiation area monitors are available from the Radiation Safety Office on request.
4. Your dosimeter is your responsibility. UCSF has over 3,000 to process and exchange monthly, so promptly return your dosimeter each month for processing. Returning dosimeters late or losing dosimeters results in extra work and delays in obtaining reports. You must fill-out a Lost Badge Report for all non-returned dosimeters.
5. Do not leave your radiation dosimeter where it can be exposed to radiation.
6. The film must be properly placed into the holder every month and stored within the holder. If you are at all uncertain about how to insert the film into the holder, ask your Laboratory Supervisor for assistance. The holder contains special filters that allow for quantitative and qualitative analysis, therefore, for accurate readings the film must be properly inserted. The finger ring is a sealed unit and should be returned intact.
7. Loss of a film badge or finger ring must be reported to the Radiation Safety Office as soon as the loss is noted so that a Lost Film Badge Report can be filed. If a dosimeter has been assigned to you, and it is not worn when working with ionizing radiation, this is a violation of the law.
8. If there is an incident involving radiation exposure, it should be reported immediately to the Radiation Safety Office. Reporting will allow immediate evaluation of your radiation dosimeter to ascertain whether a significant exposure has taken place. Otherwise there can be a significant delay in knowing the extent of exposure.
9. Ring badges should be worn whenever the hand may receive significant radiation exposure and must be worn when handling amounts of 5 mCi or more of energetic beta emitters, such as ^{32}P , and gamma emitters.

The results measured by your radiation dosimeter is UCSF's record of your occupational radiation dose. UCSF has administratively set investigational levels far below State and Federal dose limits. Should your monthly exposure exceed these levels, you will be notified and an inquiry into the causes will be made.

<u>Workers</u>	<u>Investigational Limits</u>
Research	300 mrem/quarter
Clinical	450 mrem/quarter
Interventional Radiology	750 mrem/quarter

If you are pregnant or considering pregnancy, notify your supervisor so that changes in your working conditions can be considered. The dose to your unborn baby is limited to 500 mrem for the entire gestation period.

Reports of radiation doses are prepared monthly and sent to your dosimeter coordinator. The report is generally available about one month after your badge is exchanged.

Check with the coordinator to see where the results can be reviewed. If you have questions that your coordinator can not answer, feel free to call the Radiation Safety Office. See Figure 7.1 for a sample Dosimetry Request Card, and, Figure 7.2 for the layout of a sample Dosimetry Report.

Figure 7.1 Dosimetry Request Card

UCSF DOSIMETRY PROGRAM			
Name: _____		Sex _____	
Last	First	MI	
Box _____	Phone _____	Job Title _____	Dept. _____
Birthdate _____	Social Security # _____	Employee ID #(UCSF) _____	
M / D / Y			
PI _____	RUA # _____	Series Code _____	
Use Radionuclides: Yes _____	No _____	Operate X-ray unit: Yes _____	No _____
Previous UCSF Dosimetry: Yes _____	No _____	If YES, Series Code _____	
Other Previous Dosimetry: Yes _____	No _____	If YES, Please complete and mail attached form to previous employer	
Signature _____			
<p>For Office Use Only:</p> <p>Evaluation: Exposed to ionizing radiation > 10% MPD? Yes _____ No _____ Comment _____</p> <p>Film _____ TLD _____ Series _____ Part # _____</p> <p style="text-align: center;">G1 / G8 / Other?</p> <p>Issue Date _____ Previous Hist _____ Expos Req _____ Initial _____</p>			
<p>In order to comply with the State of California requirements, we are requesting a report of the radiation exposure history for the following individual. Please include all available results of bioassays, whole body counts or calculated exposures, where applicable, in the report.</p> <p>Name _____</p> <p>Social Security Number _____</p> <p>Department _____</p> <p>Dates of Employment _____</p> <p>Signature _____</p> <p style="text-align: right;">Part # _____</p> <p>Yours Truly, Dosimetry Coordinator Office of Environmental Health and Safety UCSF Box 0942 San Francisco, CA 94143</p>			

Figure 7.2

Dosimetry Report

EFFECTIVE 1/01/94, NEW REGULATIONS WILL CAUSE A CHANGE TO ROUTINE RADIATION DOSIMETRY REPORTS

as highlighted by this sample. Refer to reverse side for more information.

LANDAUER®

Specifies the portion of participant's body for which the dose is given, e.g. whole body, chest, etc.

Landauer dosimeter, if used, or else the method of determining the dose. Special calculations are available, too.

Radiation type, and in some cases, energy.

Exposure from your most recently processed badges. NOTE: Now includes the newly required dose to LENS OF EYE.

Quarter to date dose accumulation. Reports showing lifetime, though no longer required, can also be ordered.

Year to date dose accumulation. New regulations now utilize annual rather than quarterly limits.

Refers to beginning of continuous Landauer service for a given dosimeter.

Shows month and year in which an amendment to dose was last made.

SSN or other ID

NAME	PARTICIPANT NUMBER	TYPE OF RECORD	DOSIMETER TYPE OR SOURCE	NOTES	RADIATION QUALITY	DOSE EQUIVALENT (MREM) FOR PERIODS SHOWN BELOW			ACCUMULATED DOSE EQUIVALENT (MREM)			ACCUMULATED DOSE EQUIVALENT (MREM)			INCEPTION DATE MO/YR	LAST AMENDMENT RECORDS FOR YEAR	ID NUMBER	SEX	BIRTH DATE MO/DA/YR
						DEEP DDE	EYE LDE	SHALLOW SDE	DEEP DDE	EYE LDE	SHALLOW SDE	DEEP DDE	EYE LDE	SHALLOW SDE					
FOR MONITORING PERIOD:						01/01/94 - 01/31/94			QTR 1			1994							
CONTROL	00000		G			M	M	M	M	M	M	M	M	M	1/80	1			
WASHINGTON G.	00001	WHL BODY	G			M	M	M	M	M	M	M	M	M	1/80	1	1234567890123456	M	01/01/41
ADAMS J.	00002	WHL BODY	G		PL	100	110	120	100	110	120	100	110	120	1/80	1	2222222222222222	M	01/02/42
JEFFERSON T.	00003	WHL BODY	G	SEE DR	PM	100	100	100	100	100	100	100	100	100	1/80	1193	3333333333333333	M	01/03/43
MADISON J.	00011	WHL BODY	CALC			80	80	80	80	80	80	80	80	80	6/80	1	4444444444444444	M	01/04/44
POLK J.	00014	WHL BODY	G	ABSENT											6/85	1	5555555555555555	M	01/11/51
BUCHANAN J.	00015	WHL BODY	G	MAX	PL	1000	1100	1200	1000	1100	1200	1000	1100	1200	3/87	1	0000000000000015	M	01/15/55
		CHEST	K		PL	100	110	120							3/87				
		COLLAR	K		PL	1000	1100	1200							3/87				
		RT HAND	U					M				M			4/87				
TAYLOR Z.	00022	WHL BODY	G	UNUSED											6/85	1	0000000000000012	M	01/12/52

Indicates that dose for missing badge was calculated by customer and given to Landauer.

Analytical method used to derive dose from multiple badging. For example, maximum exposure to record dose to whole body.

Number of times a report was generated for a participant.

NOTES DESCRIPTION:
DR - THIS FILM APPEARS TO HAVE BEEN EXPOSED FROM THE REAR.

Comments on individual dosimeters are shown in NOTES column or detailed below.

B. BIOASSAYS

Bioassays are performed when persons use unsealed quantities of radioactive materials to determine whether any activity has entered the body. The results are used to estimate internal organ doses, determine the presence of airborne radioactive materials, and to evaluate work habits, experiment design, and facility design. Bioassays are performed by analyzing samples of blood, urine, or tissue, or by monitoring the organ of interest (e.g. thyroid gland) to determine the presence and quantity of radioisotopes.

1. URINE ASSAY

UCSF requires that each individual using 100 millicuries or more of ^3H , ^{14}C , ^{35}S , or ^{32}P per experiment perform a urinalysis after such use and document the results. The results should be kept in the Laboratory Radiation Safety Logbook for review by the Radiation Safety Office and inspection by the State. The counting procedures, maximum values, and action levels are given in Appendix D, Part B of the Radiation Safety Manual.

2. THYROID BIOASSAY

Persons working with radioiodine may be exposed to airborne concentrations. Thyroid bioassays are performed to verify that exposures are kept to a minimum. The bioassay procedure involves placing a radiation detector, sensitive to emissions to be measured, close to the thyroid gland and obtaining a one minute count. The results are used to estimate the total activity of radioiodine in the thyroid.

The requirements for thyroid bioassays are given in Appendix D, Part C of the Radiation Safety Manual.

C. SURVEY METERS

The most common use of survey meters in UCSF laboratory situations is to detect the presence of contamination during and after experimental work involving radioisotopes.

During the review of a laboratory's application to obtain a Radiation Use Authorization permit, the Radiation Safety Office will verify that appropriate survey meters are available to detect the radioactive material to be used in the laboratory. All UCSF survey meters must be calibrated at least annually. Calibrations are performed by the Radiation Safety Office and a calibration sticker is attached to the meter noting the next calibration due date. Before using a survey meter, be sure that it has been calibrated within the past year and check the battery. If you are suspicious about the operation of a survey instrument, notify your Laboratory Supervisor.

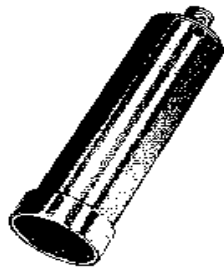
The most common radioisotopes used in research at UCSF are ^3H , ^{14}C , ^{32}P , ^{35}S , and ^{125}I . ^3H cannot be detected with a survey meter. ^{32}P is quite energetic and easily detected; ^{14}C and ^{35}S are low energy beta-emitters and are detected with much lower

efficiency than ^{32}P . The Radiation Safety Office requires that a meter having a scintillation probe be used for ^{125}I detection.

The two most common types of survey meters used in laboratories at UCSF are the Geiger-Mueller (G-M) and scintillation counter. UCSF G-M survey meters will be equipped with a thin end-window to permit detection of low energy beta radiation and a speaker that produces an audible noise relative to the radioactivity being detected. G-M detectors are filled with a gas such as argon. The meter must be carefully handled to prevent damage by rupture of the thin end-window. The G-M tube consists of a center wire surrounded by a concentric cylinder. A high voltage is applied between the wire and the cylinder. Each radioactive event causes electrical discharge in the G-M detector tube. The electrons are collected on the central wire to produce a signal. G-M tubes may be located inside the meter or contained in probes having several shapes, such as a "pancake" probe or cylindrical probe. See Figure 7.3 for sample G-M Detectors

The scintillation meter operates under a different principal than the G-M meter. When radiation interacts with the scintillation detector (often a crystal made of NaI activated with Thallium), a light flash is produced that is "seen" by a photomultiplier (PM) tube. The initial stream of electrons produced by light falling on an electron-emitting surface is multiplied to produce a current that makes the meter register. These units are required when working with ^{125}I . See Figure 7.4 for sample Scintillation Probes.

Figure 7.3 Common Types of G-M Detectors



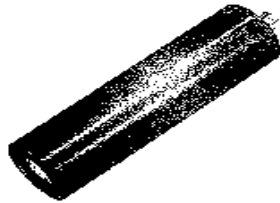
**END WINDOW
G-M DETECTOR**



**PANCAKE
G-M DETECTOR**

Figure 7.4

Common Types of Scintillation Probes



**LOW ENERGY GAMMA
SCINTILLATOR**



**LOW ENERGY GAMMA
SCINTILLATOR**

Become familiar with the survey instruments in the laboratory. Ask your Laboratory Supervisor to demonstrate the proper use of each instrument, review the manufacturer's manual for each instrument, and learn the important characteristics of the instrument such as energy dependence. An example of an energy dependence curve (measured dose rate vs energy) is given in Figure 7.5.

Some practical steps in use of survey meters:

1. Use the instrument carefully; most instruments have a slow response when surveying for low level contamination.
2. Avoid contaminating the instrument or breaking the thin window of the detector.
3. Do not cover the probe of the instrument with Parafilm or other plastic wraps. This will reduce the instrument's detection efficiency.
4. Check to battery to make sure it is in operable range.
5. Hold the instrument as close to the surface as you can, without touching the surface.

D. WIPE SURVEYS

Wipe surveys must be routinely performed as part of the laboratory contamination control program. Direct monitoring with a survey meter is a means to detect the presence of contamination and should be the first step in conducting a wipe test survey. Wipe tests are an effective method to measure the extent of contamination. In addition, wipe surveys are the only effective way to detect contamination from low-energy beta emitters such as ^3H .

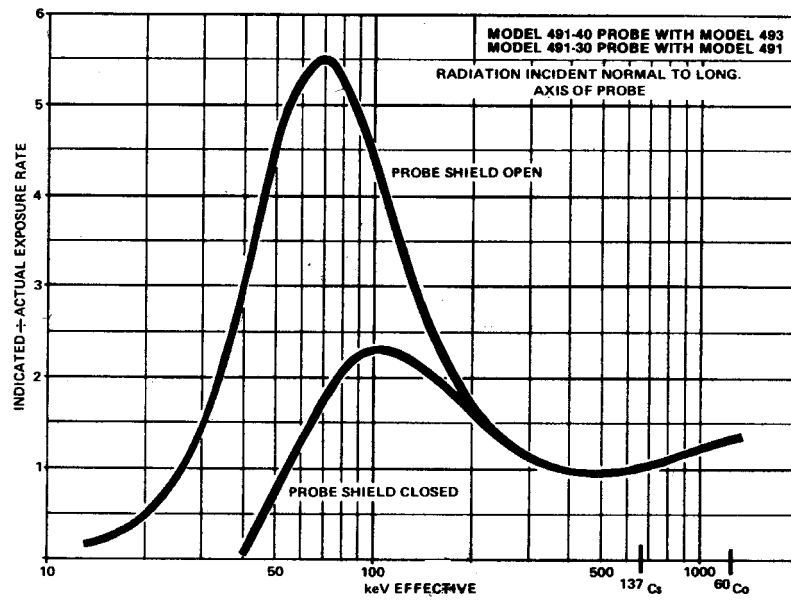
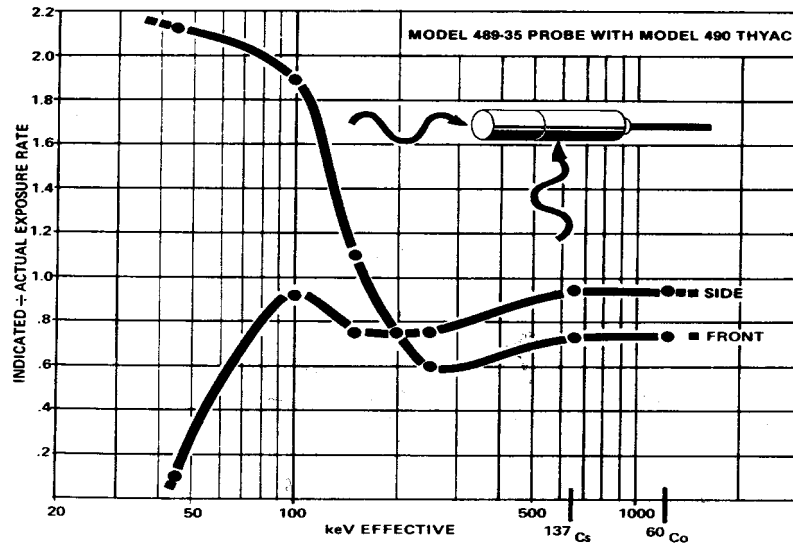
Upon completion of a thorough meter survey, identify the areas to be tested and mark them on a laboratory diagram. Wearing disposable gloves, use filter paper, or another

appropriate media such as cotton swabs, to wipe each test area. The wipe area should be at least 100 cm² or approximately 4" x 4." Label each wipe and include a control wipe to obtain a background count. Count the samples in a liquid scintillation counter (a well counter can be used for gamma emitters).

Review the results and note those samples that exceed 2 x background in uncontrolled areas and 25 x background in controlled areas. These areas must be decontaminated and re-wiped to document that decontamination has been performed. Monitor your hands and clothing after you have completed the survey.

FIGURE 7.5 Energy Response for Geiger Counters

CURVES



CHAPTER 8

RECORD KEEPING

The use of radioactive materials at the University of California, San Francisco (UCSF) is subject to strict controls regarding their receipt, usage, and disposal. Meticulous records must be kept to document adherence to the requirements. Each laboratory authorized to use radioactive materials is provided with a Radiation Safety Logbook to simplify the maintenance of required records and to expedite auditing by the Radiation Safety Office or inspection by the State.

Given below are three important record keeping elements, but the logbook should be reviewed to see the entire record keeping program for a laboratory (e.g. instrument calibrations, sealed source leak tests, personnel monitoring records).

A. UCSF RADIOISOTOPE USAGE FORM

Each laboratory must maintain records of incoming shipments, usage, and disposal of radioactive materials. Completing the information requested on the Radioisotope Usage Form largely satisfies these requirements.

Prior to delivery to the laboratory, each radioisotope vial is assigned a unique number that is also recorded on the Radioisotope Usage Form. The form should be kept in a convenient location so that it can be easily completed whenever a radioisotope is withdrawn from the vial. The number on the vial should be checked to ensure that the correct form is completed. When use of the vial is completed, the form can be filed. Every user is responsible for ensuring that the Radioisotope Usage Form is properly completed each time that radioisotopes are used.

To simplify record keeping, radioactive decay is not considered when recording the activity of radioisotopes. For example, consider a 1 mCi shipment of ^{32}P that is received and used throughout the course of a week: 100 uCi used on day 1; 250 uCi used on day 2; and 100 uCi used on day 5; then the balance on hand on day 5 would be recorded as 550 uCi. In short, if 1,000 uCi was received by the lab, records should account for 1,000 uCi leaving the laboratory.

A copy of the Radioisotope Usage Form is given in Figure 8.1.

B. RADIOISOTOPE INVENTORY

Each laboratory must submit an inventory to the Radiation Safety Office every three months listing the types and quantities of radioactive material in the laboratory. The inventory is used to document that UCSF is not exceeding the possession limits authorized by the State and to verify that each laboratory is not exceeding their individual possession limits.

The contamination limit for controlled areas is 25 x background. A controlled area is any area that access is restricted to radioisotope users only. Examples of controlled areas are:

- a. The inside of fume hoods (inside of sashes, bottom surface of the hood, side and back panels).
- b. Inside of centrifuges.
- c. Inside of radioactive waste containers, and storage areas.

These areas must be clearly labeled with CAUTION - RADIOACTIVE MATERIAL signs.

Records of weekly or monthly wipe surveys must be available for review by the Radiation Safety Office. Weekly records are required for those labs authorized to use 100 uCi or more per experiment and monthly records are required when less than 100 uCi per experiment has been authorized.

CHAPTER 9

RADIOACTIVE WASTE DISPOSAL

Radioactive Waste is defined as any material that has come in contact with radioactivity and may be contaminated. The University of California, San Francisco (UCSF) Radioactive Waste Management Program concentrates on source reduction and volume reduction. **Source reduction** can be achieved in the laboratory by using non-radioactive labeling methods whenever possible. **Volume reduction** can be achieved by both laboratory personnel before the waste is collected, and by the Office of Environmental Health and Safety (EH&S) personnel after the waste is collected. Since disposal fees are directly related to the volume of waste disposed, volume reduction is an effective method of reducing costs. Laboratory personnel should implement the following volume reduction procedures:

- Limit the areas where radioactive materials are used to a minimum. The larger the area the larger the volume of waste materials generated, such as absorbent paper. Using smaller areas also limits the opportunity for cross contamination of other materials.
- Survey materials being disposed, such as absorbent paper or pipettes, with a proper radiation detector prior to disposal, and, if uncontaminated, dispose as non-radioactive waste.
- **The use of a proper survey meter is paramount** (e.g. ^3H cannot be detected with a survey meter; the efficiency of most detectors for ^{14}C or ^{35}S is less than 5%).
- Reduce the volume of liquid used (e.g., from washes) to the minimum needed for proper conduct of the experiment.
- Try to maintain separate work areas for different radioisotopes.
- EH&S personnel use consolidation, compaction, and other techniques to further reduce the volume of waste.

A. CATEGORIES OF RADIOACTIVE WASTE

Radioactive waste must be segregated into the following general categories:

- Dry solid.
- Aqueous liquid.
- Liquid bulk organic solutions.
- Liquid scintillation vials.
- Biological materials.
- Clinical waste (from nuclear medicine and radiation oncology).
- Other miscellaneous categories, such as: bactec vials, beta plates, uranium compounds, contaminated equipment and articles, and sealed sources. sources.

The definition of each category of waste and the specific packaging requirements are given below.

1. DRY SOLID WASTE

Dry waste is defined as any solid waste, generally composed of paper, plastic, gloves, i.e., general laboratory trash, containing less than 0.5 percent by volume of free standing liquid. Dry waste shall not contain any of the following:

- a. Biological material, including sharps.
- b. Lead.
- c. Scintillation vials.
- d. Liquids.
- e. Any other waste category.

Dry waste must be packaged in 4-mil yellow transparent plastic waste bags marked with the "Caution Radioactive Materials" and trefoil radioactive symbol. These bags may be purchased from the UCSF storehouse. Bags must be securely closed with tape and the UCSF Radioactive Waste Tag (See Documentation, Section E) must be attached to each bag.

Dry waste must also be segregated into one of four categories based on the radioisotope or half-life of the radioactive material:

- ^{32}P only
- ^{35}S only
- < 90 day half-life (e.g. ^{125}I , ^{131}I , ^{51}Cr)
- > 90 day half-life (e.g. ^3H , ^{14}C , ^{57}Co)

Note: Cost reductions are made by proper segregation of waste. Every attempt should be made to segregate all categories of waste by INDIVIDUAL isotope. Large, dry waste items (e.g., equipment, trash cans) require special arrangements with EH&S for pick-up.

2. LIQUID EFFLUENT

UCSF policy prohibits the disposal of radioactive material via the sanitary sewer. The exceptions are:

- a. Excreta directly discharged into the sewer from patients who have been administered radioactive materials for diagnostic or therapeutic purposes.
- b. Radioactive material remaining in secondary washes or their equivalent.

3. AQUEOUS LIQUIDS

Aqueous radioactive liquids are those in which the solvent and solute are both water-based. These wastes must be neutralized to a pH of approximately 7 and contained in plastic transparent narrow-necked containers with secure screw tops. Containers should not be larger than one-gallon and glass and metal containers are not acceptable. One-gallon jugs which meet these criteria are available from the UCSF storehouse.

Aqueous liquid waste must also be segregated by the radioisotope or half-life of the radioactive material:

^{32}P only
< 90 day half-life (e.g. ^{35}S , ^{125}I , ^{131}I , ^{51}Cr)
> 90 day half-life (e.g. ^3H , ^{14}C , ^{57}Co)

Every attempt should be made to segregate all categories of waste by INDIVIDUAL isotope.

The UCSF Radioactive Waste Tag must be attached to each container. To allow for reuse, it is preferable that no markings or tape be placed on the container. Containers must not be leaking and the outer surfaces must be free of contamination. Leaking containers will not be picked-up by EH&S. The contents of the container should be limited to aqueous liquids; no foreign items such as pipette tips are allowed.

DO NOT ABSORB AQUEOUS LIQUIDS.

4. LIQUID BULK ORGANIC

These are free standing liquid radioactive waste that contains organic compounds such as xylene, toluene, acetone, phenol, etc. The waste must be packaged in one-gallon plastic or glass transparent containers with a screw top and narrow neck. Clear or amber bottles which originally contained other chemicals may be used for this purpose if the original labels have been removed and the empty container triple-rinsed before being used to collect waste.

Liquid Bulk Organic solutions are considered for regulatory purposes as Mixed Waste. That is, the waste not only exhibits the properties of radioactivity, but also other hazardous properties such as ignitability, corrosivity, toxicity or reactivity.

The UCSF Radioactive Waste Tag must be attached to each container. In addition, the UCSF EH&S Chemical Waste Removal Form must be completed and accompany the waste pick-up. (See Documentation, Section E). Containers must not be leaking and the outer surfaces must be free of contamination. Leaking or

contaminated containers will not be picked-up by EH&S. The contents of the container should be limited to organic liquids; no foreign items such as pipette tips are allowed.

DO NOT ABSORB ORGANIC LIQUIDS.

5. LIQUID SCINTILLATION VIALS

Liquid Scintillation vial waste consists of glass or plastic containers of less than 25-ml capacity that contain or have contained liquid scintillation media. Unused liquid scintillation vials or vials which have been used for other purposes must be handled as radioactive liquid scintillation vial waste. This latter requirement is due to the recognition by commercial waste handlers and regulatory personnel of these vials as normally containing radioactive material.

Scintillation vials are divided into three specific categories:

- a. **Exempt Vials** - contain only ^{14}C and/or ^3H with total activity concentration not exceeding 1.85 KBq per milliliter (0.05 microcuries/ml).
- b. **Regulated Vials** - may contain ^{14}C , ^3H , ^{195}Au , ^{45}Ca , ^{109}Cd , ^{141}Ce , ^{36}Cl , ^{57}Co , ^{51}Cr , ^{64}Cu , ^{59}Fe , ^{67}Ga , ^{153}Gd , ^{68}Ge , ^{203}Hg , ^{125}I , ^{131}I , ^{111}In , ^{22}Na , ^{32}P , ^{33}P , ^{86}Ru , ^{35}S , ^{46}Sc , ^{75}Se , ^{119}Sn , ^{113}Sn , ^{99}Tc , ^{65}Zn with a total activity concentration not exceeding 1.85 KBq per milliliter (0.05 microcuries/ml).
- c. **Special Vials** - exceed the maximum permissible total activity concentrations for Exempt Vials and Regulated Vials and may contain isotopes not permitted in Exempt Vials or Regulated Vials.

Glass and plastic liquid scintillation vials should be segregated whenever possible to facilitate processing by EH&S. When possible, scintillation vials should be packaged in the original trays for subsequent pick-up by EH&S. Write on the trays the category of scintillation waste, e.g., "Exempt", "Regulated", or "Special". It is not necessary to label the tray with radioactive tape nor is it necessary to attach a Radioactive Waste Tag to the tray(s).

If the original trays are not available, the waste vials must be double bagged in the 4-mil yellow transparent plastic waste bags marked with the "Caution Radioactive Materials" and trefoil radioactive symbol. Each bag must have a Radioactive Waste Tag attached with the proper category written on the tag, e.g., "Exempt", "Regulated", or "Special". Contaminated trays/bags and leaking bags will not be picked-up by EH&S.

Special Vials require the completion of a supplementary form, the EH&S Chemical Waste Removal Form, that must accompany the Radioactive Waste Disposal Form. See Figure 9.1 for a sample Radioactive Waste Disposal Form.

Vials must not contain stock solutions of radioisotopes; biological specimens, or foreign objects. All lids must be securely fastened to prevent leakage.

6. BIOLOGICAL WASTE (RADIOACTIVE)

Radioactive waste that contains biologic, pathogenic, or infectious material which must be segregated into general categories: carcass and non-carcass. Carcass waste consists only of animal carcasses and/or large carcass parts. Non-carcass waste may consist of the following:

- a. Human or animal specimen cultures.
- b. Cultures and stocks of infectious agents.
- c. Waste from the production of bacteria, viruses, spores, live and attenuated vaccines, and culture dishes and devices used to transfer, inoculate and mix cultures.
- d. Microbiological specimens.
- e. Human surgery specimens or tissues removed at surgery or autopsy.
- f. Material containing fluid blood or blood products.
- g. Material containing excreta, exudate, or secretions from humans or animals.
- h. Sharps (items or materials that can cut or pierce; examples include needles, blades, teeth, etc.).
- i. Test tubes, capillary tubes, general tubing which have come in contact with such materials.

In addition, radioactive biological waste must be segregated by radioisotopes as follows:

^3H and/or ^{14}C
 ^{32}P only
<90 days half-life, e.g., ^{125}I , ^{51}Cr
>90 days half-life

Every attempt should be made to segregate all categories of waste by INDIVIDUAL isotope.

Carcass waste containing ^{14}C and/or ^3H with a total concentration not exceeding 1.85 KBq per gram (0.05 microcuries/g) of tissue averaged over the weight of the entire carcass or carcass part may be classified as "**deminimus**". Biological material must be double-bagged in 4-mil red plastic waste bags and labeled with radioactive label tape.

Proper bags are available from the UCSF Storehouse. Bags must be securely closed with tape and the UCSF Radioactive Waste Tag must be attached to each bag.

Sharps contaminated with radioactivity must be placed in a sharps container labeled with the "Caution Radioactive Materials" and trefoil radioactive symbol. Pipettes

can be placed in hard sided containers that have a UCSF Radioactive Waste Tag attached.

Pick-up of radioactive biological waste:

Radioactive biological waste is not picked up by EH&S personnel. Laboratory personnel must deliver the waste to the approved radioactive biological waste storage cooler. You must make arrangements to meet an EH&S technician at the cooler.

- i. At the Parnassus Campus, laboratory personnel must deliver radioactive biological waste to the Health Sciences Building Animal Tower cooler. Call 476-1771 to make arrangements for an EH&S Technician to meet you at the cooler.
- ii. At the San Francisco General Hospital (SFGH) Campus, laboratory personnel must deliver radioactive biological waste to the SFGH Radiation Safety Office. Call 476-9550 to make arrangements.
- iii. For all other locations, call the EH&S office at your location or call 476-1771.

7. CLINICAL WASTE (NUCLEAR MEDICINE AND RADIATION ONCOLOGY)

May contain isotopes with half-lives not to exceed 8 days. Dry waste must be packaged in one cubic foot cardboard boxes. Sharps must be packaged in one cubic foot plastic sharps containers.

The EH&S Technician will meet you at your waste collection area and will measure the exposure rate at the surface of each waste container. The Clinical Technician should then determine the activity amount for each package and enter the data on the Radioactive Waste Disposal Form. The EH&S Technician will mark the package. EH&S Technicians may request that the waste be stored in the clinical waste collection area for an additional period of time to decay in order to decrease the exposure rate from the package.

Figure 9.1

Radioactive Waste Disposal Form

**UCSF EH&S - RADIATION SAFETY PROGRAM
RADIOACTIVE WASTE DISPOSAL FORM**

DATE: _____ P.I. _____
 BLDG: _____ ROOM # _____ RUA # _____

ISOTOPE
 Vol = VOLUME Act = ACTIVITY (mCi)

TYPE	TOTAL VOLUME	ISOTOPE					
		Vol.	Act.	Vol.	Act.	Vol.	Act.
Dry<90 days	Ft3						
Dry>90 days	Ft3						
Aqueous Liq<90 days	Gal						
Aqueous Liq>90 days	Gal						
Counting Vials	Trays						
DeMinimus Vials (1)	Trays						
Liq. Bulk Organic (2)	Gal						
Bio Carcass	Ft3						
DeMinimus Carcass (1)	Ft3						
(3)							

REDUCE DISPOSAL COSTS. SEGREGATE ALL WASTE TYPES BY ISOTOPE WHENEVER POSSIBLE.

(1) ³H or ¹⁴C Vials only <0.05 uCi/ml, ³H or ¹⁴C Carcass only <0.05 uCi/g.
 (2) For Liq. Bulk Org. List: Solvents _____ (>10% of volume).
 (3) Miscellaneous: bactec vials, beta plates, uranyl acetate, lead, non-carcass bio, etc.

SIGNATURES: _____
 Lab Personnel EH&S

White Copy - EH&S Yellow Copy - Laboratory

8. BETA PLATES

Beta plates are plastic sheets that contain scintillation media; they must be double bagged in 4-mil transparent yellow radioactive waste bags. The concentration of radioactive material in Beta plates must not exceed 1.85 KBq per milliliter (0.05 microcuries/ml).

9. BACTEC VIALS

Bacteria culture in an aqueous liquid medium, sealed in a vial of less than 40-ml capacity and containing not more than 148 KBq (4 microcuries). These vials must be autoclaved prior to disposal. Package the vials in their original container if possible or double bag.

10. URANIUM COMPOUNDS (URANYL ACETATE, URANYL NITRATE)

Dry uranyl compounds should be packaged in 4-mil transparent yellow radioactive waste bags. Uranyl compounds in solution must be packaged in airtight plastic liquid containers and accompanied by an EH&S Chemical Waste Removal Form.

11. SHARPS

Sharps are items or material that can cut or pierce. Examples are syringes, needles, blades, broken glass, pipettes, slides, teeth, etc. All sharps, including syringes with or without needles, must be placed in rigid puncture proof sharps containers complete with lids.

Sharps contaminated with biological or infectious material must be classified as radioactive biological waste. The package must be an approved hard-sided plastic sharps container that displays the universal biohazard symbol. Broken glass may be placed in hard-sided cardboard glass disposal boxes.

Infectious pipettes may be placed into cardboard pipette disposal sleeves that display the universal biohazard symbol. The sleeves may then be placed into 4-ml red plastic waste bags labeled with radioactive tape.

Sharps that are not contaminated with infectious material may be classified as dry waste. All markings, labeling, or coloring that would indicate the presence of biological or infectious material, e.g., the universal biohazard symbol, red or orange color, on any sharps waste packaging must be removed or obliterated.

B. RADIOACTIVE DECAY

The UCSF Radioactive Materials License specifically prohibits the decay of radioactive waste materials and subsequent disposal into the ordinary trash or sanitary sewer by laboratory personnel. Decay programs are only authorized to be carried out by EH&S under the direct supervision of the RSO at State Radiologic Health Branch approved locations.

C. STORAGE CONSIDERATIONS FOR RADIOACTIVE WASTE

Radioactive waste must be stored in an approved secure radioactive materials use location. Each laboratory should designate a single location within the laboratory where waste will be consolidated for pick-up by EH&S technicians. The location should be cleaned regularly and surveyed for contamination.

All waste prepared for disposal must be kept off of the floor, preferably in a dedicated waste containment vessel such as a metal trash can with a step lid or a lucite box. The containment vessel must be labeled for use with radioactive waste material. Color-coded container labels are available from EH&S. See Figure 9.2 for examples of radioactive waste container labels. Secondary containment is recommended for liquids.

Container Label Color Codes

³² P only	RED
half life less than 90 days	YELLOW
half life greater than 90 days	ORANGE

D. CLASSIFICATION

If you cannot determine the proper category classification for your radioactive waste, contact your EH&S Department Safety Advisor. You may also submit a UCSF Low-Level Radioactive Waste Profile Form and EH&S will help you determine the proper category for your waste.

E. DOCUMENTATION

Appropriate forms must be completed and accompany all radioactive waste to be collected from radioactive waste generators by EH&S. The basic form is the Radioactive Waste Disposal Form which must be completed for ALL radioactive waste disposals.

The EH&S Chemical Waste Removal Form is a supplementary document that must be prepared for liquid bulk organic waste (Mixed Waste), special vials, and uranyl compounds.

Each package of radioactive waste must have the appropriate color-coded radioactive tag securely attached (with some exceptions, e.g., vials in trays, clinical dry waste). See Figure 9.3 for examples of radioactive waste tags.

Waste Tag Color Codes

³² P only	RED
half life less than 90 days	YELLOW
half life greater than 90 days	ORANGE

Waste which has not been packaged according to established UCSF policies and procedures will not be collected by EH&S. A "Radioactive Waste Deficiency Form" will be left with the laboratory which identifies the reason that the waste was not collected. Upon correction of the deficiency, the waste will be picked-up.

Figure 9.2

Radioactive Waste Container Labels

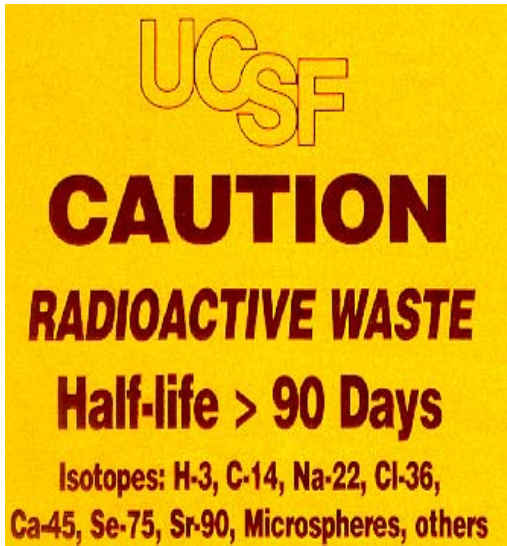
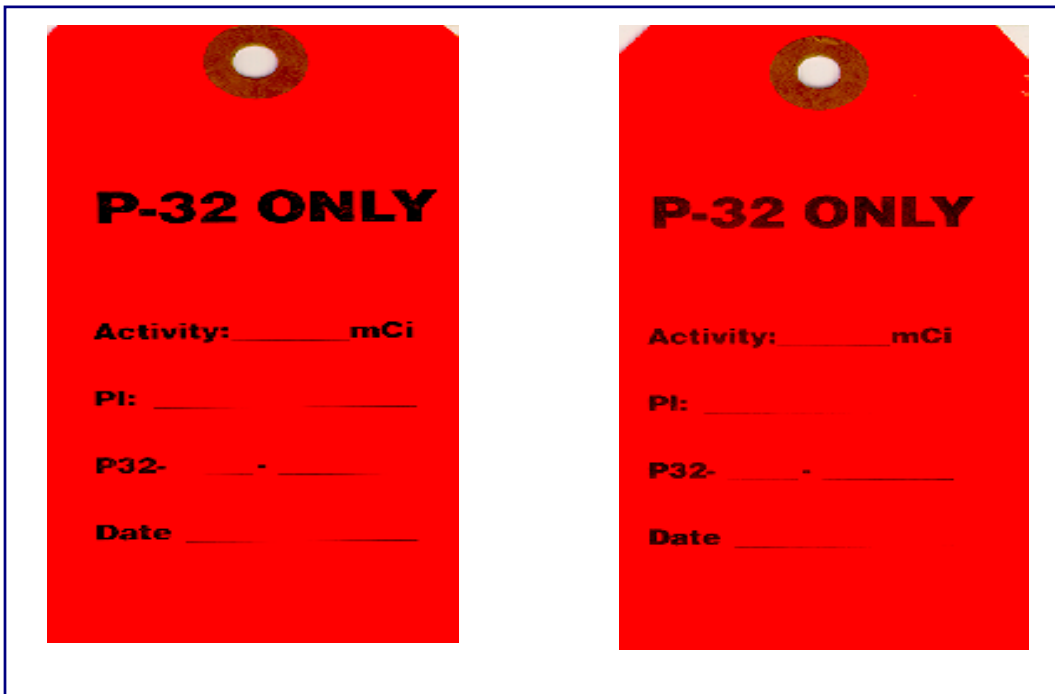


Figure 9.3

Radioactive Waste Tags



$T_{1/2} < 90$ Days Only

LIST OF ISOTOPES

P-33
 S-35
 K-42
 Cr-51
 Rb-86
 I-125
 I-131
 others

Date _____

$T_{1/2} < 90$ Days Only

S-35 _____ mCi
 Cr-51 _____ mCi
 I-125 _____ mCi

Others:

_____ mCi
 _____ mCi
 _____ mCi

PI: _____

LT-90- _____ - _____

Date _____

F. SCHEDULING OF RADIOACTIVE WASTE PICK-UPS

If you regularly generate radioactive waste, contact EH&S to be placed on the radioactive waste collection schedule. Non-routine pick-ups can be scheduled by calling 476-1771 at the Parnassus campus. Call 476-9550 at SFGH.

If the EH&S Technician cannot complete the pick-up on the scheduled day (door locked, documentation incomplete or not available, laboratory closed, etc.), the technician will leave an Attempt to Pick Up Notice.

G. DOSE RATE LIMITS FOR RADIOACTIVE WASTE PACKAGES

Technicians have been instructed to only collect waste that is packaged in accordance with established UCSF policies and procedures.

Waste must be packaged so that the exposure rate at one meter from the surface of the package does not exceed 0.00005 Sv/hr (5.0 mR/hr) and the exterior of the package must not be contaminated. If the waste exceeds this exposure rate criteria, please notify EH&S prior to the pick-up so that appropriate shielding can be utilized.

H. BILLING

The costs of collecting and disposing of radioactive wastes are recharged to laboratories on a monthly basis. The recharge rate is based on waste category and waste volume. The billing data are taken from the Radioactive Waste Disposal Form and the EH&S Chemical Waste Removal Form, if applicable.

CHAPTER 10

EMERGENCY PROCEDURES

An important aspect of radiation safety is being prepared for the unexpected. The following steps are to be taken should an accident occur despite precautionary measures. The information presented in Chapter 6 of the University of California, San Francisco (UCSF) Radiation Safety Manual should be completely reviewed.

A. NOTIFICATION OF THE RADIATION SAFETY OFFICE

Notify the Radiation Safety Office as soon as possible of any accident involving ionizing radiation. This includes, but is not limited to, accidental direct radiation exposure, extensive contamination of floors and work surfaces, or contamination of laboratory personnel. If it is anticipated that a procedure may result in contamination or other hazard, prior approval from the Radiation Safety Office is required.

B. MANAGEMENT OF RADIATION INCIDENTS

Major area contamination involving potential health hazard:

1. In the event of spread, or a suspected spread, of radioactive contamination over a significant portion of a room or larger area:
 - a. Vacate the area, leaving behind clothing and other articles which may be contaminated.
 - b. Keep all persons out of the area, except for monitoring and rescue teams.
 - c. Call the Radiation Safety Office immediately.
 - d. Do not attempt decontamination except as expressly directed by the Radiation Safety Office.
2. Minor contamination (uCi) amounts involving no immediate health hazard:
 - a. Notify everyone in the room and area at once.
 - b. Monitor personnel before they leave and then change clothes or lab coat, as necessary.
 - c. Put on disposable gloves to prevent contamination of your hands. Wash your hands first if they are contaminated -- following the UCSF Radiation Safety Manual procedures for decontamination of the hands and skin.
 - d. Survey, mark, or block off the contaminated area with warning signs or labels.
 - e. Use absorbent paper or absorbent material on the spill to limit the spread of contamination.

- f. Notify the Radiation Safety Office of the accident as soon as possible. Call 476-1300 or 476-6911.
- g. Start decontamination procedures as soon as possible. Normal cleaning agents, or commercial decontamination agents should be adequate. Put on shoe covers and begin procedures by using paper towels with the decontamination agent. Scrub from the outermost edges of the contaminated areas and work inward, reducing the area that is contaminated.
- h. Put all contaminated objects and cleaning materials into containers to prevent spread of contamination.
- i. In the case of large spills, block off the area. Assign a person equipped with a survey meter and wipe test the materials to help prevent the accidental spread of contamination.
- j. Decontaminate the area to background count rates. There should be no removable contamination on the surface after decontamination.
- k. Report the accident to the Principal Investigator, Laboratory Supervisor, and the Radiation Safety Officer.

C. PERSONNEL CONTAMINATION

In the event that persons are contaminated as a result of a contamination incident:

1. Administer first aid measures, as necessary.
2. Remove the person from the contaminated area and hold at a transfer point.
3. Report the incident immediately to the Radiation Safety Office.
4. Flush the contaminated skin area with water and soap using care not to abrade the skin.
5. Refer suspected internal contamination immediately to the Radiation Safety Office.
6. Personnel are not to leave UCSF property for the purpose of decontaminating themselves unless specifically advised to do so by the Radiation Safety Office.

Note: If applicable, have a survey meter available to monitor the area, clothing, shoes, etc. and to prevent the spread of contamination.

D. EMERGENCY TELEPHONE NUMBERS

The Office of Environmental Health and Safety Radiation Safety Office 24 hour Emergency Response number is:

206-8111 at San Francisco General Hospital only
476-6911 at all other locations.

E. INJURY AND CONTAMINATION

1. INGESTION

Treat ingestion of radioactive material like any other acute poisoning. Induce vomiting rapidly by swallowing large volumes of water and stimulate the throat with the fingers. Mild emetics (an agent that induces vomiting) may be added to the water. Repeat this once or twice. The Radiation Safety Officer must be notified immediately after the ingestion.

2. CONTAMINATED WOUNDS

Any wounds from radioactive contaminated glassware, instruments, or needles should be treated immediately. Wash the injured area under a strong stream of water. (See procedures described in Sections 3 and 4 below.)

3. SKIN CONTAMINATION

The best method of decontamination is thorough washing with soap and water (See washing procedures described in this Section and Section 4 below.), unless the contamination is very localized. For localized decontamination, swabbing of a masked area is preferable, as this prevents the spreading of the contamination.

If the nature of the contaminant is known, a suitable reagent may be used to immerse the skin, followed by washing. Detergents and wetting agents are also useful. Organic solvents must not be used as they may increase skin penetration.

4. HAND WASHING METHOD

- a. Wash for 2 or 3 minutes under tepid water, using a mild and pure soap. Create a lather using light scrubbing, to avoid eroding the skin and causing further penetration. Pay attention to the areas between fingers and under nails and to the outer edges of the hands, which are often neglected. Rinse thoroughly and monitor.

- b. If monitoring still reveals contamination, rinse again using a soft brush to create a lather. Rinse and lather repeatedly.
- c. Apply lanolin or hand cream to prevent chapping.

If contamination is still evident, the above procedures may be used in the order presented. Contact the Radiation Safety Officer.

CHAPTER 11

GLOSSARY

A	Symbol for mass number.
Absorbed dose	The amount of energy imparted to matter by ionizing radiation per unit mass of irradiated material at the place of interest (see rad or Gray).
Absorption	The process by which radiation imparts some or all of its energy to material through which it passes.
Absorption Coefficient	The fractional decrease in the intensity of a beam of x-rays or gamma radiation. <ul style="list-style-type: none">• Linear absorption coefficient (per unit lengths)• Mass absorption coefficient (per mass thickness)• Atomic absorption coefficient (per atom)
ALARA	ALARA refers to the policy of maintaining radiation levels of exposure As Low As is Reasonably Achievable.
Allowable Limit On Intake (ALI)	The annual intake that would lead to an effective committed dose equivalent (a 50 year dose commitment) not exceeding 5 rem and an annual dose equivalent to any single organ or tissue not exceeding 50 rem.
Alpha-Particles	These are equivalent in mass (~4 atomic mass units (amu)) and charge (2 positive units) to helium nuclei. They are emitted primarily during decay of heavy nuclides including uranium, thorium, radium and elements in the trans-uranium series. Alpha-particles are emitted with discrete energies characteristic of the radionuclide. The energies for alpha-particles emitted from typical nuclides are in the 3-6 MeV range. Alpha-particles, because of their large mass, have a relatively low velocity. This velocity and the double positive charge mean that alpha-particles interact strongly with matter, producing intense ionization as they dissipate their kinetic energy in very short distances. Alpha-particles with an energy of 5 MeV will penetrate about 50 microns in tissue and produce $(20-60) \times 10^3$ ion pairs per centimeter in air. In general, alpha-particles can travel only short distances (about 8 cm) in air and can be stopped by a thin sheet of paper, although the highest energy alpha-particles can penetrate to the living basal epidermal cells. When nuclides which emit alpha-particles become deposited within a person's

body, those cells within a fraction of a millimeter of the site of deposition will receive very large doses of radiation.

Anode	Positive electrode; electrode to which negative ions (or electrons) are attracted.
Area Monitoring	Routine monitoring of the level of radiation or of radioactive contamination of any particular area, building, room or equipment.
Atomic Mass	The mass of a neutral atom of a nuclide is usually expressed in atomic mass units (amu) which is 1/12 the mass of the neutral ^{12}C atom.
Atomic Number	The number of protons in the nucleus of an atom of a nuclide (symbol Z).
Background	Ionizing radiation arising from radioactive material other than the one directly under consideration. Background radiation due to cosmic rays and natural radioactivity is always present. There may also be background radiation due to the presence of radioactive substances in other parts of the building, in the building material itself, etc.
Becquerel (Bq)	Special name for the unit of activity of radionuclide. One Bq equals one disintegration per second.
Beta Particles	These are emitted from the nucleus and are identical to orbital electrons in mass (1/1840 amu) and charge (1 negative unit). As the result of the emission of a beta-particle (negative), a neutron is converted to a proton in the nucleus so that the atomic number is increased by one. The atomic mass number remains the same. Beta-particles are more penetrating than alpha-particles. A beta-particle will produce 50-200 ion pairs per centimeter of track length in air. Beta-particles are emitted in a spectrum of energies; the average energy is 1/3 of the maximum.
Bioassay	Determination of personnel contamination by urine analysis, blood analysis, thyroid analysis or other means.

Bremsstrahlung	Electromagnetic radiation produced when charged particles decelerate in matter. The production of bremsstrahlung depends directly upon the energy of the particle and the atomic number of the absorber. This means that large activity, high energy beta sources require shielding with sufficient thickness of low atomic number substances such as plastic. At low energies the fraction of energy converted to bremsstrahlung approximately equals $ZE/1000$, where Z is the atomic number of the absorber and E is the average of energy of the beta-particles. Usually associated with energetic beta-emitters, e.g., ^{32}P .
Broad License	Normally, the State of California Department of Health Services issues a specific license for each proposed radiation use. In exceptional cases, a Type A Broad Scope Radioactive Material License is issued to an organization for the use of different quantities and types of radioactive materials in research, development or human use. The University of California, San Francisco (UCSF) has a Broad License.
Carrier Free	An adjective applied to one or more radionuclides in minute quantity, essentially undiluted with stable radionuclide carrier.
Contamination, Radioactive	Deposition of radioactive material in any location where it is not desired, particularly where its presence may be harmful.
Controlled Area	A defined area in which occupational exposure of personnel to radiation or radioactive materials is under the supervision of a Radiation Safety Officer. This implies that a controlled area requires control of access, occupancy and working conditions for radiation safety purposes.
Curie (Ci)	A unit of radioactivity defined as the quantity of any radionuclide that will produce 3.7×10^{10} disintegrations per second. This unit has been replaced in the literature with the term becquerel.
Critical Organ	That organ or tissue the irradiation of which will result in the greatest hazard to the health of the individual.
Decay, Radioactive	Disintegration of an unstable nuclide by the spontaneous emission of charged particles and/or photons.
Dose	A general term denoting the quantity of radiation or energy absorbed in a specified mass. For special purposes it must be appropriately qualified, e.g., absorbed dose.

Dose Equivalent (DE)	A quantity used in radiation protection. It expresses all radiations on a common scale for calculating the effective absorbed dose. It is defined as the product of absorbed dose (in rads or grays) and certain modifying factors. The unit is the rem or sievert.
Electron Volt (eV)	The unit of energy equivalent to energy gained by an electron passing through a potential difference of 1 volt (a very small unit of energy) $1 \text{ eV} = 1.6 \times 10^{-12} \text{ ergs}$. Usually multiples are used $\text{KeV} = 1000 \text{ eV}$ and $\text{MeV} = 1,000,000 \text{ eV}$.
Film Badges	A packet of photographic film used for the approximate measurement of radiation exposure for personnel monitoring purposes. The badge holder may contain two or more films of differing sensitivity, and it may contain filters which shield parts of the film from certain types of radiation.
Gamma-Rays and X-Rays	<p>These are part of the electromagnetic energy spectrum which also includes radio waves, visible light and ultraviolet light, etc. X-rays and gamma-rays have very high energies; they have short wavelengths and readily penetrate matter. Gamma-rays and x-rays differ only in their source. Gamma-rays arise from the atomic nucleus while x-rays arise from orbital electron energy transitions.</p> <p>Both of these radiations interact with matter mainly by transferring energy to orbital electrons of absorber atoms causing ionization. The ejected orbital electrons then decelerate and lose energy, in the same manner as beta-particles. Because the photons have no mass or electrical charge the probabilities of interaction are small and the radiations are difficult to attenuate. Dense materials with high atomic numbers, i.e., lead, uranium, etc., make the best shields against these radiations.</p>
Geiger Mueller (GM) Counter	A highly sensitive gas-filled detector and associated circuitry used for radiation detection and measurements.
Gray (Gy)	The unit of absorbed dose, namely, absorption of 1 joule in a kilogram of absorbing medium. One gray equals 100 rads (see rad).
Half-life, Biological	The time required for a body to eliminate one-half of an administered dose of any substance by the regular process of elimination. This time is approximately the same for both stable and radioactive isotopes of a particular element.

Half-life, Effective	<p>The time required for a radioactive nuclide in a system to be diminished 50% as a result of the combined action of radioactive decay and biological elimination.</p> $T_{\text{eff}} = T_{\text{bio}} \times T_{\text{rad}} / (T_{\text{bio}} + T_{\text{rad}})$
Half-life, Radioactive	<p>The time required for a radioactive substance to lose 50% of its activity by decay. Each radionuclide has a unique half-life.</p>
Half-value Layer (HVL)	<p>The thickness of a material which if placed in a radiation beam, for example a shield, will reduce the intensity of the beam by half.</p>
Hazard Guide Value	<p>These values are computed by the formula $HGV = QTU$, where Q equals quantity of radionuclides in mCi; T equals relative toxicity factor based on permissible air concentration of radionuclides; U equals use factor.</p>
Health Physics	<p>A term in common use for that branch of radiological science dealing with the protection of personnel from harmful effects of ionizing radiation.</p>
High Radiation Area	<p>Any area accessible to individuals, in which there exists radiation at such levels that an individual could receive in any one hour a dose to the whole body in excess of 100 mrem.</p>
Inverse Square Law	<p>The intensity of radiation at any distance from a point source varies inversely as the square of that distance. For example, if the radiation exposure rate is 50 mR/hr at 1 cm from a source, the exposure rate will be 0.5 mR/hr at 10 cm.</p>
Investigation Level (Action level)	<p>A limit set by an organization as an internal control, which if exceeded will result in an investigation and an effort to reduce exposure. This limit is generally set as a small fraction of the Maximum Permissible Body Burden (MPBB).</p>
Ionization	<p>The process by which a neutral atom or molecules acquires a positive or negative electrical charge.</p>
Ionizing Radiation	<p>Any electromagnetic or particulate radiation capable of producing ions directly or indirectly in its passage through matter. In general, it will refer to gamma-rays and x-rays, alpha and beta-particles, neutrons, protons, high speed electrons and other nuclear particles.</p>
Isotopes	<p>Nuclides having the same number of protons in their nuclei, (the same atomic number), but differing in the</p>

number of neutrons and therefore in the mass number. Essentially identical chemical properties exist between isotopes of a particular element but they can have different nuclear decay properties.

KeV One-thousand electron volts. This is a unit used to specify the energy of ionizing radiation.

Mass Number The number of nucleons (protons and neutrons) in the nucleus of an atom (Symbol A).

Maximum Permissible Dose (MPD) The maximum dose of radiation which may be received by an individual working with ionizing radiation.

Maximum Permissible Body Burden (MPBB) The quantity of a radionuclide which can be in the body without exceeding the maximum permissible dose equivalent.

MeV One million electron volts. This is a unit used to specify the energy of ionizing radiation.

Monitoring Checking for presence of sources of radiation under a specific set of conditions. Monitoring includes measurements of levels of radiation or concentrations of radioactivity and is done for protection of health.

Neutrons Electrically neutral particles with a mass of about 1 amu. Neutrons can interact with nuclei and transmute stable nuclides into radioactive nuclides. Special precautions may be required around sources where neutrons are being produced to protect against the induced radioactivity in the shielding, air, etc.

Personnel Monitoring Monitoring any part of an individual, his/her breath, excretions or any part of his/her clothing.

Personnel Dosimetry Determination of the cumulative dose of radiation to an individual by various means such as film badges, finger rings, and bioassays.

Positrons These are positively charged beta-particles (equivalent in mass to electrons). They are emitted from the nucleus in the same manner as negatively charged electrons. The process results in a proton being transformed to a neutron. The resulting nucleus will have one less positive charge and the same mass number as the original nucleus.

Positrons are emitted in a spectrum of energies. When the positron collides with a negative electron, both particles are annihilated. The masses of the positron and electron (each of which has a mass 1/1840 of an atomic mass unit) are totally converted to energy in accordance with formula $E = mc^2$; two photons with energies of 0.511 MeV are produced. Since the annihilation radiations have the same characteristics as gamma-rays, positron sources require shielding like that for gamma sources.

Quality Factor (QF)

Number by which absorbed doses are to be multiplied to obtain dose for radiation protection purposes. It is a quantity that expresses on a common scale the radiation harm incurred by exposed persons. It is selected based upon review of human and animal exposure data for various kinds of radiation. Quantitatively, QF is related only to linear energy transfer of the radiation. The QF for x-rays, gamma-rays and beta-particles is approximately one.

Rad (Radiation Absorbed Dose)

The unit of absorbed dose. A dose of one rad means the absorption of 100 ergs of radiation energy per gram of absorber or 0.01 joule per kilogram of absorbing material. This term has been superseded in the literature by the term Gray. 100 rad equal one Gray.

Radioactive Materials

Any material, solid, liquid, or gas, which emits ionizing radiation spontaneously.

Radiological Survey	An evaluation of the radiation hazards incident to the production, use or existence of radioactive materials or other sources of radiation under a specific set of conditions. Such evaluation customarily includes a physical survey of the disposition of materials and equipment, measurements or estimates of the levels of radiation that may be involved, and a sufficient knowledge of processes using or affecting these materials to predict hazards resulting from expected or possible changes in materials or equipment.
Radiotoxicity	A term referring to the potential of a radionuclide to cause damage to living tissue by absorption of energy from the disintegration of the radioactive material introduced into the body.
Relative Biological Effectiveness (RBE)	The factor used to compare the biological effectiveness of absorbed radiation doses due to different types of ionizing radiation. This factor is usually 1 for commonly used x-ray, gamma and beta sources.
Rem (Roentgen Equivalent Man)	The unit of dose equivalent. The dose equivalent in rems is numerically equal to the absorbed dose in rads multiplied by the quality factor, the distribution factor and other necessary modifying factors. This term has been superseded in the literature by the term sievert. 100 rem equal one sievert.
Restricted Area	For purposes of responsibility for radiation safety and for controlling exposure to ionizing radiation, areas under the control of the University of California where radioactive radionuclides are used or stored or ionizing radiation generators are in use are considered restricted areas. Same as Controlled Area.
Roentgen (R)	A unit of exposure that is only defined for x-rays and gamma-rays up to the energy of 3 MeV. It is the amount of energy required to produce ions able to carry one electrostatic unit of charge of either sign in 1 cc of dry air at STP. (Survey meter readings of pure beta-emitters must be monitored on the count rate scale not the mR/hr scale.)

Scintillation Counter	A counter in which light flashes produced in a scintillator by ionizing radiation are converted into electric pulses by a photomultiplier tube. This may be obtained by the use of a liquid fluor and sample or within or against a solid crystal.
Sealed Source	A radioactive source that is hermetically sealed and not intended to be opened.
Sievert (Sv)	Special name for the SI unit of dose equivalence. One sievert equals 100 rem.
Specific Activity	Total radioactivity of a given nuclide per gram of a compound, element or radioactive nuclide.
Tenth Value Layer (TVL)	The thickness of a substance which if introduced into a beam of radiation (for example, as a shield) will reduce the intensity of the beam by a factor 10.
Tracer, Isotopic	The radionuclide or non-natural mixture of radionuclides of an element which may be incorporated into a sample to make possible observation of the course of that element, alone or in combination, through a chemical, biological, or physical process. The observations may be made by measurement of radioactivity or of isotopic abundance.
User	Any person who is involved with handling radionuclides. This definition includes students, staff, visiting appointees and faculty. All users must have an approved user training number, a Supplement A (training and experience record) on file and be personally instructed by the license-holder or an alternate in practical safety matters.
Wipe Test	A procedure in which a swab, e.g., a circle of filter paper, is rubbed on a surface, generally over an area of approximately 100 cm ² , and its radioactivity measured to determine if the surface is contaminated with loose radioactive material.

X-Rays

Part of the electromagnetic energy spectrum which also includes radio waves, infrared, visible light and ultraviolet light, etc. x-rays and Gamma-rays have very high energies; they have short wave lengths and readily penetrate matter. Gamma-rays and x-rays differ only in their source. Gamma-rays arise from the atomic nucleus while x-rays arise from orbital electron energy transitions. x-rays produced by machines usually have two components: bremsstrahlung and characteristic x-rays.

Both of these radiations interact with matter mainly by transferring energy to orbital electrons of absorber atoms causing ionization. The ejected orbital electrons then decelerate and lose energy, in the same manner as beta-particles. Because the photons have no mass or electrical charge, the probabilities of interaction are small and the radiations are difficult to attenuate. Dense materials with high atomic numbers, i.e., lead, uranium, etc., make the best shields against these radiations.

Z

Symbol for atomic number.

CHAPTER 12

SELF-ASSESSMENT QUIZ

CHAPTER 1: PROPERTIES OF IONIZING RADIATION

1. What thickness of lead is required to give complete absorption of gamma-rays?
2. When comparing Beta-emitters, the average path length in air is proportional to what property of the Beta-particle?
3. Why is it better to use plastic, rather than lead, to shield energetic beta-emitters such as ^{32}P ?
4. What is the difference between the shielding required for positrons and for negatively charged beta-particles of the same energy?
5. The path length of a beta-particle in water is about what fraction of its path length in air?
6. The path length of a beta-particle in water is about what fraction of its path length in lead?
7. You purchased a radionuclide with a 14 day half-life. Eight weeks later, how much is left?
8. Both gamma-rays and x-rays are electromagnetic radiation. How do they differ?
9. If the intensity of gamma-radiation at 1 cm is 1 mR/hr, what is it at 10 cm?
10. The half-value layer of lead for ^{125}I is .02 mm. What fraction of the gamma-rays gets through 0.04 mm?
11. What is the value of the curie expressed in Becquerels?

CHAPTER 2: UNITS FOR MEASURING IONIZING RADIATION

1. What are the three energy units used to measure the interaction of ionizing radiation with matter?
2. For beta, gamma and x-rays how are these three units related?
3. The total damage caused by radioactive material is dependent on:
 - a. the number of disintegrations per second
 - b. the energy of the decay particle
 - c. the nature of the decay particle
 - d. all of the above.

4. Match the following terms:

- | | |
|-----------------------|------------------------------------------------------|
| ___ Roentgen | a) Unit of radioactivity |
| ___ Rem | b) Amount of radioactivity/gram |
| ___ Curie | c) Unit of radiation dose |
| ___ Specific activity | d) Unit of radiation exposure |
| ___ Film badge | e) A device which measures cumulative radiation dose |
| | f) Legal definition of allowed dose |

CHAPTER 3: MAXIMUM PERMISSIBLE EXPOSURES

1. The State of California's limit for whole body radiation exposure is 5000 mrem/yr for people over 18. What is the UCSF alert level?
2. Do we know that exposure to the maximum amounts approved by the State will cause cancer, or is this an extrapolation from high doses?
3. What is the philosophy of UCSF on radiation exposure reduction?
4. How does the background radiation in San Francisco compare with the State guideline for maximum radiation exposure per year?
5. If a researcher receives a dose of 10 rem/yr to the skin in one calendar year, has he/she exceeded the maximum permitted dose?
6. Does the State allow radiation users and non-users to be exposed to the same radiation levels?
7. How much radiation can a fetus maximally be exposed to during gestation?
8. Have the dangers due to low levels of exposure to ionizing radiation been scientifically proven?
9. If you are pregnant and you have received 0.5 rem of exposure in the first three months of pregnancy, what should you do?
10. As supervisor of female workers considering pregnancy and who use ionizing radiation, your responsibilities are:
 - a. none, the responsibilities are the woman's
 - b. to encourage her to read this Training Manual
 - c. to insist that she know of and be familiar with the contents of the Supplemental Guide on Prenatal Radiation Exposure available from EH&S.

CHAPTER 4: BIOLOGICAL EFFECTS OF RADIATION

1. Give an example of (a) a prompt and (b) a delayed somatic effect due to high levels of radiation.
2. Are genetic delayed effects of ionizing radiation less or more severe than the cancer producing effects?
3. Which types of tissue are more sensitive to radiation?

CHAPTER 5: SAFETY HAZARDS ASSOCIATED WITH COMMONLY USED RADIONUCLIDES

1. The annual limit of ingestion of radionuclides gives the maximum amount that can be inadvertently ingested or inhaled yet remain below the guidelines.
For ^{125}I is it:
 - a. 1 mCi
 - b. 10 μCi
 - c. 0.1 μCi
2. What depth through the skin do ^3H , ^{14}C and ^{32}P penetrate?
3. 1 μCi of ^{14}C on 1 cm of skin delivers approximately how much radiation to basal cells of the skin:
 - a. none
 - b. about 3 mrad/hr
 - c. about 3 rad/hr?
4. Will external ^{32}P sources do much radiation damage to internal organs?
5. The commonly used radionuclide ^{125}I has a Gamma Factor of 0.7 roentgens/hr/mCi. How many roentgens/hr are generated by 1 mCi at 1 cm? At 10 cm from the source?
6. Why is the eye the major organ at risk when working with an external source of ^{32}P ?
7. What level of radiation does UCSF allow at 30 cm from a stored gamma-emitter?

CHAPTER 6: PRACTICAL STEPS TO RADIATION SAFETY

1. Why should one practice a procedure first with non-radioactive material?
2. What are tongs used for in a well-equipped radiation safety laboratory?
3. If it takes 0.1 mm of lead to reduce ^{125}I generated gamma-rays by one-tenth, how much is needed to reduce it by one-thousandth?

4. Why are the regulations so insistent on the absence of food and drink from areas where radionuclides are used or stored?
5. When a potentially volatile radionuclide such as ^{125}I is used, where must experiments be performed?
6. What four precautions are essential for every manipulation involving radionuclides?
7. If you have been working with ^3H , how is contamination assayed?
8. What should be done about radioactive signs on cartons used for shipping before disposal?
9. Before storing a radioactive sample or leaving a radioactive waste container on your bench, it should be marked with radioactive tape specifying what?
10. What thickness of lucite effectively screens ^{32}P :
 - a. none
 - b. 1 mm
 - c. 1 cm
11. Why should deliveries of radionuclides be opened wearing disposable gloves?
12. What bookkeeping is required when a new batch of radionuclides arrives?
13. Why should one wear two pairs of gloves during iodinations and change them every 10 minutes?
14. Why should ^{125}I and ^{131}I wastes be wrapped before disposal?
15. When is mouth pipetting allowed?
16. Can you lend 5 mCi of Na^{125}I to a laboratory until their license gets approved?
17. Can you lend 5 mCi of Na^{125}I to another laboratory that has run out and needs it?
18. You may store food in a refrigerator containing radionuclides if the food is kept in a sealed container. True or false?
19. You must use a specialized container for the disposal of used hypodermic syringes prior to placing them in the dry radioactive waste box. True or False?
20. Your G-M counter registers 150 mR/hr. How long can you work in the area and remain under the campus' monthly limit?
21. You must monitor your laboratory by wipe method:
 - a. monthly or weekly as specified by the activity used in the lab

- b. only when EH&S detects contamination
- c. from time to time
- d. twice per year
- e. after each experiment in which a volatile iodide is used

CHAPTER 7: MEASUREMENTS OF RADIATION EXPOSURE

1. Your film badge records
 - a. ^{32}P and ^{14}C
 - b. ^3H and ^{60}Co
 - c. ^{32}P and ^{125}I
 - d. ^{35}S and ^{14}C
 - e. ^3H and ^{125}I
2. You are required to wear your ring badge when working with 1 mCi of ^{32}P . True or false?
3. Finger rings should be worn when working with which radionuclides?
4. A thyroid scan must be performed if more than what quantity of volatile ^{125}I is used routinely per month?
5. What is the equivalent amount for ^{131}I ?
6. If you work with more than 100 mCi of a ^3H -nucleotide precursor, what are you required to do?
7. Does a Geiger-Mueller counter measure mRoentgens directly?
8. If, while monitoring your laboratory, you detect some small amount of contamination, you must:
 - a. disregard the contamination
 - b. clean it up if it is over 2 x background cpm
 - c. call Radiation Safety and report the findings
 - d. send Radiation Safety a "Report of Laboratory Contamination" form

CHAPTER 8: RECORD KEEPING

1. How often are you required to monitor your laboratory?
 - a. each day
 - b. each week
 - c. each month
 - d. each year
 - e. As specific by the activity amount being used, weekly if $>$ or $=$ 100 μ Ci, monthly if $<$ 100 μ Ci.
2. Why are you required to keep a map of your laboratory?
 - a. to know where to find radionuclides
 - b. to keep a record of where you have monitored for contamination
 - c. to help you if lost
 - d. all of the above

CHAPTER 9: RADIOACTIVE WASTE DISPOSAL

1. What is the limit for "de minimus" liquid scintillation vials?
2. How is radioactive waste segregated:
 - a. by category (e.g. dry, biological)
 - b. by half-life
 - c. by disposal cost
 - d. (a) & (b)
3. What do you do with radioactive scintillation vials?
 - a. separate them into those with ^3H and ^{14}C
 - b. make sure levels of radioactivity are below 0.5 mCi/ml
 - c. mark them "counting vials"
 - d. keep them in storage flats, if possible
 - e. all of the above
4. Dry waste containers must have what three items of information in addition to the radiation symbol?
 - a. chemical form
 - b. name of Principal Investigator
 - c. radionuclides and amount
 - d. date
 - e. recharge account number
5. When disposing of an outer shipping box that a vendor has used to send you radionuclides, you:

- a. must use the radioactive trash box in your laboratory and crush the shipping container to save space.
 - b. may throw it in the normal trash.
 - c. may leave it in the hall with a note saying "trash", for custodial personnel to remove.
 - d. monitor to verify it is not contaminated, remove or deface all labels then throw in normal trash.
 - e. must bring it down to the loading docks, separate from your regular waste, on the assigned day for pickups.
6. You accidentally spill some radionuclide on yourself and it contaminates your skin. You must:
- a. call Radiation Safety
 - b. go to the Student Health center
 - c. wash the skin in cold water with hand soap
 - d. first (c) then (a)
7. Aqueous liquid radioactive waste must:
- a. contain no organic compounds
 - b. be stored in capped plastic jars
 - c. be segregated by half-life category
 - d. all of the above
8. Contaminated animal carcasses must be:
- a. packaged in red bags
 - b. taken to the designated freezer
 - c. segregated by half-life category
 - d. all of the above
9. Sharps and blades used in animal surgery must be:
- a. packaged with animal carcasses
 - b. packaged with dry waste
 - c. packaged in sharps container

CHAPTER 10: EMERGENCY PROCEDURES

1. What should be done first if there is a major accident involving radioactivity?
2. What is the best method of skin decontamination?
3. What if the skin is broken?

SELF-ASSESSMENT QUIZ ANSWERS

CHAPTER 1: PROPERTIES OF IONIZING RADIATION

1. Statistically speaking there is no such thickness.
2. E_{mean}
3. To minimize Bremsstrahlung production.
4. Positrons produce x-rays by annihilation.
5. About 1/1000
6. About 1/10,000
7. 1/16
8. Their origin; x-rays come from electron shells; gamma-rays from the nucleus.
9. 1/100
10. One-quarter
11. 3.7×10^{10} Becquerels

CHAPTER 2: UNITS FOR MEASURING IONIZING RADIATION

1. Roentgens, rems, rads
2. Nominally the same
3. (d)
4. (d) Roentgen a) Unit of radioactivity
(c) Rem b) Amount of radioactivity/gram
(a) Curie c) Unit of radiation dose
(b) Specific activity d) Unit of radiation exposure
(e) Film badge e) A device which measures cumulative radiation dose

CHAPTER 3: MAXIMUM PERMISSIBLE EXPOSURES

1. 100 mrem/month
2. The latter
3. The philosophy of ALARA, As Low As is Reasonably Achievable.

4. One fiftieth
5. No. The maximum permissible dose to the hands is 50 rem/year as opposed to 5 rem for the whole body.
6. No, those who are certified as trained in the use of ionizing radiation can receive up to 10 times more.
7. 0.5 rems/gestation period (500 mrem/gestation period)
8. No, they are extrapolations from high levels of radiation. They could be low estimates or high.
9. Stop working with ionizing radiation immediately, until a fetal dose evaluation is performed.
10. (c)

CHAPTER 4: BIOLOGICAL EFFECTS OF RADIATION

1. (a) Radiation burns, sterility, etc., (b) Cancer
2. Less
3. Those which are rapidly dividing.

CHAPTER 5: SAFETY HAZARDS ASSOCIATED WITH COMMONLY USED RADIONUCLIDES

1. (b)
2. 0, 0.3 mm and 1 cm
3. (c)
4. No, their beta-particles only penetrate 1 cm in tissue
5. 0.7, 0.007
6. Since ^{32}P only penetrates 1 cm into tissue, the eye is the major radiation sensitive organ exposed.
7. 2 mR/hr

CHAPTER 6: PRACTICAL STEPS TO RADIATION SAFETY

1. To reduce time of exposure by practice.
2. To enhance distance between the user and the source.
3. 0.3 mm
4. Because the major danger, especially for low energy beta-emitters, is from ingestion.
5. In an approved fume hood.
6.
 - a. Use of protective clothing, gloves and lab coats.
 - b. Anticipation of accidental spills by using absorbent paper, trays, etc.
 - c. Disposing of waste appropriately afterwards.
 - d. Monitoring the work area for contamination.
7. By wipe and liquid scintillation counting.
8. Defaced or removed.
9. The date, the radionuclide, the amount and the user.
10. (c)
11. Shipments are often contaminated due to leakage during transport.
12. The date, amount and chemical form must be logged into the laboratory usage records.
13. Iodide vapor penetrates through the material.
14. To reduce leaks due to volatilization.
15. NEVER
16. No
17. If they have authorization to receive 5 mCi of Na¹²⁵I, and after completion of the proper "Transfer Form".
18. False
19. True
20. Forty minutes
21. (a)

CHAPTER 7: MEASUREMENTS OF RADIATION EXPOSURE

1. (c)
2. True
3. High energy beta and gamma-emitters.
4. 15 mCi
5. 1 mCi
6. Tritium urinalysis after each use.
7. No. It measures events, that is, counts per minute independent of energy. Conversion of cpm to mR/hr depends on the calibration of the system to a specific energy.
8. (b)

CHAPTER 8: RECORD KEEPING

1. (e)
2. (b)

CHAPTER 9: RADIOACTIVE WASTE DISPOSAL

1. 0.05 uCi/ml
2. (d)
3. (e)
4. (a, c, d)
5. (d)
6. (d)
7. (d)
8. (d)
9. (c)

CHAPTER 10: EMERGENCY PROCEDURES

1.
 - a. Attend to injured
 - b. Wash contaminated skin
 - c. Call your DSA
 - d. Call the Radiation Safety Office immediately
2. Thorough washing with soap and water.
3. Wash with a strong stream of water and seek medical help.